GUIDELINES FOR SOIL BIOENGINEERING APPLICATIONS ON NATURAL TERRAIN LANDSLIDE SCARS

GEO REPORT No. 227

S.D.G. Campbell, R. Shaw, R.J. Sewell & J.C.F. Wong

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CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
July 2008

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FOREWORD

Demand for a declining supply of new land for residential and infrastructural projects has meant that new development sites are encroaching closer to steep natural slopes. Consequently, the HKSAR Government has been increasingly focusing attention on the hazards presented by natural terrain in Hong Kong. Currently, the preferred strategy for stabilising large areas of natural hillside close to developments is to seek low cost, environmentally compatible, and sustainable alternatives to conventional engineering methods. Soil bioengineering provides one such alternative although its use in Hong Kong to date has been largely restricted to direct planting in areas of severe erosion.

This document contains initial guidance on the selection and installation of soil bioengineering measures for the repair of natural terrain landslide scars and related soil erosion. These guidelines have been compiled to assist engineers with the task of selecting the most appropriate soil bioengineering measures to repair, stabilise, and protect the soil scars that result from slope failures on natural terrain. They form part of a commitment by the HKSAR Government to ensure that the potential hazards presented by natural slopes in Hong Kong are reduced to a minimum.

The project was supervised by members of the Planning Division of the Geotechnical Engineering Office, namely Dr S.D.G. Campbell (formerly of GEO), Dr R.J. Sewell, Dr R. Shaw, Ms A.M.H. Lai and Mr J.C.F. Wong, under the direction of Mr H.N. Wong. The document was reviewed by colleagues from Civil Engineering & Development Department and Agriculture, Fisheries & Conservation Department, who are experienced in landscaping, slope greening and erosion control planting.

Field work, contract preparation and management, site supervision, and drafting of the document was carried out under a consultancy let to Maunsell Geotechnical Services Limited (MGSL). The MGSL team comprised Mr P.A. Chau, Ms M. Law, Mr H. Wang and Mr A. Dias, and was assisted by Ms Robbin B. Sotir of Robbin B. Sotir & Associates, Inc.

These guidelines provide an introductory guide to non-specialists and are not intended to be prescriptive. They should be used giving full consideration to the topographical setting, the nature and extent of existing vegetation, the hydrological conditions, and to the perceived risk to existing developments. Practitioners may wish to use alternative measures, or combinations of measures. All users are encouraged to provide comments on the content of this document so that improvements can be made to future editions.

(H.N. Wong)
Chief Geotechnical Engineer/Planning

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ABSTRACT

This report outlines a range of soil bioengineering measures, suitable for Hong Kong, that provide a low-cost, environmentally sensitive approach to the repair and protection of disturbed natural terrain. The techniques combine mechanical, biological, and ecological principles to repair erosion gullies, remediate shallow mass movement scars, and to protect the slope. They integrate established engineering practices with ecological principles to provide broad mechanical, hydrological and environmental benefits.

Soil bioengineering measures broadly comprise direct and indirect measures. Direct measures are installed on sites that require repair or stabilisation. They include 'living' (*i.e.* the planting of herbaceous and woody species) and 'structural' (*e.g.* timber cribwalls and bender fences) components, although the two components are commonly combined (*e.g.* live cribwalls). The living approach includes conventional direct planting of grasses, shrubs or trees, and techniques that use the stems or branches of living plants to reinforce the soil. The latter include live stakes, live fascines, brushlayers, hedgelayers, and branchpacking. Following installation, the growth of stems and roots, combined with invasive species, create the major structural components. Each measure offers different immediate depths of effectiveness (prior to rooting), typically between 200 to 1200 mm for natural hillsides. Indirect measures consist of live barriers, which are belts of hardy species (trees and bamboo) that are strategically planted to restrict the movement of landslide debris. They can be planted within drainage lines to restrict the passage of channellised debris flows, or below steep slopes to restrict the movement of debris from open hillslope failures.

The effective installation of soil bioengineering measures requires careful planning and design, based upon the specific characteristics of each site. These include factors such as the site geology, soils, slope angle, slope aspect, hydrology, existing vegetation cover, *etc.*, which should all be assessed before appropriate measures can be prescribed. Soil bioengineering measures cannot be installed where the site is in bedrock, on deep-seated failures with high back scars, or on steep slopes (over about 35-50º).

The selection of suitable plant species and species combinations soil bioengineering measures must be based on careful vegetation surveys. The plants must tolerate thin, well-drained soils, steep slopes, and exposed sites. Native species, mainly shrubs, are preferred. These are compatible with local ecosystems and are relatively inexpensive, because they can be harvested from areas adjacent to the site. Also, they are well suited to the local climate, soil and moisture conditions. Exotic species may be considered in certain circumstances.

These guidelines present standards for the collection and assessment of desk study and site-specific data, guidance on the design and construction of specific soil bioengineering measures, selection of appropriate plant species, the maintenance requirements during the establishment period of the measures, and the subsequent monitoring and evaluation procedures. Many of the techniques described are based on the results of a pilot project initiated by the Geotechnical Engineering Office in 2003 to install various soil bioengineering measures on areas of natural terrain affected by recent, shallow landsliding and subsequent gully erosion. Since a full evaluation of the performance of the various measures requires continuous monitoring over a 3-5 year period, these guidelines should be regarded as a work in progress.

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1. INTRODUCTION

1.1 Background

This document outlines a range of soil bioengineering measures that are considered to be suitable for the stabilisation and restoration of natural terrain landslide scars in the Hong Kong Special Administrative Region (hereafter referred to as Hong Kong). These preliminary guidelines are presented as a foundation for further research and development into the applications of soil bioengineering in Hong Kong. The contents are intended for practitioners who are engaged in the preservation, enhancement and restoration of natural terrain in Hong Kong, e.g. geotechnical engineers and plant ecologists.

This report is a guidance document. Consequently, the methodologies described are not mandatory. It is probable that situations will arise for which the report provides inadequate, or inappropriate, guidance. In these cases, designers should seek alternative methods. There will also be improvements in soil bioengineering practice that will supersede the specific recommendations made in this report. Consequently, it is essential that practitioners provide the Geotechnical Engineering Office (GEO) with information about any advances in knowledge, and with suggestions for improvements to this report.

1.2 Definition of Soil Bioengineering

For centuries, living plants have been used to control erosion on slopes and along river banks (MGS, 2003). A classical Hong Kong example is the Feng Shui woodland, which was planted upslope from New Territories houses for protection. However, with the advent of the industrial revolution, steel and concrete were increasingly used, being more amenable to exact designs. Bioengineering enjoyed a resurgence in the 1930s, with several new techniques being developed, such as willow for construction, and vegetated crib walls. The development of these techniques was described by Schiechtl (1980).

Bioengineering, or biotechnical slope protection, has been defined variously as 'the use of mechanical elements (or structures) in combination with biological elements (or plants) to arrest and prevent slope failures and erosion' (Gray & Leiser, 1982), 'the use of living vegetation, either alone or in conjunction with non-living plant material and civil engineering structures, to stabilise slopes and/or reduce erosion' and 'the use of any form of vegetation, whether a single plant or collection of plants, as an engineering material (i.e. one that has quantifiable characteristics and behaviour)' (Morgan & Rickson, 1995; quoted in GEO, 2000).

The term soil bioengineering is considered to be a specific term that refers to 'the use of live plants and plant parts, in which live cuttings and stems are placed in the ground, or in earthen structures, where they provide additional mechanical support to soil, and act as hydraulic drains, barriers to earth movement, and hydraulic pumps or wicks' (Gray & Sotir, 1996). Soil bioengineering systems commonly incorporate inert materials such as rock and wood, or geo-synthetics, geo-composites and other manufactured products.

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1.3 Objectives of Soil Bioengineering Measures

Soil bioengineering is a relatively new approach to the remediation of natural terrain landslide scars in Hong Kong (Campbell et al., 2005). The primary objective is that soil bioengineering measures will provide self-sustaining protection to natural terrain affected by erosion and shallow mass movements. They increase the resistance of slopes to surface erosion by providing limited mechanical support to the soil, thereby reducing the potential for further surface erosion, gully formation, shallow failures, surface debris movement, and debris entrainment.

Soil bioengineering measures combine mechanical, biological, and ecological principles and practices to protect and enhance slopes, repair erosion gullies and remediate shallow mass movement scars. Importantly, the techniques are generally considered to be cost-effective, with desirable environmental and visual characteristics. In addition, soil bioengineering measures are intended to both encourage and accelerate the processes of natural re-vegetation, thus enhancing natural diversity and sustaining the natural hillside ecosystems.

