Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

Landscaping and Bio-Engineering of Slopes in Hong Kong

R. P. Martin
Geotechnical Engineering Office, Civil Engineering Department, Hong Kong

Abstract: Growing interest in the appearance of slopes in Hong Kong complements similar changes in the region and the profession at large. Recent developments in local slope landscaping and bio-engineering practice include employment of landscape architects on all Government slope projects and publication of new technical guidelines by the Geotechnical Engineering Office. Based on a review of papers submitted to the session, areas of interest and potential future development are discussed, with special reference to slopes in Hong Kong. These include the value of vegetation roots for different slope settings, use of native vegetation species and alternative forms of bio-engineering, purpose and specification of erosion control products, landscaping of hard surfaces and aesthetic aspects of slope 'infrastructure'.

1 THE SOCIAL CONTEXT

"Meeting Society's Needs" is our conference theme. Few areas of geotechnical engineering have such a direct social impact in Hong Kong as slope works. No other major city has such extensive dense urban development lying on or close to steep hillsides (Figure 1). Most of Hong Kong's population of *c*.6.8 million live within a few kilometres of steep slopes.

The Government's Geotechnical Engineering Office (GEO) has a register of over 54,000 sizeable man-made slopes and retaining walls. It was only a matter of time before the appearance of these features attracted attention. Huge increases in slope construction over the last decade, coupled with indiscriminate use of shotcrete as a quick and durable means of slope surfacing, became a focus of community concern in the late 1990s. The public interest prompted special-feature TV programmes and a host of written articles and letters to the press (Table 1).

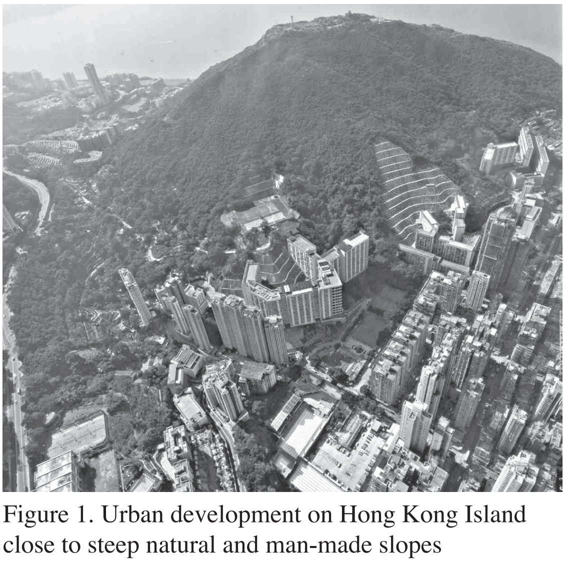


Figure 1. Urban development on Hong Kong Island close to steep natural and man-made slopes

Public opinion has been a driving force for change in the approach to local landscaping and bio-engineering. The use of shotcrete on Government slopes now has to be justified on a case-by-case basis and is vetted by committees chaired by senior officials in all public works departments.

This panelist report attempts to review recent developments in local landscaping and bio-engineering in the context of broader professional trends, summarise the submitted papers under the theme and discuss areas of interest and potential future development.

2 RECENT DEVELOPMENTS IN PRACTICE

2.1 *Professional Background*

Civil Engineering was recently redefined by the UK's Institution of Civil Engineers as follows:

- the art of directing the great sources of power and nature for the use and convenience of mankind (ICE 1821).
- improving and maintaining the built and natural environment to enhance the quality of life for present and future generations (ICE 1999).

Increasing awareness of vegetation as an engineering material is a significant component of the new environmental focus in civil engineering. Interest in bio-engineering has surged in the last decade, drawing on traditional usage dating back over 50 years in continental Europe and the USA. This is well documented in books, journals and guidance manuals, e.g. Coppin & Richards (1990), Morgan & Rickson (1995), Gray & Sotir (1996), Howell (1999), Ground Engineering (2001). Much of the original work

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

has been done in temperate climates and vegetation systems, but applications in tropical and subtropical areas are also now well advanced (e.g. Clark & Hellin 1996, IECA 1999, Howell 1999).

Table 1. Examples of public concern over slope appearance

Item	Title/Topic	Date
Legislative Council Query	Numbers of 'greened' slopes; reasons for not greening slopes	21.5.97
Fax to GEO by the Hong Kong Conservation Photography Foundation	Nine questions on slope safety and roadside shotcreting	24.1.99
20-minute TV Programme (ATV)	Visual impact of slope works	22.3.99
Newspaper article (South China Morning Post, SCMP)	Indiscriminate shotcreting of slopes in Country Parks	30.4.00
Newspaper article (Ming Pao)	Slope greening : hydroseeding replaces shotcrete	24.5.00
Newspaper article (SCMP)	Visual impact of slope identification signs	4.6.00
Magazine article (Post-SCMP)	Over-use of shotcrete	4.6.00
Newspaper critics column (The Sun)	GEO lacks environmental consciousness in slope upgrading	29.9.00
Newspaper article (SCMP)	"Roadside slope policy just a shotcrete in the dark"	5.10.00
>25 letters to newspapers and the GEO	Unsightly hard slope surfaces (general)	1997-2000

2.2 *Regional (Southeast Asian) Practice*

An indication of the state of practice in the region is given in the Proceedings of the First Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, held in Manila (IECA 1999). The conference featured wide-ranging applications throughout the region. Bio-engineering practice appears to be especially strong in Nepal, Mainland China, Thailand, Malaysia and the Philippines.

From the case studies presented at the conference, applications to slopes in the region are best developed in generally low-risk, rural settings. It seems most vegetated slope surfaces are designed, constructed and assessed on a trial and error basis. Field trials within a scientific framework (i.e. involving measurements of factors related to slope stability or erosion control) are relatively rare. Bio-engineering schemes appear to have been notably successful where an observational approach has been taken to optimizing species selection and cultivation.

2.3 *Practice in Hong Kong*

There are several indicators of increasing environmental awareness in Hong Kong. In 1999 the HKSAR Government's Chief Executive launched a "Greening Hong Kong" campaign as a general new policy initiative. Within the Government, the Civil Engineering Department has pledged to fulfil its environmental responsibilities as one of five missions to achieve a departmental vision of assuring "the highest standards and quality of services in slope safety and land formation".

In local private sector practice most engineering consultants involved in new site formation projects or landslip preventive works to existing slopes were using landscape architects in their project teams by the mid- to late-1990s.

Within the GEO a project team was formed between 1999 and 2001 to incorporate landscaping and bio-engineering into the Government's Landslip Preventive Measures (LPM) Programme. A significant outcome of this work was the decision to publish the first set of local technical guidelines on landscape treatment and bio-engineering (GEO 2000). Prepared by landscape architect consultants (Urbis Ltd) with a geotechnical subconsultant (Halcrow China Ltd), the guidelines were developed from an earlier review of techniques for roadside slopes prepared by the same firms (Halcrow China Ltd 2000).

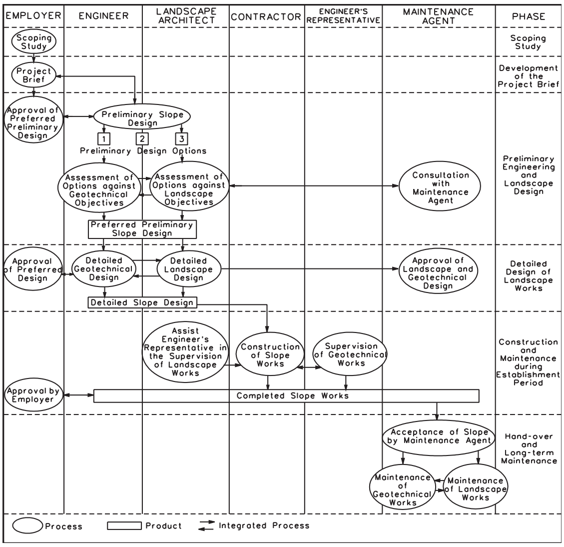


Figure 2. Integrated engineering and landscape architect input to slope design and construction (from GEO 2000)

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

A key concept introduced in the new guidelines is integration of landscape architect and geotechnical engineering skills throughout the course of a slope project (Figure 2). The guidelines recommend and illustrate good practice in the design, construction and maintenance of various landscaping techniques but note that, apart from standard hydroseeding, other bio-engineering techniques have so far not been extensively applied in Hong Kong.

3 SESSION PAPERS AND INSIGHTS

Barker (2001) reviews the use of live poles and brushlayering in slope works. Beneficial aspects of live poles include increased soil shear resistance close to the slope surface, buttressing and arching. Brush layers are regarded as having a reinforcement effect similar to geotextile/geogrid layers, also to act as debris barriers and continuous shallow raking drains (the latter effect due to looser soil around the installed brush). Evapotranspirative effects of living poles or brushes may also enhance slope stability by reducing pore-water pressures.

Barker proposes that live poles 2.5 m long would provide roots deeper than most failures in natural and formed slopes. An intriguing extra justification is that if growing conditions are too harsh to sustain 'live' growth, dying-off of the poles is itself a helpful indicator of improved slope stability, i.e. the dead poles indicate drier slope conditions than may have been assumed in stability assessments.

Barker considers these techniques have widespread application and are currently underused, notably in high risk settings such as Hong Kong. Points made in this paper worth discussing are: (i) claims that a large proportion of slope failures worldwide are shallower than 2 m, (ii) field evidence of successful live pole installations, (iii) if willow and bamboo are inappropriate in Hong Kong, what other species are potentially suitable live poles?, and (iv) what are the typical costs (capital and maintenance) of live poles and brushlayers as compared with other bio-engineering techniques?

Docker & Hubble's (2001 a, b) studies of four tree types from the Nepean River Basin near Sydney show common trends in root distribution but sufficient differences to permit ranking of root reinforcement potential. In their second paper the lowest-ranking of the four types (*Casuarina glauca*) is assessed in relation to slope stability through the use of in-situ shear box tests, calculation of root area ratios (RARs), and limit equilibrium modelling of stability against circular failure with depth-distributed additional cohesion due to the roots.

Suggested discussion points arising from these papers are: (i) relative abundances of the four species, tolerance of environmental conditions and ease of planting, (ii) basis for calculating the maximum rooting depth (MRD) – is it assumed to be a constant 41% of the above-ground height based on the sample of three 1-2 year old *C. glauca* trees?, (iii) are there any impediments in the soil profile to greater root depth – if it is assumed linearly related to height above ground level?, (iv) types and depths of failures observed on the river banks, e.g. is a circular mode used in the stability models appropriate?, and (v) any empirical evidence for tall trees (>8 m) providing the claimed stability effect?

Ling et al. (2001) and Martin et al. (2001) describe work done on landscaping and bio-engineering in Hong Kong's Landslip Preventive Measures (LPM) Programme. The former describe five techniques new to the LPM Programme, four aimed at enhancing vegetation growth on very steep (up to 70°) soil cut slopes, the fifth (artificial rock) being appropriate to hard surface mitigation. Martin et al. provide an overview of slope surface treatment in the LPM Programme, with emphasis on design issues, construction and maintenance.