1.4 Description of Soil Bioengineering Measures

Soil bioengineering measures are not simply "greening" techniques. They involve far more than simply applying a green vegetative cover to the degraded slopes.

Soil bioengineering is the combined application of engineering practices and ecological principles to design and build systems that contain living plant materials (Sotir, 2001). The application of soil bioengineering measures involves the installation of woody plant materials, securely embedded in the ground and placed in specific planned configurations to create effective erosion control measures. They are intended to have an immediate effect, but also to provide a foundation that will encourage colonisation by the surrounding plants, thus ensuring long-term remediation and protection of slopes scarred by erosion scars, experiencing active soil erosion, and affected by shallow slope failures.

Soil bioengineering measures integrate established engineering practices with ecological principles to provide installations that offer broad mechanical, hydrological and environmental benefits. Therefore, the effective application of these measures requires careful planning and design, taking into account the specific characteristics of each site. Factors such as the geology, soils, slope angle, slope aspect, hydrology, existing vegetation cover, etc., should all be assessed before the appropriate soil bioengineering measures can be prescribed.

Several potential environmental benefits can be achieved by using soil bioengineering measures as opposed to conventional engineering methods. Notably, they generally require only minimal access provisions for equipment, materials and workers, and typically create only minor disturbance to the site and environs during installation. In environmentally sensitive locations, where preservation of scenery or wildlife habitats may be critical, soil bioengineering measures can usually offer more environmentally compatible solutions. Importantly, for sensitive or remote sites, these do not require long-term maintenance, thereby creating less disturbance.

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Soil bioengineering measures comprise both direct measures, which are installed on sites requiring repair or stabilisation, and indirect measures, that are applied to areas adjacent to damaged sites.

(1) *Direct Measures* Direct measures include two distinct components, namely, ‘living’ (i.e. the use of live herbaceous and woody species) and ‘non-living’ or ‘structural’ (i.e. the use of dead stakes, timber cribwalls, etc.). The living approach includes conventional direct planting of shrubs or trees, and more specific soil bioengineering measures that use stems or branches of living plants as the primary mechanical soil supporting agents. The latter techniques include live stakes, live fascines, brushlayers, hedgelayers, branchpacking and pole drains. Following installation of the stems and branches, the subsequent growth of foliage and development of roots, combined with the establishment of colonising species, form the major structural components of the soil bioengineering system. In practice, the two components are usually combined (e.g. live cribwalls, in which live branch cuttings and/or rooted plants are installed within timber cribwalls), and individual measures are commonly integrated into a comprehensive soil bioengineering strategy.

(2) *Indirect Measures* Indirect measures include live barriers. These are belts of hardy species (trees and bamboos) that are strategically planted, in stream courses or on open slopes, to restrict the movement of landslide debris. Details of indirect soil bioengineering measures are described in Section 3.6.

1.5 Limitations of Soil Bioengineering Measures

Soil bioengineering measures have several important limitations. They cannot be recommended where erosion has removed the soil. Thus, in the case of landslide scars that expose bedrock, there is no unstable soil remaining to be stabilised, and also no soil in which to establish plants. Deep-seated failures with high back-scars (with headwalls greater than about 2 metres), which are particularly prone to retrogressive failures, are beyond the capacity of most rooted plants to successfully repair and stabilise. Steep slopes, of over about 50°, present problems, being both difficult to access and expensive to repair.

Although the benefits of using vegetation to prevent soil erosion are well established, its ability to stabilise slopes subject to shallow failures is less well proven, and certainly less well quantified. Woody vegetation contributes to preventing, or retarding, shallow instability in soil mainly by increasing the shear strength of the soil via root action (Gray & Sotir, 1996). However, although the value of woody vegetation in protecting slopes against shallow failures has gained increasing recognition in recent years (Greenway, 1987; Coppin & Richards, 1990), soil bioengineering measures are not amenable to conventional Factor of Safety (F.O.S.) analyses.

1.6 Soil Bioengineering Applications

The soil bioengineering measures outlined in this document are considered to be appropriate for:

(a) the repair of hillsides affected by general surface erosion, shallow rilling and/or gullying, and shallow failures.

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Appropriate measures include live fascines, brushlayers, hedgelayers, branchpacking and live gully repairs,

(b) reducing the rate or extent of hillside deterioration and thereby the potential for further erosion and shallow failures. Appropriate measures include live stakes, brushlayers, hedgelayers, pole drains and live fascines,

(c) restraining the downslope movement of landslide debris, particularly the entrainment of loose slope materials. Appropriate measures include live cribwalls, bender fences and live barriers.

The measures are most suitable for use in areas of natural scenery (e.g. in Country Parks), in locations where the consequences in the event of slope failures are low (e.g. above minor roads), on sites where hillside deterioration needs to be controlled (e.g. eroded or failed natural slopes, and areas affected by recent hill fires), and in association with conventional engineering mitigation measures.

Different soil bioengineering measures can be used individually, or in combination, to address different problems. Each method has its own particular strengths and weaknesses, depending upon the particular site conditions and project objectives. For example, live stakes and direct planting are relative simple, economical and rapid measures that provide limited protection to a slope surface, so are recommended for areas of minor erosion (e.g. areas burned by recent hill fires). Live fascines and pole drains control surface water flow and provide more protection against surface erosion, such as rilling and gullying. Brushlayers and hedgelayers provide a degree of mechanical support to reinforce the soil against shallow mass movements, but are more difficult to install. Live cribwalls and bender fences provide lateral support to the slopes and can also be used to protect the slope toe. Live barriers, which are indirect measures, can be planted downslope from areas of instability, to provide a degree of protection to minor facilities.

1.7 Integrated Planning and Design Requirements

Soil bioengineering measures integrate conventional engineering practices with ecological principles to offer a range of alternative slope protection and repair methods that offer broad mechanical, hydrological and environmental advantages. To achieve maximum benefits from the measures, the characteristics and requirements of each method must be carefully considered during the planning and design stages of the project. The measures described in this report can, in most circumstances, be applied to all sites, particularly if appropriate modifications are incorporated during the planning and design stage. Compatibility with local conditions can typically be achieved by adopting a creative approach to the repair of natural terrain landslide scars in Hong Kong.

When using these guidelines, designers should ensure that the works are assessed, designed and constructed in accordance with the latest versions of the relevant geotechnical and safety standards, including, but not limited to, the following documents:

(a) GEO Publication No. 1/2000 - Technical Guidelines on

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Landscape Treatment and Bioengineering for Man-made Slopes and Retaining Walls (GEO, 2000).

(b) GEO SPR 6/2004 - Performance Assessment of Greening Techniques on Slopes (Lui & Shui, 2004).

(c) GEO Report No. 138 - Guidelines for Natural Terrain Hazard Studies (Ng et al., 2003).

(d) Geotechnical Manual for Slopes (GCO, 1984).

(e) Construction Site Safety Handbook (Works Bureau, 2000).

Designers should bear in mind the need to minimise future maintenance commitments by, wherever possible, ensuring that the soil bioengineering measures fully self-sustaining after an initial period of establishment and maintenance.

1.8 Field Trials in Hong Kong

The use of soil bioengineering measures in Hong Kong is still very much in its infancy. Clearly, it will take many years to fully explore and develop the application of soil bioengineering measures on Hong Kong hillsides. This report presents, in general terms, descriptions of the currently available techniques for the stabilisation and restoration of natural hillsides. It is intended that these guidelines will form a foundation for future research and development into the suitability of soil bioengineering measures for repairing natural terrain landslide scars and lowering the risk of natural terrain landslides. Because local experience is so far limited, brief reference is made to overseas experience where it is considered to be essential.

Most of the site assessment methods, design processes, and bioengineering measures presented in this report have been field-tested on hillsides in three different regions of Hong Kong. Trials were carried out in 2004 and 2005 at Cloudy Hill North and Cloudy Hill South (Tai Po), Sham Wat (Lantau) and Por Lo Shan (Tuen Mun). Descriptions, and brief performance reports, of the trial measures are described in Chapter 3. Soil bioengineering measures installed were direct planting, live fascines, brushlayers, hedgelayers, branchpacking, live gully repairs, tension crack repairs, berm construction, live cribwalls, bender fences and pole drains. The installation trials were designed to test both the suitability of selected soil bioengineering measures and to assess the performance of native species in combination with these measures. In addition, the mechanical performance of the trial installations was tested over wet and dry seasons to determine the capabilities of the soil bioengineering measures to successfully establish, to resist heavy rainfalls, and thus to repair the landslide scars and to control soil erosion and shallow mass movements.