Some points of interest from Ling et al.'s paper are: (i) are all the vegetative systems proposed for use together with soil nails, i.e. including the spray mat and soil grillage systems?, (ii) methods of specifying the erosion control and system products – are these generic, or by named proprietary products?, (iii) if the spray mat is so cheap (essentially normal hydroseeding plus an organic 'glue'), is there any drawback to it replacing standard hydroseeding as a more resilient surface treatment?, (iv) the planter grillage system introduces permeable openings (up to 50% of the slope area) in slopes where a "hard cover has to be adopted on safety grounds" – are there concerns over design issues, e.g. enhanced potential for development of perched water tables?

Noraini & Ghani (2001) describe the use of 1.5 m-long live poles and various geostructures (bamboo and brushwood fascines, coir (coconut mat) rolls and straw wattle fences) as remedial works to failure scars on two cut slopes in Malaysia. Based on comparison with a control plot with no remedial treatment, the combination of live stakes and mini-structures is concluded to have controlled soil erosion and stabilised the slide scars, with sediment retention rates of 10 m^3/ha/year (= prevention of ground losses of 1 mm/year). Items of interest here are: (i) nature of the soil materials and profile, depths of the original failures, and (ii) evidence for the claim that the geostructures have stabilised the slopes (some evidence is given for improved erosion resistance in the treated areas).

Thomas et al. (2001) continue the story of bio-engineering work in Hong Kong but focus more on the ecological aspects of establishing vegetation on steep slopes. Some of the techniques they suggest as having wider application feature in the trials covered by Ling et al. (e.g. cellular grids, vegetated gabions ≈ soil-filled panels). Thomas et al. see scope for a much

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

greater range of slope revegetation techniques to be used locally, including Vetiver grass. They promote bamboo as one of a number of suitable species for local use, which appears to contrast with Barker's view of bamboo.

Overall, the papers point to four themes of particular relevance to the panel topic, viz. (i) value of vegetation roots in different slope settings, (ii) use of native vegetation species, (iii) use of alternative bio-engineering measures beyond the range of techniques tested to date, and (iv) purpose and specification of erosion control products on steep slopes. This list has a distinctive 'green' bias. To balance the treatment, two other topics more relevant to hard slope surfaces are also considered in the following discussion, viz. (v) future landscaping of rock slopes and soil slopes with hard covers, and (vi) the visual impact of slope 'infrastructure'.

4 FUTURE DEVELOPMENTS

4.1 *Value of Vegetation Roots*

The general effects of vegetation on slope stability (hydrological and mechanical, beneficial and adverse) are well known. Quantification of the effects is beset with uncertainties but appropriate sampling, testing and analytical techniques are fairly well documented (e.g. Greenway 1987, Collison et al. 1995, Ekanayake et al. 1999, Wu et al. 1999). The field instrumentation required is relatively standardised. Laboratory testing of soils with included roots presents difficulties but can be overcome with the use of large shear boxes, or by in-situ testing.

Successful slope stabilisation through purpose-planted vegetation is widely claimed in the conference and case study report literature. It is rare to find accounts of field trials involving sites treated with different surface covers and measurements (in terms of soil losses and changes in slope profiles, runoff, infiltration and pore water pressures) compared against a control site allowed to revegetate naturally. The success criterion often used in bio-engineering schemes is simply casual observation over time – if the landslide scar, eroded gully or engineered bare slope is successfully vegetated, a tempting conclusion is that slope stability has been improved by the vegetation alone. The distinction between improved surface erosion resistance and improved stability at depth is often not addressed. Reliability of the conclusion may be of no great importance in a low-risk setting, hence the trial-and-error approach used in much rural roadside bio-engineering, but takes on greater significance in a high-risk setting such as urban Hong Kong.

In current local practice, reliance is routinely placed on vegetation to help control surface erosion, but rarely to strengthen the ground (Martin et al. 2001). Apart from lack of knowledge of net hydrological effects, the main uncertainty is the adequacy of root-enhanced soil strength with depth.

Knowledge of local ground and groundwater conditions (e.g. nature and depth of soil profile, data on past failures, depth and shape of maximum credible failure surfaces) is obviously important but needs to be emphasised. Reported case histories often contain little information on ground conditions. Reliance on root enhancement will be very different in a thick tropical weathering profile as compared to a thin soil profile under a temperate forest where roots can readily lock into shallow bedrock (e.g. Wu et al. 1979), see Figure 3. For a given maximum depth of failure, shape of the shear surface may also be important, with translational slab shapes benefiting less from the vegetation than circular surfaces.

Barker's observations on typical failure depths are pertinent. Slope stability assessment in local practice traditionally covers trial shear surfaces up to 5 m deep or more, but is this realistic? What can be drawn from local landslide studies? Figure 4 shows the maximum scar depths of 77 landslides studied by the GEO in the last 20 years. The data are from studies where the slide scars were surveyed in detail and the pre-

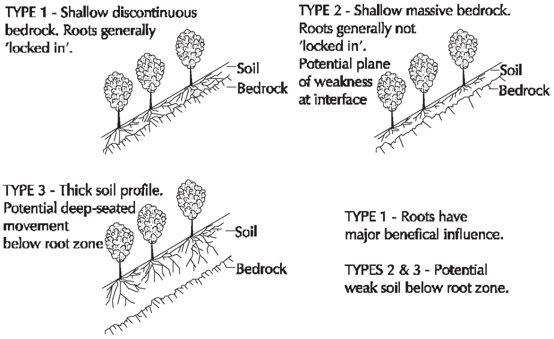


Figure 3. Relative significance of root reinforcement for slope stability in different settings (based on Tsukamoto & Kusakabe 1984)