Based on the assessment of plant performance after the first year of the field trials (MGS, 2006a), it appears that there is a limited number of local species that can successfully propagate from cuttings on hillside sites in Hong Kong. Currently available species include *Ficus microcarpa*, *Gardenia jasminoides* and *Salix babylomica*. Soil bioengineering measures are new to Hong Kong, so are clearly in the early stages of development. Further field trials should examine the suitability of additional local species for various applications

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and environmental settings. Overseas experience indicates that *Cornus* and *Viburnum* species may be well adapted.

There is very little published information about the rooting depths and characteristics of Hong Kong native plants. Consequently, a preliminary study of the rooting characteristics of several native species (MGS, 2006b) was conducted on the trial sites at Cloudy Hill North. The roots of selected species were carefully unearthed one year after their installation to investigate the extent of their development. Measurements were made of the total root length, root morphology, and the general health of the selected species, in order to develop an understanding of their physical extent and mechanical properties, and thus to begin to assess their potential effectiveness in reinforcing the soil mass. A summary of the results is given in Section 2.3.4.

Importantly, all three trial sites were located in areas underlain by volcanic rocks, which characteristically have thinner and more clayey soils than are developed over granitic rocks. The latter are generally more sandy and more free-draining. Consequently, the soil tests carried out during this project are limited to specific volcanic lithologies. Further soil tests would be required to determine the characterisitcs of soils developed over other lithologies in Hong Kong.

Several supplementary measures, including vegetated gabions and joint planting, were not field tested in Hong Kong. However, they are described in Chapter 3, where reference is made to overseas experience with the measures. These measures could usefully be tested in future projects or practical applications in Hong Kong.

2. CHARACTERISTICS OF SOIL BIOENGINEERING MEASURES

2.1 General

The soil bioengineering measures described in these guidelines are suitable for the repair, restoration, protection, and enhancement of natural hillsides in Hong Kong. They can be applied to sites affected both by fluvial erosional processes, such as sheet, rill and gully erosion, and by shallow mass movements and their debris trails.

The specifications take into account the characteristics of selected native vegetation species, both herbaceous and woody, that grow on hillsides in Hong Kong. However, limited field trials indicate that there may be certain situations where non-native species might be considered. These species may be used alone, or in combination with man-made structures such as cribwalls and fencing. Specific characteristics of both the vegetative and structural components are described below.

2.1.1 Plant Components

2.1.1.1 Herbaceous Species

Herbaceous plants (e.g. grasses and herbs), when sufficiently well established, offer short-term protection (3-7 years) against surface (water and wind) erosion on natural terrain in Hong Kong. However, they provide only limited protection on slopes susceptible to shallow mass movements. The specific characteristics of these species that are the most valuable for

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soil bioengineering include their capacity to:

(a) intercept raindrops, thereby reducing erosion by direct raindrop impact and splash,

(b) bind and restrain soil particles,

(c) reduce the degree of soil saturation near the ground surface,

(d) retard surface runoff velocities, and

(e) reduce the amount of eroded and translocated soil materials

2.1.1.2 Woody Species

Woody plants, when sufficiently well established, offer longer-term protection against surface (water and wind) erosion on natural hillsides. Field trials have demonstrated that, because of the strength and depth of their root systems, woody plants are able to provide substantial protection against shallow mass movements. The specific characteristics of these species that are the most valuable for soil bioengineering include their capacity to:

(a) intercept raindrops, thereby reducing erosion by direct raindrop impact and splash,

(b) maintain and enhance the natural infiltration capacity of the natural slope surface,

(c) reduce the volume of soil-water through interception and transpiration,

(d) retard surface runoff velocities,

(e) reduce the amount of eroded and translocated soil materials,

(f) provide mechanical support to the surface soil through root action,

(g) provide additional further structural support to the slope through the buttressing and soil-arching action of embedded stems, and

(h) provide erosion control immediately after planting.

2.1.1.3 Native and Exotic Species

Native plant species are those plant species living, or occurring naturally, in an area (e.g. *Gardenia jasminoides*) (GEO, 2000). In line with the long-term objectives of soil bioengineering, which is to facilitate natural vegetation regeneration and succession, the use

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of native species, rather than exotic species, is preferred. Exotic plant species, that is those originating from another part of the world (GEO, 2000), tend to grow faster than native species. However, exotic species may not readily blend in with the local vegetation, support local ecosystems, or enhance the existing vegetation community.

The use of certain naturalised-exotics may be considered if their presence does not result in negative ecological effects. One possible benefit of planting fast growing exotic species (e.g. *Acacia confuse, Duranta erecta*) is their ability to rapidly establish favourable micro-climates that would encourage the establishment of slower-growing native species. The soil bioengineering field trials confirmed that the exotic species *Acacia confusa* and *Duranta erecta* initially grew faster than most of the native plants used in the trials. AFCD (1999) and Kadoorie Farm & Botanic Garden (2001) observed that, although their initial growth rate may be slower, native species eventually outperform exotic species.

Guidelines on the selection of appropriate plant species for soil erosion control planting are given in CEDD's Landscape Guidance Notes No. 1/2006 (CEDD, 2006). The CEDD has been undertaking soil erosion control planting around the fringes of New Towns and new development areas for many years, planting that is intended to control soil erosion by re-establishing a vegetation cover on bare and badly scarred land. This involves the use of fast-growing species with pioneering characteristics that are effective in establishing themselves on eroded surfaces. Experience to date has shown that some exotic species and a few native species have promising pioneering characteristics. However, while erosion control planting may require the use of some exotic species, due consideration should be given to native species in order to create wildlife habitats and to enhance biodiversity, with the ultimate goal of establishing ecologically sustainable woodlands (CEDD, 2006). It should be noted that the characteristics of the plant species suitable for use in bioengineering repairs of natural terrain landslide scars may be very different from those that are most suitable for erosion control planting around urban areas. Natural terrain landslides occur on steep natural hillsides subject to transient water pressure. These hillsides commonly have a vegetation cover, rather than being bare and badly eroded. However, the objective of achieving biodiversity and ecological sustainability in a natural setting is a common principle, and there is potentially better scope for using native species for repairing natural terrain landslide scars.

2.1.2 Structural Support Components

Carefully planned, designed, and installed retaining structures (e.g. cribwalls and bender fences) can provide, at least in the initial stages, considerable structural support to areas of natural terrain affected by, for example, rill and gully erosion or shallow mass movements. In addition to stabilising a slope and providing a stable growing environment, their capacity to reduce erosion assists the successful establishment and growth of rooted plantings and live branch cuttings planted at the site. Also, they assist the germination of colonising seeds during the establishment period, which is their most vulnerable time of growth.

2.1.2.1 Materials

Supporting structures on natural terrain landslide scars can be built using natural or manufactured materials. Natural materials, such as soil, rock and raft materials (discrete

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masses of the soil layer, with attached plants, that have moved downslope as part of a landslide) are usually cheaper to use, because they are immediately available on the site, thus not incurring extra costs. In addition, they are more environmentally and visually compatible with the surroundings than imported materials. Consequently, it is recommended that local materials are utilised wherever possible and permissible.

2.1.2.2 Retaining Structures

Retaining structures, such as fencing and cribwalls, on natural terrain landslide scars can be built from materials such as rock and timber. These structures not only enhance the potential for the re-establishment of vegetation by mechanically stabilising the soil, but they also allow the incorporation of vegetative components during construction.

2.1.2.3 Grade Control Structures

Grade control measures (e.g. timber/rock and soil embankments) can be used to control severe erosion. They reduce the local gradient, which dissipates the energy of surface water flows and reduces the potential for further erosion, thus promoting ecological restoration. In all cases, with or without structural measures, the presence of concentrated surface water flows must be controlled prior to the installation of any soil bioengineering measures. For example, construction of a perimeter pole drain around the crown of the landslide scar is an effective method of diverting surface water flow from the scar. Simply planting vegetation on severely eroded sites (e.g. very steep slopes, or slopes with high runoff and high velocity flows) may provide only short term, marginal stabilisation. The construction of grade control measures in combination with planting assists with the effective stabilisation and subsequent re-vegetation of these sites. Initially, the structural and vegetative components act together as an integrated bioengineering strategy. However, the ultimate purpose of these combinations is to facilitate the long-term establishment of the installed vegetation, and to support natural colonisation by the surrounding plant community. This is achieved through providing mechanical stabilisation in addition to ecological restoration of the eroded hillslope sites.

2.1.3 Applicability

Soil bioengineering measures are not an appropriate solution for all surface erosion conditions, or for all natural terrain landslide scars. In certain cases, conventional re-vegetative methods such as grass seeding or direct planting would be quite adequate, considerably cheaper, and involve less site disturbance (e.g. on ground sloping at less than about 15°). However, in the case of deep-seated failures, or of over-steepened landslide scars, a more appropriate solution would be the construction of a conventional engineering structure, for example a concrete gravity retaining wall.

The following factors should be carefully considered before deciding to install soil bioengineering measures.

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2.1.3.1 <u>Environmental Compatibility</u>

The installation of soil bioengineering measures generally requires only limited access for equipment, materials and workers, thus creating only relatively minor site disturbance during the works. In environmentally sensitive areas, such as Country Parks, scenic corridors, or other locations where visual quality, wildlife habitat, and similar factors may be critical, soil bioengineering usually offers the highest level of environmental compatibility.

2.1.3.2 <u>Cost Effectiveness</u>

The cost effectiveness of soil bioengineering measures depends upon a range of factors, the most important of which is the charging rates and availability of labourers. Other considerations include the site location, ease of site access, proximity to sources of vegetation, the timing of installation, and details of project organisation. Overseas studies have shown that, where labour costs are reasonable, combined slope protection measures prove cheaper than either vegetative or structural solutions alone. Table 1 presents a comparison of costs per unit area of soil bioengineering measures versus conventional engineering slope repair methods.

In Hong Kong, there have been too few applications of soil bioengineering measures to enable their cost effectiveness to be reliably determined. The field trials carried out so far have been restricted to a limited range of lithologies and slope conditions. Consequently, it is not yet possible to provide detailed figures about the cost-effectiveness of soil bioengineering measures for a wide range of slope conditions and site settings. Further work is required to establish cost comparisons for a range of site conditions, although figures will become available as soil bioengineering measures are further developed. However, in areas of difficult access and demanding site conditions, it has proven to be an effective approach to the stabilisation and restoration of natural terrain landslide scars in Hong Kong.

2.1.3.3 <u>Installation Seasons</u>

Soil bioengineering measures are most effective when they are installed immediately prior to the onset of the rainy season. In Hong Kong, the period between March and May (see Figure 1) is considered to be the optimal planting season, with only minimal requirements for follow-up watering and/or plant replacement.

Designers should refer to GEO Publication No. 1/2000 (GEO, 2000) for details of the optimum planting seasons for a variety of rooted plants.

2.1.3.4 <u>Difficult Sites</u>

Soil bioengineering methods are ideal for the repair of natural terrain sites in highly sensitive or relatively remote sites where the use of machinery is not feasible, and where hand labour is required.

In some instances, the applicability of soil bioengineering methods may be limited by the paucity, or complete lack, of a suitable medium for plant establishment and growth.

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Consequently, landslide scars in bedrock, or those with a broken rock or gravel cover, lack sufficient fines or moisture retention capacity to support plant growth. Restrictive layers in the soil, such as "hardpans" or extremely thin soils over rock, may prevent the proper installation of plants, or their later root development. Also, soil bioengineering measures may be unsuitable for use on slopes with the following characteristics:

(a) slopes exposed to high velocity water flows;

(b) slopes with deep-seated failures;

(c) extremely steep slopes; or

(d) slopes with large soil pipes.

Slopes exhibiting these characteristics may need to be treated using conventional engineering measures, or possibly by using soil bioengineering measures in combination with conventional engineering methods.

Importantly, slopes inclined at 50°, or more, are considered to be too difficult and dangerous for workers. Consequently, slopes of this gradient are typically too steep for installing soil bioengineering measures. Measures installed during the Hong Kong field trials were typically on slopes of about 40°.

2.1.3.5 Bioengineering Benefits

The recommended soil bioengineering measures are intended to offer immediate mechanical improvements and hydrological benefits to the natural terrain landslide scars, providing mechanical support to the soil, while controlling the retention and movement of water. Their effectiveness increases with time. As the vegetation becomes established, the root system expands and top-growth increases. The final, critical, stage of development is the natural colonisation by the surrounding (ideally climatic climax) plant community, and their firm establishment to yield a long-term, ecologically diverse and sustainable natural or semi-natural vegetation community.

2.2 Basic Principles

The basic principles that apply to conventional soil erosion control are also broadly applicable to soil bioengineering. These principles, well known to experienced geotechnical engineers and horticulturists for the assessment of site characteristics, include the planning, timing, and minimisation of site disturbance during the construction phases, and the appropriate design of the individual measures.

2.2.1 Preliminary Site Selection Criteria

The selection of landslide sites to be repaired using soil bioengineering measures should be carried out using the following three criteria, which are summarised in the flow chart as Figure 2.

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(1) *Extent of Re-growth.* In certain cases, when the failures occurred in an earlier wet season, a certain amount of natural re-vegetation will have occurred. Observations of the typical natural re-vegetation patterns of natural terrain landslides in Hong Kong indicate that the landslide trails re-vegetate more rapidly than landslide source areas (scars). This phenomenon is most probably explained by the lack of topsoil at, and the steep gradient of, the scar. In contrast, the landslide trails are commonly covered with a veneer of debris derived from the failure scar, material that is reasonably stable and capable of supporting vegetation, and the existing slope vegetation cover is close to the margins of the trail, which facilitates rapid re-colonisation. However, in locations where the landslide trails are scoured and eroded, re-planting or the installation of soil bioengineering measures on the eroded sections of the trail should also be considered. Clearly, the process of evaluating the extent of natural re-vegetation is, in fact, an assessment of the areas of the failure that are erosional, as opposed to those that are depositional.

As a general rule, whenever about 50 to 60% of the eroded sections of the failure have naturally re-vegetated, the feature is considered to have sufficiently recovered, and no longer requires further attention. However, it is stressed that a clear distinction should be made between vegetation that has re-established on *in situ* soil, and vegetation growing on residual "islands" or on vegetated debris rafts that have moved, intact, as part of the landslide material. Each site should be carefully surveyed to establish the prevailing conditions. Although no definitive information is available, it is generally believed that the vegetated debris rafts are unlikely to be as stable as *in situ* vegetation re-growth, due to the existence of a basal plane of detachment. Therefore, the potential for these debris rafts to remobilise should also be carefully considered when evaluating the suitability of a site for installing soil bioengineering measures.

(2) *Site Gradient and Safety Considerations.* Due to the potential hazards associated with working on steep natural terrain in Hong Kong, the gradients of the landslide sites should be carefully evaluated prior to recommending the installation of soil bioengineering measures.

Limited experience obtained so far in Hong Kong, during the construction works for the Main Phase of bioengineering trials, has demonstrated that work on terrain sloping at less than 35^o can be carried out cost-effectively and relatively safely. Further, it was determined that while soil bioengineering measures can be successfully installed on terrain sloping up to 50^o, progress was generally slower because of the increased site safety management and supervision. Work on slopes greater than 50° is not recommended.

It should be noted that the slope angles specified above for safe-working refer to the overall slope gradients and not to small, localised facets of the topography within, or adjacent to, a landslide scar. Where localised areas of steeper terrain occur, these should typically not exceed about 25% of the overall site area. If steep gradients constitute more than about 25% of the site area, the cost effectiveness may be reduced because progress will be slower, and the safety risk will be increased requiring precautions that will further slow down the work. In particular cases where steep sections occur within the landslide scar, it may be possible to install soil bioengineering measures, or to carry out direct planting, below the toe of the landslide. This will screen the scar, provide additional mechanical support, and help to control erosion.

In localities where the landslide scars are located within areas of excessively steep terrain, access to the site should also be carefully considered because the requirement to

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negotiate and traverse steep slopes will incur higher costs, will introduce potentially unacceptable risks to safety, and will also reduce overall productivity.

(3) *Material, Mechanism and Dimensions of the Failure.* The material characteristics of the landslide scars also need to be carefully considered when evaluating the suitability of each site for the installation of soil bioengineering measures. Because soil bioengineering measures should be installed in suitable soils, the occurrence of excessive areas of rock outcrop within the scars precludes their effective treatment. Sites containing more than 50% rock outcrop are considered to be unsuitable for the installation of soil bioengineering measures, due to their increased installation cost, and their reduced effectiveness.