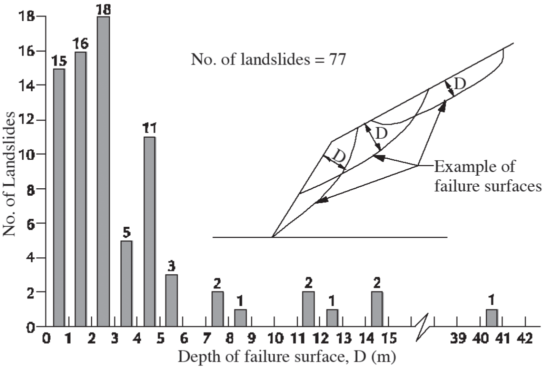


Figure 4. Depth of failure surfaces from GEO landslide investigations 1982-2001

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

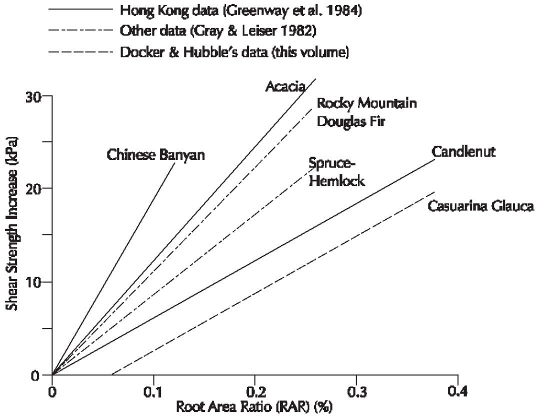


Figure 5. Predicted soil shear strength increase due to tree root reinforcement.

failure slope geometry could be established from as-built drawings or by inference from adjacent unfailed sections of the slopes. More than half these failures had shear surfaces with maximum depths greater than 2 m.

Figure 5 shows the relationship between increased shear strength and RARs for three Hong Kong species reported by Greenway et al. (1984), together with other data, including Docker & Hubbell's. Greenway et al. (1984) found that the RARs of all three local species decreased rapidly with depth, generally to <0.1% at 1 m and <0.02% at 2 m. Similar rapid reductions with depth are reported from both temperate and tropical regions (e.g. Wu et al. 1999, Nilaweera & Nutalaya 1999).

The conclusion is that significant root enhancement of soil strength appears to be generally limited to the upper metre of the soil profile, exceptionally two metres. Slope designers in high-risk settings need to look for other means of enhancing stability at depth. Live pole installation to 2-3 m deep, if successful, may extend the zone of reliable strength increase by a metre or so but will not resolve concerns about potential deeper-seated failures in thick soil profiles.

Combined 'bio-technical' solutions, e.g. involving slope reinforcement or retention in combination with green surfaces, seems the most promising direction for future local design practice.

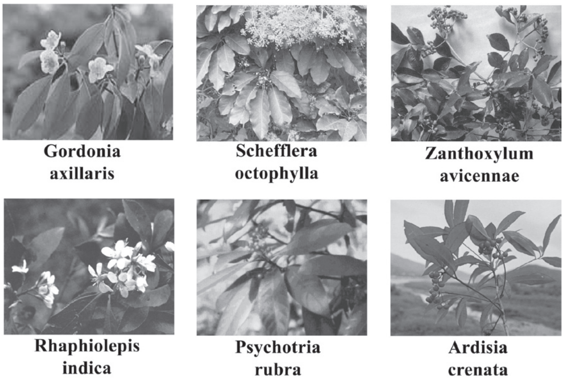
4.2 *Trials of Native Vegetation Species*

Native species are currently under-represented in hydroseeding mixtures and direct planting of seedlings used in Hong Kong (Li et al. 1999). The technical guidance suggests that tree planting is limited to slopes <45° because of concerns over uprooting under typhoon wind loading, and root wedging effects (GEO 2000). For steep soil cut slopes there is a need to research the use of local shrub species.

A long-term field trial was established under the LPM Programme in Tai Lam Country Park in 2001. The work involves comparisons of different native vegetation species mixes and five types of erosion control mats on thirteen panels of steep (55°) cut slopes in a dense saprolitic soil consisting of highly to completely decomposed coarse-grained granite. Each panel is about 10 m long and up to 8 m high (Figure 6). Six of the panels feature trials of transplanted native shrub seedlings after hydroseeding with grass but with no erosion control mat (Figure 7). Ecological advice from local research institutes (Kadoorie Farm and Botanic Garden, and the University of Hong Kong) is being incorporated in the trials. Development of the surface covers and changes in the slope profiles will be monitored for several years.

Meanwhile, a valid question is whether the experience gained with alternative bio-engineering methods elsewhere can be used to introduce new techniques into local practice.

Figure 6. Part of the LPM trial site five months after hydroseeding and shrub planting



Gordonia axillaris **Schefflera octophylla** **Zanthoxylum avicennae**

Rhaphiolepis indica **Psychotria rubra** **Ardisia crenata**

Figure 7. Native shrubs used at the LPM trial site

4.3 *Alternatives to Hydroseeded Surfaces*

Many bio-engineering techniques used commonly elsewhere have not yet been taken up in Hong Kong or are still under trial. The techniques shown in Table 2 all have potential application locally, especially in new

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

site formation works and in restoring degraded natural terrain. They are also relevant to the LPM Programme but here their use is considered less likely to become widespread, for several reasons:

(i) Geometrical constraints generally preclude the use of 'green' walls (reinforced fills) and buttress fills in LPM works. There is rarely room to build new earth structures in front of existing cut and fill slopes. Excavation into existing slopes to form new structures usually requires substantial support of steep temporary cuts.