The failure mechanism (cause of the failure), dimensions of the landslide scar (overall size of the failure site) and prevailing site conditions (elements such as slope angle, rock outcrops, vegetation rafts, and areas of soil erosion and soil deposition) must be carefully considered when evaluating the suitability of a particular site for the installation of soil bioengineering measures. Careful consideration must also be given to the particular failure mechanism at the site, and to the potential for continued failure of adjacent terrain (i.e. retrogressive failure). Sites where the landslide scar is located upon a terrain facet that is unlikely to be affected by further failures (e.g. immediately below a ridge or spurline) are considered to be the most suitable for the installation of soil bioengineering measures because of the reduced potential for further failures in the surrounding terrain, especially when rapid restoration is required. Where rapid restoration is considered to be unnecessary, soil bioengineering measures would not be installed and the site would be left to regenerate naturally. Scars that have the potential for further failure should be carefully evaluated prior to recommending the installation of soil bioengineering measures. In these cases, it should be determined if soil bioengineering measures are capable of providing additional stability to the bare soil scars, and the potential benefits should also be carefully considered.

At sites where the failed debris remains within the source area, the depth of the failure must be accurately determined, because soil bioengineering measures are only capable of providing additional mechanical support to a shallow surface zone. The effective depth is estimated to not exceed 2 metres, which is the maximum rooting depth of most available plant species, as well as the installation depth of the structural measures. Remediation of deep-seated landslide scars must be considered on a case-by-case basis to evaluate the possible advantages of installing soil bioengineering measures alone, or in combination with conventional engineering methods.

Finally, the overall size of the landslide scar is a further factor to be considered, although size alone is not a definitive selection criterion. The location and accessibility of the scar are more important criteria, because installing soil bioengineering measures on small, inaccessible landslide scars would generally not be cost-effective, unless the feature presents a particular hazard to infrastructure, or creates an undesirable visual impact. This assessment must also be made on a case-by-case basis.

2.2.2 Site-Specific Design

2.2.2.1 Desk Study and Site Inspection

Soil bioengineering measures may be recommended to repair natural hillsides affected

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by landslides or hill fires, to control surface erosion and related soil loss, and to prevent further deterioration of the scarred hillsides. There is also scope for using soil bioengineering methods as landslide mitigation measures, to reduce the potential consequences of natural terrain landslides either to partially retain coarse debris, or to reduce entrainment by stabilising loose deposits (Ng et al., 2003).

Most natural terrain landslides in Hong Kong are relatively shallow and commonly occur along geological/hydrogeological boundaries such as the colluvium/saprolite interface. Consequently, the organic-rich topsoil and other suitable growth media are commonly removed, and natural re-growth can be slow. Furthermore, natural terrain landslides can take many forms, resulting in a wide range of soil damage (Ng et al., 2003). Therefore, a review of site-specific characteristics of each location needs to be made by a qualified geologist or geotechnical engineer to determine the most appropriate techniques for that site. The site-specific factors given in GEO Report No. 138 – “Guidelines for Natural Terrain Hazard Studies” (Ng et al., 2003) include:

(a) Slope morphology

(b) Identified processes - landsliding, gullying, etc.

(c) Incipient processes - tension cracks, soil piping, etc.

(d) Superficial material

(e) Solid geology

(f) Drainage lines

(g) Groundwater

(h) Vegetation

(i) Human activity

Detailed reviews of the above factors are contained in GEO Report No. 138 (Ng et al., 2003). A careful review of the following two additional factors should also be carried out prior to installing soil bioengineering measures:

(a) Hill fire frequency - Areas affected by recent hill fires can be used to identify the typical pioneering vegetation species. Because of the severe impact of hill fires on the existing vegetation cover, and on subsequent re-growth, the frequency and extent of this hazard should also be considered when selecting, and recommending, soil bioengineering measures and the appropriate plant species.

(b) Vegetation cover - Identification of the different vegetation types growing within the study area, and on the adjacent slopes, is necessary to provide an understanding of the typical hillside communities present within the study area.

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In addition, the percentage cover of vegetation on the scarp(s), and their relative ages, will furnish information about the progress, and rate, of re-vegetation and the sequence of erosion or mass movement. The services of a qualified plant ecologist, horticulturalist or landscape architect is recommended to make these assessments.

The data listed in Table 7 of GEO Report No. 138 (Ng et al., 2003) should then be collected during the field mapping phase, including inspection by a qualified geologist or geotechnical engineer, who should also verify the data compiled during the desk study phase. To further enhance the understanding of the specific characteristics of the site, collection of the following additional field information is also recommended:

(a) Detailed vegetation surveys (by a qualified plant ecologist, horticulturalist or landscape architect) - Mapping of the vegetation species located within, and immediately adjacent to, the eroded or failed sites should be completed together with an assessment of the type and density of the vegetation growing on nearby slopes with different aspects. Upon completion of the field mapping, the propagation characteristics of the species identified, as well as other desirable species, should be investigated. This information will enable the designers to determine if locally available plants can be used to provide cuttings and/or rooted stock for the soil bioengineering works. These surveys should also record the vegetation form (bushy, creeper, etc.), and its status (exotic or native, and possibly rare and protected) in Hong Kong.

(b) Soil sampling - Representative samples should be taken of the range of soil types that occur on the sites. Soil testing of these materials should then be carried out to determine their suitability as growth media for soil bioengineering remediation. The soil tests should include, but not be limited to, the pH value, and the content of the nutrients nitrogen, potassium, phosphorous, carbon, sulphur, organic matter and trace metals. Particle size analyses are also recommended, particularly at sites where the soils are extremely clayey or sandy.

(c) Site storage - Areas suitable for the storage of vegetation, construction materials and equipment should be demarcated during the mapping, to facilitate the planning of later works.

(d) Site Access - Access conditions, including terrain difficulties, the journey time, and potential safety concerns, should be assessed, for subsequent calculations of costs, production rates and anticipated results.

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2.2.2.2. Retention and Removal of Existing Vegetation

Wherever possible, existing vegetation should be left in place. Well-established vegetation on, and adjacent to, the scar provides protection against further shallow slope failures and fluvial erosion. Any installed soil bioengineering systems should be designed to support the existing vegetation cover, and also to encourage the re-establishment of the local plant community. The existing vegetation cover will, in several ways, promote more rapid and effective re-vegetation of the bare areas. The designer should also aim to:

(a) Limit any vegetation clearance to an absolute minimum

(b) Restrict the period of disturbance to the shortest practical time

(c) Schedule any planned vegetation clearance during periods of low precipitation to prevent erosion of the bared soil

When existing woody plants (rooted plants and/or vegetative cuttings) or vegetation rafts are removed from the site, they should be stored and maintained in an appropriate manner (see Section 4.1.1) for subsequent use.

2.2.2.3 Stockpiling

Soils removed during site preparation operations, such as trimming and re-profiling of the scarp, crown and flanks of the scar, should be retained on a suitable stockpile, ready to be re-used during installation of the works.

2.2.2.4 Site Protection

The construction period should be limited to minimise disturbance to both the existing and the installed plants. During construction, exposed areas should be covered with plastic sheeting or other protective materials until completion of the works. When the soil bioengineering installations are completed, further disturbance should be avoided to prevent unnecessary soil compaction or unearthing of the new plants.

2.2.2.5 Diversion and Draining of Excess Water

Permanent erosion control measures, such as perimeter pole drains, should be installed before any other measures. Perimeter pole drains can be installed to reduce surface flow over the natural hillside, thereby reducing the risk of additional failures. The drains should be directed into existing natural drainage lines. Of course, the pole drains should be designed to handle any increased or concentrated runoff generated on, or around, the repaired site.

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2.3 Design and Construction Considerations

2.3.1 Scheduling and Timing

For optimum results, detailed consideration of the time of onset and the length of the growing season, the availability of different plant species (i.e. vegetative cuttings and/or rooted plant material), and the climatic conditions occurring at particular times of year, is required. It is necessary to ensure that the measures are installed at the optimum time of the year (i.e. generally between March and May in Hong Kong).

Rooted plant stock may be used as an alternative, or in addition, to live branch cuttings when additional species are desired to create greater ecological diversity (including the reintroduction of rare plant species that originally grew on the site), to improve the aesthetic appeal of the works, or to introduce other desirable environmental qualities. Rooted plants may also be used when the construction schedules do not coincide with the optimum seasons (i.e. outside the period between March and May).

2.3.2 Site Preparation

Typically, a minimal amount of site preparation is usually required, such as rounding off the steep flanks of the landslide scar. However, the objective should always be to retain and re-use all soil material occurring on site, e.g. vegetation rafts. This requirement is largely dictated by the steep and remote nature of the working sites. Consequently, the total amount of site preparation work is generally related to the overall difficulties of working on landslide sites, and the overriding concerns for safety of the workers.