(ii) Techniques involving labour-intensive methods on steep slopes, for example intensive hand planting, closely-spaced strip planting (e.g. Vetiver grass), or placing of vegetation cuttings, brush layering, fascines, live check dams or palisades, are inherently more risky than mechanised hydroseeding. Safety during construction is an important consideration following recent tightening of Hong Kong's Construction Site Safety Regulations.

(iii) None of these techniques compare favourably on cost grounds with standard hydroseeding (usually <US$5/m^2). The more expensive methods, e.g. soil-filled panels, green fibre-reinforced soils and other systems involving thick soil layers fixed to steep slopes (e.g. hydromulching), are typically in the range US$70-150/m^2. The value-for-money question is then whether the additional cost of the alternative techniques is justified through achieving an earlier green cover or a richer mix of species (landscape/ecological benefits), or perhaps deeper-rooting or more efficient moisture-extracting species (geotechnical benefits).

Designers need to consider and judge the above issues in selecting appropriate techniques. Input from landscape architects, ecologists or other professionals with knowledge of species growth characteristics may be essential to reach an informed conclusion.

Standard hydroseeding, typically with gradual invasions of native species from the slope surroundings, can lead to dramatic changes in surface appearance over 5 to 15 years (Figure 8). The original geometry of the man-made slopes is often completely masked, rendering them similar to natural slopes. The failure record of hydroseeded surfaces in 20 years of LPM work is generally good. If significant immediate benefit from the alternative techniques cannot be readily demonstrated, the cost- and safety-conscious engineer may well ask what more is required than standard hydroseed treatment at <US$5/m^2?

Alternative bio-engineering techniques in Hong Kong have greater potential application in new slope works, where there are more opportunities for controlling the slope form and layout, and in repairing landslide scars and erosion gullies on natural terrain. Modern bio-engineering methods may complement the traditional reafforestation methods used to restore degraded natural terrain and old borrow areas (Chong 1997). Another bio-engineering technique of potential interest is the use of mycorrhiza inoculants (fungi) to create threadlike growths for enhancing take-up of moisture and minerals around tree roots.

Table 2. Bio-engineering techniques not commonly used in Hong Kong (based on GEO 2000)

Technique	Description
Brush Layering	Woody cuttings placed on a slope between soil layers (fill), or on narrow benches (cut), to prevent development of rills and gullies
Fascines	Bundles of live branches laid in trenches across a slope, usually following the contour
Live Check Dams	Small check dams constructed from live plants and locally available materials in existing gullies and depressions to prevent further rill and gully development
Palisades	Woody/hardwood cuttings planted across a slope, usually following the contour
Soil-filled Panels	Mesh panels constructed from twisted metal wire, polymer meshes or natural fibre geotextile matting forming a box filled with a topsoil/seed mix, and laid on the slope surface
Vetiver Grass	Proprietary deep-rooting sterile plant species planted in dense strips along the contour to stabilise surface layers and control surface erosion
Live Poles	Vertical or inclined live straight tree cuttings inserted in augered or drilled holes, typically 50-100 mm diameter, up to 3 m long, in orthogonal arrays at close centres
'Green' Walls	Reinforced earth, gabion or crib wall structures with a vegetated surface cover
'Green' Fibre – Reinforced Soil	Reinforced sandy soil with continuous polyester fibres mixed in 3-D, with grass, shrub and tree planting on surface or seeds added to soil/fibre mix

4.4 *Erosion Control Products*

The use of geosynthetic or natural materials for erosion control on steep soil slopes in tropical and subtropical conditions is not well researched. Review

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

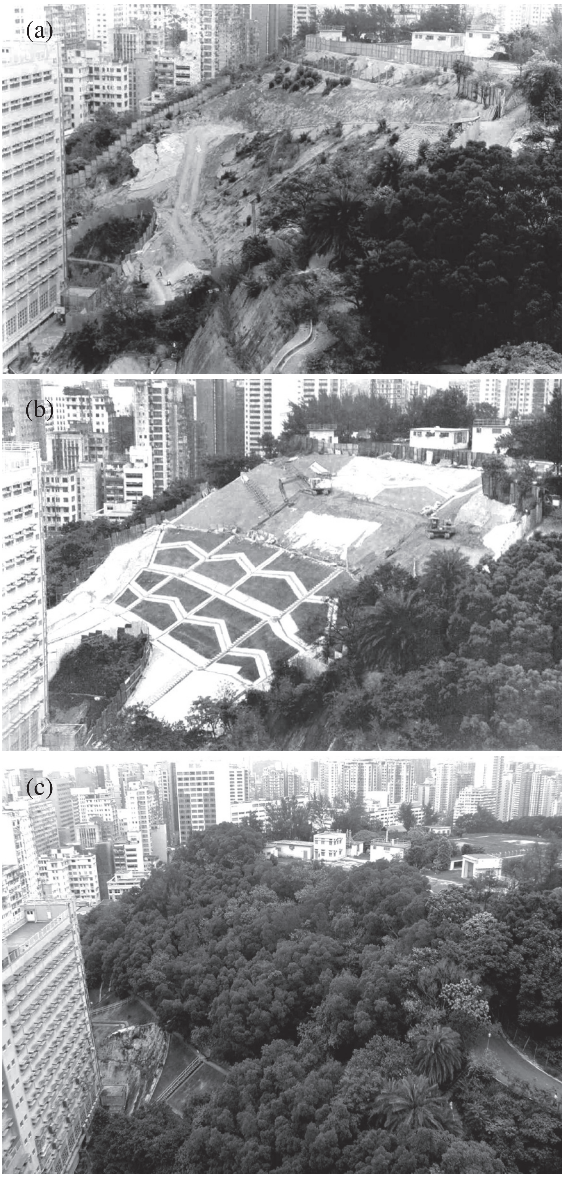


Figure 8. LPM works on a 40 m-high fill slope (a) in progress (1986), (b) nearing completion (1986), and (c) after 15 years' growth of the hydroseeded surface cover (2001).

papers and case histories tend to be dominated by experience in temperate climates and soil conditions (e.g. Rickson & Vella 1992). Field comparisons of different erosion control products on steep soil slopes are rare. An exception is Li et al.'s (1999) comparative study of four different proprietary erosion control mats and a control panel treated only with hydroseeding. Differences in performance of the erosion control mats were judged by observing signs of erosion or landsliding. Soil losses and slope hydrology were not measured.

Theoretical and practical considerations governing the use and specification of geosynthetic products in reinforced earth or hydraulic structures are not directly applicable to erosion control on steep slopes. Some of the pertinent issues are summarised in Table 3. Commonly–specified index properties, such as tensile strength and weight per unit area, are of doubtful relevance (Table 3) but tend to be used by default.

Given the inadequate knowledge of performance–based parameters, erosion control mats in LPM contracts are currently specified by listing a series of proprietary products, together with provision for the contractor to propose "equivalent" alternatives to the Engineer's satisfaction. Values of strength, minimum thickness and minimum weight/unit area, where known, are quoted for guidance. World Trade Organization guidelines now prohibit the use of patented or trademark products without provisions for "equal or equivalent" products to be adopted. Even with such provisions, specifications of this form cannot be regarded as unbiased. Generic, performance-based specifications need to be developed for erosion control products on steep slopes. The trials mentioned in Section 4.2 should provide useful information to help improve local specifications.

Whichever product is specified, close attention to construction detailing is important, as shown by a performance review of 120 slopes upgraded and 'greened' under the LPM Programme since 1991 (Martin et al. 2001). The data assessed for each slope included type of surfacing, slope angle and bearing (azimuth), degree of shadiness, condition of existing vegetated cover, and details of any recorded or ongoing signs of distress, surface erosion or instability. The review showed that nine of the slopes (i.e. about 8%) experienced some erosion after completion of the LPM works. Seven of these incidents involved minor surface erosion with estimated debris volumes of 1 – 20 m^3. The other two were larger washouts (debris volumes 50 – 500 m^3) which caused temporary road blockage. Eight of the nine incidents occurred on slopes with gradients of 40^o or greater. Five occurred within one year of completion of the slope surfacing. The review concluded that inadequate construction detailing is the main factor responsible for these erosion incidents, rather than inherent problems of soil erodibility or infertility. The common defects are poor surface drainage detailing, leading to overspills and splash erosion around drainage channels, and inadequate fixing of erosion protection mats to conform closely to undulating slope surfaces.

4.5 *Hard Surfaces and Rock Slopes*

Further experimentation with the use of tiles, facing blocks and the like is expected in the LPM Programme over the next few years. For example, architectural spray coatings have been used in a few cases to create pseudo stone-block finishes to shotcreted surfaces

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

Table 3. Purpose and specification of erosion control mats on steep soil slopes

Purpose		
Water Erosion Control	Wind Erosion Control	Vegetation Establishment
Reduce rates of soil detachment by raindrop impact, i.e. splash erosion Reduce total runoff (? – generally not supported by scientific data) Delay onset to runoff and reduce peak runoff Reduce runoff velocities and soil transport capacity Increase soil strength (? - possible if fibres degrade and mix with soil) Reduce overall soil losses (effects generally greater for more erodible soils and for higher intensity rainfalls)	Increase roughness, reduce near-surface wind speed Maintain surface moisture, reduce rate of drying of soil	Modified microclimate (temperature and light conditions – may be beneficial or adverse depending on colour, mesh size/ porosity, etc.) Increase near-surface soil moisture Protect sown seeds from foreign seeding Protect soil from trafficking (humans/animals)
Specification – Possible Properties		
Index Properties		Performance Properties
Tensile Strength (? – only minimum strength for fixing in place needed; some long-term decline in strength (e.g. biodegradable mat) is beneficial) Friction/Adhesion (? – only needs to be adequate to remain securely on slope) Puncture Resistance (?) Flexibility/Stiffness (not too stiff, otherwise difficult to lay closely on irregular surface) UV Radiation Stability (? – reduction in time beneficial if non-biodegradable) Opening Size/Pore Size Distribution Permeability Transmissivity (in-plane flow capacity) Clogging Resistance (? – some degree of soil retention beneficial) Weight/Unit Area (? – discriminates against lightweight materials)		Soil Retention (arguably the only valid performance measure) Friction/Adhesion (?) Stress-Strain Characteristics (?)
? = common misconception, or doubt over relevance		

(Figure 9). These products are appropriate for slopes and walls in an urban setting. Lightweight materials are likely to become popular on steep man-made slopes without vehicular access, e.g. behind terraced village houses.

Weepholes at 1.5 m or 2 m spacing are a standard prescriptive feature in all shotcrete covers in order to prevent locally high water pressures developing behind the surface. Staining below weepholes is a common occurrence on finished slopes. More can be done to mask the effects of staining, e.g. by forming small channels or grooves in the hard surface to link the seepage point with a toe or berm channel.