2.3.3 Plant Species Selection

Plant species incorporated in the soil bioengineering strategy should be carefully selected. Depending on both the type of remediation required, and the proportion of structural components used, certain plant species will perform better than others.

For example, when structural components are used to provide an element of mechanical stability, damage to the plants may occur if the chosen plants exceed the size of the openings in the face of the structures. Commonly, when adopting an integrated bioengineering approach, woody shrubs are selected in preference to trees, due to their smaller girth and typically multi-stemmed nature. Importantly, the structural elements are only intended to be temporary, remaining in place until the vegetative components have become established and taken over the stabilisation role.

The results of a survey of the species encountered on, and immediately adjacent to, three trial sites at Cloudy Hill, Sham Wat and Por Lo Shan are summarised in Table 2. Selected species from this list were used for the trials of soil bioengineering measures. In addition, harvested live-cut branches and container nursery plants used for the field trials are listed in Tables 3 and 4 respectively. Table 5 lists the species used for the live barrier trials.

During the trials, it was found that rooted plants generally performed better than live-cut branches, with all species of rooted plants performing significantly better than

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live-cut branches and having a superior survival rate. Because the field trials were experimental applications, many aspects were tested beyond normal ranges to determine their limits.

Overall, the following lessons were learned from the field trials:

(a) Time of planting - In order to achieve optimum results, soil bioengineering measures should be installed immediately prior to onset of the rainy season.

(b) Soil trenches - Trenches dug for the installation of specific soil bioengineering should not be used as access routes by the workers. It is vital that separate safe site access is provided prior to the commencement of the works.

(c) Pole drains and live fascines - Most of the leaves should be removed from the live-cut branches, and the twines tying the live-cut branch bundles should be removed at 600 mm intervals after installation in the ground. This will ensure that the ameliorated soil materials fill all voids between the branches, will facilitate rooting of the live-cut branches, and will prevent the branches from drying out.

(d) Species propagation from cuttings - Information about the propagation of upland woody vegetation in Hong Kong is sparse. Further studies and trials should be conducted.

During the trials, both *Ficus microcarpa* and *Gardenia jasminoides* performed better than other species, closely followed by *Duranta erecta*, *Macaranga tanarius* and *Melastoma candidum*, which showed a fair performance (Table 2). All rooted plants species selected demonstrated good individual performance in the field trials (Table 3).

Several additional plant species were tested during the field trial (Table 4). The results demonstrated that most species used as live-cut branches performed poorly, except for *Salix babylomica*, which performed equally to *Ficus microcarpa*.

Based on the experience gained from the trials, the list of recommended species is shown in Table 6.

2.3.4 Results of the Root Investigation

Very little factual information exists about the rooting depths and root morphology of the native plants of Hong Kong. Clearly, this information is vital to develop an understanding of the potential effectiveness of soil bioengineering measures in Hong Kong. Therefore, in the summer of 2005, a small-scale field investigation was carried out to study the rooting characteristics of several examples of the better performing species that had been planted at the trial sites. The study involved the careful excavation of the root systems of the selected plants. Information gathered for each plant included the dimensions of the top growth, and of the subsurface root morphology and extent. Examples of characteristic

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plant species from the surrounding natural terrain were also sampled to provide information about the development of root systems in an undisturbed hillside setting. The results are summarised in Table 7.

Findings of the limited root sampling exercise (MGS, 2006b) indicated that *Machilus checkiengensis* appeared to have the largest lateral root spread among the plants growing on the surrounding natural terrain. However, its rooting depth was the shallowest. In contrast, the roots of *Gardenia jasminoides* were found to be the deepest, yet they had a relatively restricted lateral spread. Clearly, the sample-size used in the study was far too small to draw any far-reaching conclusions, and it may well be found in a larger, more comprehensive root investigation, that *Gardenia jasminoides* has a shallow and restricted fibrous root system.

Among the species planted at the trial sites, *Schefflera octophylla* and *Acacia confusa* were found to have the best-developed root system. The results suggest that both these plant species were well-adapted to the site conditions, and thus performed well. However, the sample size was again too small, and the site conditions too restricted, to enable firm conclusions to be drawn about the most suitable species for this and other locations.

Gardenia jasminoides and *Schefflera octophylla* were the only two species sampled from both the trial sites and from the surrounding natural terrain. The study results indicated that *Gardenia jasminoides* had a fibrous root system in the natural terrain example, which is considered normal for this species. The rooting characteristics of *Schefflera octophylla* on the adjacent terrain were found to be similar to those that developed on the direct-plantings at the trial sites. Direct-plantings at the trial sites were found to have a greater abundance of adventitious roots than those unearthed from the brushlayers and branchpacking measures. The trials demonstrated that *Gardenia jasminoides* was the best performing species used for live branch cuttings, e.g. in brushlayers.

Clearly, it is desirable that directly planted species should develop roots along the entire length of the embedded stems so that, with time, the plants will develop the same rooting characteristics as the mature plants found growing naturally. Typically, only juvenile roots develop initially on the plants installed in the measures. In nature, *Acacia confusa* and *Schefflera octophylla* exhibit rapid growth. Consequently, they are probably the most effective species for providing almost immediate mechanical support to the soil. However, it should be emphasised that it is important to plant a carefully planned mixture of species, each with different rooting characteristics, in order to achieve optimum mechanical support and to promote biodiversity.

A comparison between native and exotic species showed that exotics are normally faster growing than the natives. Exotics typically out-perform the natives in the early stages, depending upon the species, although over time the converse may apply.

The ultimate performance of the plants is influenced by the following environmental factors:

(a) Time of planting

(b) Type of soil materials

(c) Density of the soil

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(d) Nutrient content

(e) Soil acidity (ph)

(f) Rainfall amounts and distribution

(g) Drainage characteristics of the site

(h) Slope angle and aspect

(i) Surrounding ecology

In conclusion, although the sample size for the root study was small, and the findings are inconclusive, the pioneering results provide a useful reference for the future application of soil bioengineering measures and for plant species selection. In particular, little is known about the depth and lateral extent of the root systems of the majority of the commonly occurring plants, and consequently about their ability to survive in the harsh conditions on Hong Kong hillsides. However, despite the limited scope of the study, initial recommendations for plant species selection for different types of soil bioengineering measures are presented in Table 8.

2.3.5 Hydrological Requirements of Structural Components

The requirements of both the plants and the structures must be taken into account when designing an integrated soil bioengineering strategy for hillside sites. Free drainage is essential to the mechanical integrity of an earth-retaining structure, as well as being important to the vegetation. Most upland plants are unable to tolerate waterlogged conditions, but they do require adequate moisture. The upland soils are also deficient in essential nutrients. Consequently, as specified in Clause 3.26 of General Specification for Civil Engineering Works (CED, 1992), the fill material placed behind a retaining structure should consist of free-draining soil, as well as containing sufficient fines and organic material to retain adequate moisture and nutrients for plant growth. With careful planning, the biological requirements can be satisfied without compromising the engineering performance of structures.

2.3.6 Harvesting Local Plants

Selected native plants, and in some cases exotic species, harvested from existing stands of living woody plants are the preferred soil bioengineering materials. These plants can usually be obtained from the slopes adjacent to, or within a reasonable distance of, the work site. The plants in these locations are well suited to the climate, soil conditions and available moisture at the location, and so will probably survive transplanting well. However, successful harvesting requires that close site supervision be carried out to ensure that proper harvesting procedures are strictly adhered to. In addition, formal approval from relevant government departments, such as the AFCD, appropriate DLO, etc., may be required.

Usually, locally harvested plants are relatively easy to obtain, are inexpensive, can be planted easily, will propagate from cuttings, will develop the desired extensive and deep root

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systems, and will produce strong top growth. Also, locally harvested plants will encourage natural colonisation and the establishment of a thriving plant community, thus achieving the ultimate goal of producing a sustainable native, or semi-native, and diverse plant cover that is compatible with the existing ecology.

Overseas experience indicates that there is no significant difference in the establishment period between plants propagated from cuttings and pit plants.

2.3.7 Site Safety

In common with other types of construction site, it is necessary to follow all relevant safety legislation, regulations and codes of practices on soil bioengineering work sites. The relevant guides include, but are not limited to:

(a) "A Guide to the Construction Sites (Safety) Regulations" published by the Labour Department;

(b) "Construction Site Safety Handbook" by Works Bureau.