The 'greening' of hard rock and shotcreted soil cut slopes is another area of interest. Recent trials have included testing of soil- and fertiliser-filled perforated PVC tubes ('hydro-planters') bolted onto shotcreted slopes with a wire mesh cover (Figure 10). The idea is that seedlings planted in the perforated tubes eventually spread over the mesh and form a slightly-raised green cover to the slope. 'Bio-drains' incorporating Vetiver grass cuttings planted in pockets or arrays on steep cut slopes are also being tested (Figure 11). Further effort to enhance the growing conditions of climbing plants and grasses placed in planter holes cut into hard surfaces is warranted. Identification of planting opportunities to provide a screening effect in front of hard-surfaced slopes and walls also deserves more attention.

4.6 *Slope Infrastructure*

Even where vegetated surfaces are used, artificial elements are still present on most engineered slopes in Hong Kong. Concrete surface channels on berms (usually at 7.5 m spacing) are common on cut slopes and many of the higher fill slopes, as are concrete crest and toe channels.

There are increasing demands by slope owners and maintenance authorities for improved access to slope crests and berms for inspection and maintenance. Concrete staircases and permanent metal handrails are the typical provisions (Figure 12), often with a high

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

Figure 9. Granolithic spray coating used to create a stone-block effect on a shotcreted soil cut slope

Figure 10. Hydro-planters bolted onto a steep shotcreted cut slope

Figure 11. Vetiver grass cuttings in pockets and strips on the upper two batters of a 40° – 45° soil cut slope

Figure 12. Typical concrete staircase and metal railings for slope access and maintenance

degree of visual impact.

Adding to the visually intrusive aspects of slope infrastructure are high boundary fences, usually formed of chain link topped with barbed wire strands, and lockable metal gates at the foot or crest of staircases. These are often placed in areas with no apparent over-riding security concerns. The boundary fences are especially unsightly when placed along the crests of fill slopes supporting roads and building platforms with open scenic views (Figure 13).

Figure 13. Chain link fence at the crest of a roadside fill slope in a scenic area

There is scope for reducing the negative visual impact of such elements. In many cases a considered analysis of safety and security concerns should allow gates and railings to be omitted. Small boundary walls may be used in preference to high fences. Where safe access to berms is of genuine concern on steeper slopes, the use of temporary or folding handrails, eyebolts and footrails (for attachment of safety lines) should be considered as alternatives to permanent handrails (Figure 14).

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

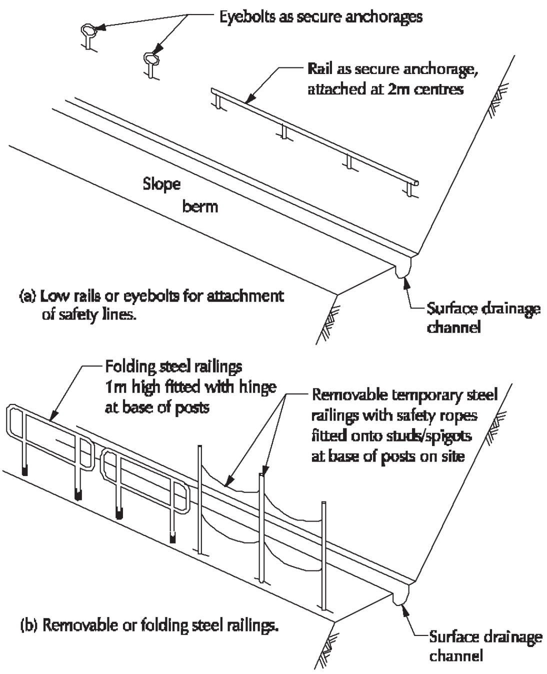


Figure 14. Alternatives to permanent railings for inspection and maintenance works along slope crests and berms

5 CONCLUSIONS

Slope bio-engineering and landscaping are currently in vogue as part of a new environmental focus in civil engineering. Recent public concern over slope appearance in Hong Kong has been the catalyst for increased professional input to these topics.

Despite the renewed interest, and publication of new GEO guidelines, bio-engineering practice in Hong Kong is not yet well advanced. Heavy reliance is still placed on standard hydroseeding to form vegetated slope surfaces.

In Hong Kong's high-risk setting geotechnical designers are reluctant to rely on vegetation alone for enhanced slope stability. Present evidence suggests that the significant slope-stabilising effects of vegetation rarely extends below the top 1-2 m of the soil profile. Integrated biotechnical solutions involving vegetated surfaces together with conventional deeper slope reinforcement, retention and drainage techniques seems a more fruitful direction for improved design practice, with the vegetation primarily providing resistance to surface erosion.

There is broad scope in Hong Kong for application of alternative bio-engineering techniques in new site formation works and restoration of degraded natural terrain. Cost, lack of working space and construction site safety constraints are factors restricting wider use of other bio-engineering techniques in upgrading existing slopes under the LPM Programme.

Native vegetation species are under-represented in current hydroseeding and transplanting practice. Local research is underway with a view to promoting greater use of native species on slopes, especially shrubs.

There is room for improvement in the specification of erosion control mats for use on slopes. Ensuring that erosion mats are fixed closely to irregular surfaces is very important for successful performance on steep slopes.

Several innovative techniques for improving the appearance of rock slopes and hard-surfaced soil slopes are being tested. Indiscriminate shotcreting is no longer a major threat, but the adverse visual impact of concrete access steps, metal handrails and boundary fencing is still of concern. More effort is required to mitigate these effects and to develop alternatives to allow safe inspection and maintenance on steep slopes.

ACKNOWLEDGEMENTS

This report is published by permission of the Director of Civil Engineering of the Government of the Hong Kong Special Administrative Region.

REFERENCES

Barker, D.H. 1999. The introduction of ground and water bioengineering techniques to the humid tropics. Proc. 1st Asia-Pacific Conf. on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization, Manila : 3-17.

Barker, D.H. 2001. Innovative bioengineering techniques for rapid slope stabilisation. (This volume).

Chong, S.L. 1997. Restoration of degraded lands in Hong Kong. Proc. Conf. on Remediation and Management of Degraded Lands, Hong Kong. 10p.

Clark, J. & Hellin J. 1996. Bio-engineering for Effective Road Maintenance in the Carribbean. Natural Resources Institute, Chatham, U.K. 121 p.

Collison, A.J.C., Anderson, M.G. & Lloyd, D.M. 1995. Impact of vegetation on slope stability in a humid tropical environment : a modelling approach. Proc. Instn. Civ. Engrs. Water, Maritime & Energy. 112: 168-175.

Coppin, N.J. & Richards, I.G. (eds). 1990. Use of Vegetation in Civil Engineering. Construction Industry Research and Information Association. Butterworths, London. 292 p.

Docker, B.B. & Hubble, T.C.T. 2001a. Earth reinforcement potential of four tree species as determined by root system architecture. (This volume).

Docker, B.B. & Hubble, T.C.T. 2001b. Strength and

Martin, R.P., Landscaping and bio-engineering of slopes in Hong Kong. In: Ho, K.K.S. & Li, K.S. (eds) Proceedings of the Fourteenth Southeast Asian Geotechnical Conference – Geotechnical Engineering Meeting Society's Needs, vol. 1, pp 661-670 © CRC Press/Balkema.

distribution of Casuarina glauca roots in relation to slope stability : a case study from the Nepean River, NSW, Australia. (This volume).

Ekanayake, J.C. Phillips, C.J. & Marden, M. 1999. A comparison of methods for stability analysis of vegetated slopes. Proc. 1st Asia-Pacific Conf. on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization, Manila : 411-418.

GEO 2000. Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls in Hong Kong. GEO Publication 1/2000. Geotechnical Engineering Office, Hong Kong. 146 p.

Gray, D.H. & Leiser, A.J. 1982. Biotechnical Slope Protection and Erosion Control. Van Nostrand Reinhold, New York. 271 p.

Gray, D.H. & Sotir, R.B. 1996. Biotechnical and Soil Bioengineering Slope Stabilization : A Practical Guide for Erosion Control. John Wiley and Sons, Inc., New York. 378 p.

Greenway, D.R. 1987. Vegetation and slope stability. In M. G. Anderson & K. S. Richards (eds). Slope Stability : Geotechnical Engineering and Geomorphology. John Wiley & Sons, Chichester, UK: 187-230.

Greenway, D.R., Anderson, M.G. & Brian-Boys, K.C. 1984. Influence of vegetation on slope stability in Hong Kong. Proc. 4th Int. Symp. on Landslides, Toronto. 1: 399-404.

Ground Engineering 2001. Soil bio-engineering : integrating ecology with engineering practice. Ground Engineering. Supplement, 19 p.

Halcrow China Ltd. 2000. Review of Effective Methods of Integrating Man-made Slopes and Retaining Walls (Particularly for Roadside Slopes) into Their Surroundings. GEO Report 116. Geotechnical Engineering Office, Hong Kong. 212 p.

Howell, J.H. 1999. Roadside Bio-engineering, Site Handbook and Reference Manual. Department of Roads, Nepal and His Majesty's Government of Nepal. 160 p and 216 p.

IECA 1999. Proc. 1st Asia-Pacific Conf. on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization, Manila. International Erosion Control Association, 528 p.

Li, C.O., Watkins, A.T. & Ho, Y.K. 1999. Use of vegetation as surface protection for steep slopes in Hong Kong. Proc. 1st Asia-Pacific Conf. on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization, Manila : 477-484.

Ling, K.B., Ho, Y.K., Wong, W.P. & Chang, M.K. 2001. New initiatives to improve appearance of steep slopes. (This volume).

Martin, R.P., Li, C.O. & Pryor, M.R. 2001. Bio-engineering and landscape treatment of slopes and retaining walls in Hong Kong's Landslip Preventive Measures Programme. (This volume).

Morgan, R.P.C. & Rickson, R.J. (eds.) 1995. Slope Stabilization and Erosion Control : a Bioengineering Approach. E & F N Spon, London. 274 p.

Nilaweera, N.S. & Nutalaya, P. 1999. Role of tree roots in slope stabilisation. Bull. Eng. Geol. Env. 57: 337-342.

Noraini, M.T. & Ghani, J.A. 2001. Bioengineering on slopes for landslide stabilization and prevention in Malaysia. (This volume).

Rickson, R.J. & Vella, P. 1992. Experiments on the role of natural and synthetic geotextiles for the control of soil erosion. Proc. Congress Geosintetico per le Costruzioni in Terra – Il Controllo Dell'erosione, Bologna. 28 p.

Thomas, B.R., Sayer, P.R., Bridges, C.A. & Knight, J. 2001. Integration of man-made slopes into Hong Kong's urban environment. (This volume).

Tsukamoto, Y. & Kusakabe, O. 1984. Vegetative influences on debris slide occurrences on steep slopes in Japan. Proc. Symp. on Effects of Forest Land Use on Erosion and Slope Stability, Honolulu, Hawaii.

Wu, T.H., McKinnell, W.P. & Swanston, D.N. 1979. Strength of tree roots and landslides on Prince of Wales Island, Alaska. Can. Geot. J., 16:19-33.

Wu, T.H., Watson, A. & El-Khouly, M.A. 1999. Soil-root interaction and slope stability. Proc. 1st Asia-Pacific Conf. on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization, Manila : 514-521.