Unlike typical Landslip Preventive Works, because of the remoteness of the sites, and the typical characteristics of landslide scars, it is generally impracticable to provide working platforms for personnel operating on a natural terrain hillside site. Therefore, as stated in Works Bureau (2000), it is more appropriate to provide safety belts and a system of independent safety ropes fixed to reliable anchorage points.

As cautioned in Section 2.3.3, trenches and terraces for the installed soil bioengineering measures should not be used as access routes, as this may cause over-compaction of the soils. Consequently, prior to the commencement of the works, it is necessary to plan for, and to provide, safe site access for the workers.

3. SOIL BIOENGINEERING METHODS

3.1 General

Soil bioengineering methods can be divided into two categories, termed the 'living' and the 'combined living and non-living' approaches.

The living approach to soil bioengineering comprises the planting of live woody plants. These plants are placed in the ground in specific configurations designed to provide immediate mechanical support to the soil, to effect improvements to the local slope hydrology, and to control surface erosion in areas left bare following shallow mass movements.

The combined living and non-living approach to soil bioengineering comprises the use of inert structural components, such as cribwalls, wooden fencing, and rocks in combination with live plants. The most important objective of this approach is to provide immediate support to areas affected by shallow mass movement, to locally stabilise the slope. Inert structures provide stable zones in which the plants can take root and grow, controlling erosion and supporting the re-establishment of the native plant community.

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The effective depths of the various soil bioengineering measures differ, ranging from about 150 to 2000 mm, depending upon the type of inert measure installed and the rooting depths of the selected plant species (see Paragraph 2.3.4 above).

3.2 Living Approach

3.2.1 Vegetation Planting

Vegetation planting includes the conventional direct planting of grasses, herbs, shrubs or trees. This is the method that is commonly adopted on man-made slopes in Hong Kong. Consequently, detailed descriptions of these methods are not included in these Guidelines. Typically, these techniques are combined with soil bioengineering measures to create a more integrated approach to slope greening and slope stabilisation. For further details, reference should be made to the Geotechnical Manual for Slopes (GCO, 1984) and Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2000).

3.2.1.1 Grasses

Grasses and herbs are used primarily as an erosion control measure on a variety of slope surfaces. They can be applied to the slope using a range of techniques, which include sprigging and turfing, hydroseeding, and broadcast seeding.

(a) Sprigging and turfing - This is the direct placement of growing grasses onto the slope surface in the form of either a 'clump' or a 'mat'. These methods usually produce reliable results, even outside the normal planting season in Hong Kong, provided that watering is carried out until the turf mats become established. However, these methods are slow and labour intensive, requiring each turf to be manually placed. As a result, they are relatively expensive.

(b) Hydroseeding - This is the simplest form of slope protection and is widely used in Hong Kong due to the speed and convenience of application, and consequently the relatively low cost. The technique involves the spraying of an aqueous solution containing grass seeds, fertiliser and mulch onto the slope surface. Hydroseeding can also be applied in conjunction with erosion control materials, should they be considered necessary. Hydroseeding is not recommended in conjunction with soil bioengineering measures as the grasses, which are faster growing than the woody plants compete aggressively for sunlight, moisture and nutrients.

(c) Broadcast seeding - this is the direct spreading of grass seeds over a soil surface, either by hand or using automated methods. Although the technique does not always produce

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uniformly reliable results in Hong Kong, due primarily to the variability of seed germination, broadcast seeding is an inexpensive approach that requires minimal equipment. Broadcast seeding can be used in conjunction with several soil bioengineering measures at specific locations.

3.2.1.2 Trees and Shrubs

Trees and shrubs can be planted directly on a slope surface. Once established, they provide additional stability to the soil, added diversity to the vegetation community, and aesthetic benefits. They are commonly planted in excavated pits, which are backfilled with a soil and fertiliser mix. One or two year old tree saplings have commonly been transplanted onto man-made slopes in Hong Kong. Thus, it is a well-established technique that is also applicable to natural hillsides in Hong Kong. Shrubs should be used in preference to trees where low-growing vegetation is desirable, such as, for example, in exposed locations, to maintain visual compatibility, or where maximum vegetative diversity is required. Trees generally have an extensive canopy, which may shade-out lower growing shrub species. Direct planting of trees and shrubs in conjunction with soil bioengineering measures offers a cost effective, and environmentally compatible, solution to repairing hillsides in Hong Kong.

Transplanting of trees and shrubs has both hydrological and mechanical effects upon a site. Changes to the local hillslope hydrology may occur due to the effect that this type of vegetation has on the hydrological cycle. These changes can be both beneficial and detrimental. They include:

(a) Hydrological Advantages:

(i) Interception - Foliage intercepts rainfall, reduces raindrop impact on the soil, and reduces moisture by evaporation from leaf surfaces, effectively decreasing runoff from the slope.

(ii) Evapotranspiration - Roots absorb moisture from the soil, which is subsequently transpired by the plants, thereby reducing pore-water pressures.

(b) Hydrological Disadvantages:

(i) Infiltration - Infiltration potential of the soil is increased by the retarding action of vegetation roots and stems.

Changes to the mechanical characteristics of the soil result from the physical interaction between the plant roots and stems, and the slope materials. These changes can be both beneficial and detrimental. They include:

(a) Mechanical Advantages:

(i) Support - Roots provide additional mechanical support

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to the soil, by increasing its shearing resistance.

(ii) Binding action - Roots bind the surface soil particles, reducing their susceptibility to erosion.

(iii) Anchoring - Roots may penetrate into a firmer substrate, thereby anchoring the upper soil layers.

(b) Mechanical Disadvantages:

(i) Prising action - Vegetation (tall trees rather than lower shrubs) exposed to strong winds may transmit potentially destabilising forces to the soil, increasing the potential for uprooting and erosion.

(ii) Failures - If rooting depths are shallow, rafts of soil with *in situ* plants may detach as a discrete units.

In addition to the above, it should be noted that the weight of large trees on a slope surface increases the normal and vertical forces on potential shear surfaces within the soil layer. This can have both beneficial and detrimental effects.

Once established, tree roots can create an arching and buttressing effect, which may be very beneficial to the hillslope, especially in the lower sections of landslide sites. Trees can also be used directly, to provide debris barriers along potential failure runout paths (and boulder fall tracks). They also have the potential to reduce both debris flow velocities and entrainment potentials within the flow paths. To accomplish this objective requires strategic planting along recognisable flow paths below known, or potential, failure zones.

3.2.2 Live Construction

Live stakes, live fascines, pole drains, brushlayers, hedgelayers, branchpacking and live gully repairs are direct soil bioengineering measures that all utilise the stems or branches of living plants. These woody branches provide the primary mechanical support for the soil, at least in the initial stages, until the growing plants develop roots and become fully established. Maturing of the installed measures, combined with colonisation by the surrounding hillslope vegetation community, constitute the major structural and ecological components of the soil bioengineering system.

3.3 Combined Living and Non-Living Approach

Cribwalls and bender fences are direct measures that use both inert structural and living vegetative elements. This approach establishes uses structures, usually of wood, which generally retain a bank of soil, with openings through which live cuttings of adventitiously rooting woody plant species, or rooted plants, are inserted. Their purpose is to create stable benches, with a reasonable depth of soil, upon which vegetation may be planted.

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As the plants become established, their root system develops and permeates the interior of the structure. Gradually, the roots penetrate the underlying *in situ* soil and the surrounding slope, binding it together into a coherent mass. The importance of the inert structural elements diminishes over time as the plants become fully established. Ultimately, the inert structural elements decay, leaving the established plants as the main supporting structure.

Section 3.4 describes the various direct soil bioengineering measures that were field-tested at the Hong Kong trial sites, together with a discussion of their applications, effectiveness and construction methods. Section 3.5 describes the indirect measures that were tried, and Section 3.6 presents several supplementary soil bioengineering measures that have not been tested in Hong Kong, but could be considered for future projects. Although the measures are described independently, it should be noted that, at any one site, it is advisable to install a variety of soil bioengineering measures to ensure both the immediate and long-term remediation of the scar.

3.4 Direct Soil Bioengineering Measures Installed in the Field Trials

3.4.1 Live Stakes

3.4.1.1 Description

Live staking refers to the procedure of inserting and tamping live branch cuttings (see Glossary) into holes reamed into the ground (Figure 3 and Plates 1 to 5). This measure provides neither immediate erosion control nor immediate mechanical support to the soil. However, as the cuttings develop, the live stakes create a living root mat that binds the soil particles together, thereby stabilising the soil and reducing the possibility of shallow failures. The plants also serve to extract excess moisture from the soil. Suitable pioneering species of native plants should be selected for this method. They should have suitably large stem diameters, and have the capacity to root and grow easily from cuttings i.e. plants with adventitious rooting abilities. This technique is most suited to areas with reasonably thick soil covers, which are subject to shallow erosion or shallow mass movement, and have shallow subsurface water flows.

Clearly, as with all the techniques, careful site surveys should be conducted to determine if the soil cover is sufficiently thick to enable the stakes to root and grow. The thin hillslope soil profiles commonly encountered in Hong Kong may not provide adequate soil depths for live stakes. Thicker and more nutrient-rich soils occurring within restricted zones of a landslide scar and along the depositional debris trail, present a more suitable environment for establishment and development of the live stakes.

(a) Applications and Effectiveness:

(i) The live stake method is best suited to the remediation of simple shallow erosion or mass movement features. Scars with shallow gradient, sites where construction time is limited, or sites where an inexpensive method is required are the most appropriate.

(ii) Live staking may also be used to secure surface

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erosion control materials, such as a biodegradable erosion control mat.

(iii) Once established, live staking changes the local site conditions, making them more suitable for natural invasion by plants from the surrounding plant community.

(iv) Live staking is commonly used to connect the repaired site to the stable surrounding slope. Live staking may be used in conjunction with live fascines, or to provide deeper, localised stabilisation in otherwise unprotected sections of the slope that are located between other soil bioengineering measures.

Live stakes can be modified to deal with variety of other slope problems, such as tension cracks. Tension crack repair involves filling up the tension crack with ameliorated soil material (see Glossary), followed by the insertion of live stakes along both sides of the rupture in an oblique configuration. Details of tension crack repairs are described in Section 3.4.8.

3.4.1.2 <u>Construction Guidelines</u>

(1) *Material Sizes.* The cuttings should be 12 to 40 mm in diameter, and 750 to 1000 mm long.

(2) *Material Preparation.* Prior to installation, live stakes should be prepared according to the following guidelines:

(a) The stakes should be harvest from living plants by cutting the top, growing-end flat, and the basal end at an angle for easy insertion into the soil. Alternatively, the stake may be sharpened at the tip.

(b) Side branches should be cleanly removed from the stem, ensuring that growing buds and the bark are left intact.

(c) Ideally, the live stakes should be installed on the same day that they are harvested. They can be installed directly, without treatment, or after soaking in a root activating solution. When installed directly, this should be accomplished within 4 hours of harvesting. It is important to keep the stakes, either by temporarily storing them in a tub of water, or by wrapping them in wetted straw, burlap, hessian cloth, or erosion control fabric. Soaking in root activating solution should be carried out in accordance with the manufacturer's recommendations.

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(3) *Installation.* The following procedures should be followed when installing the measures in the soil:

(a) Installation can begin at any point on the site.

(b) The density of stakes should range between 2 to 4 stakes per square metre, placed in a triangular grid pattern.

(c) The live stakes should be driven into the ground at an angle of approximately 45° to the horizontal using a “dead blow hammer”.

(d) The live stakes should be installed with the buds oriented upwards.

(e) Up to 80% of the length of the live stake should be inserted into the ground, and then the soil around the stake firmly compacted by foot.

(f) The live stake should be held firmly while being tamped. This will minimise lateral movement, which enlarges the hole, resulting in sections of the stake not being in contact with the soil.

(g) If the ground is hard, a steel bar, or similar implement, should be used to make a pilot hole for the stake. To ensure close contact with the soil, the bar should have a diameter slightly less than that of the smallest stake.

(h) Care should be taken to ensure that the live stakes do not split during installation.

3.4.1.3 Hong Kong Field Trials

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) *Ficus microcarpa* and *Salix babylomica* achieved the best overall survival rate among the species selected for live stakes.

(b) The performance of live stakes is primarily dependent upon both the time of planting and the species selected. Early spring, immediately prior to the onset of the wet season, is the optimum time for installation of live stakes. *Ficus microcarpa* and *Salix babylomica* are recommended for use as live stakes. Other *Ficus* species, which have good aerial roots, are also recommended for future trials.

(c) Based on visual inspection of the trial sites, there was no

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evidence of further soil erosion, gully development or mass movement in the areas where the live stakes had been installed.

3.4.2 Live Fascines

3.4.2.1 Description

Live fascines comprise numerous live branch cuttings, harvested from adventitiously rooting plant species, bound into a cylindrical bundle (Figure 4 and Plates 6 to 15). Suitable plant species recommended for fascine fabrication are tabulated in Table 8. When properly fabricated, handled and installed, live fascines provide immediate mechanical protection to the surface of the slope. Following the development of vigorous roots and foliage, they also provide improved shallow slope stabilisation.

Live fascines are typically placed within shallow trenches. On slopes with low to moderate surface water flows they should be constructed along the slope contour, whereas on slopes with continuous seepage or more concentrated surface water flows they should be inclined to the contour in a chevron pattern. The primary purpose of live fascines is to reduce the potential for both surface erosion and shallow mass movement. In addition to augmenting the collection of surface and subsurface water flows (e.g. soil pipes), they assist with the diversion of runoff to safe collection sites. Live fascines are considered to be well-suited to the thin soil mantles commonly encountered on Hong Kong hillsides.

(a) Applications and Effectiveness:

(i) Live fascines are best suited to the restoration of shallow mass movement scars that require surface protection, the control of surface and subsurface runoff, and shallow stabilisation. They are recommended for use on steep slopes, and on sites where the soil profile is thin and where excavation is problematical.

(ii) Live fascines provide immediate stabilisation to the top 150 to 500 mm of a slope, depending upon the diameter of the live fascine.

(iii) Live fascines reduce sheet erosion or rilling by lowering the velocity of surface runoff, and by collecting and redirecting the water.

(iv) Live fascines trap and retain slope wash materials on the slope.

(v) Live fascines can be used in an inclined layout to control slope drainage.

(vi) Live fascines can be installed to sub-divide long,

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straight slope sections of natural hillside, or landslide scars, into a series of shorter slope sections.

(vii) Once established, live fascines provide an arching and buttressing root system in the soil mantle, improving the local conditions and making them more suitable for natural colonisation by plants from the surrounding plant communities.

(viii) Live fascines that fail to establish and grow still maintain a mechanical and drainage function, and continue to improve conditions for natural colonisation.

3.4.2.2 Construction Guidelines

(1) *Material Sizes.* A completed live fascine is typically 150 to 300 mm in diameter, although it may be up to 500 mm for use in a pole drain (see Section 3.4.3). Live fascines may vary in length from 2 to 10 m, depending on site conditions, and also upon the restrictions on fascine fabrication and handling.

(2) *Material Preparation.* The following guidelines should be followed prior to the installation of the live fascines:

(a) Live fascines should be fabricated from fresh, live branch cuttings, using plant species that root easily from cuttings.

(b) The live branch cuttings should be straight, long, flexible and well-branched.

(c) All the growing tips on the branches should be aligned in the same direction, with the growing tips arranged so that they are staggered along the length of the fascine.

(d) The selected live branch cuttings should comprise a well-mixed range of species, diameters and ages within each fascine.

(e) Fascines should be bound at 200 to 300 mm intervals along the length of the bundle, using untreated twine.

(f) Dead stakes, used to secure the bundle in the trench, should be between 750 and 1000 mm long and prepared from untreated wood.

(g) Live stakes, ranging between 600 and 750 mm in length, should be placed between the dead stakes.

(3) *Installation.* The following procedures should be followed when installing the

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live fascines:

(a) The live fascines and live stakes should be prepared a maximum of two hours before they are installed.

(b) Commencing at any point on the site, a trench should be dug along the contour, slightly wider and deeper than the diameter of the live fascine. The spacing and configuration of the fascine trenches depends upon the slope gradient, and on local conditions such as the density of rills and gullies, and the area of existing vegetation (Table 9).

(c) Depending upon the local conditions, the trenches can be lined with degradable erosion control mats, such as woven coir matting, to stabilise the trench.

(d) Prior to placing the live fascine in the trench, a small amount of soil fill should first be placed in the base and sides of the trench, or on top of the erosion control matting. Fertilisers and other additives can then be applied.

(e) The live fascine should then be placed in the trench. When placing live fascines on a slope, the growing tips should be oriented upslope. Between 300 to 450 mm of the leading growing tip should be left exposed above the trench.

(f) Dead stakes should be driven vertically through the live fascine at intervals of 500 to 1000 mm along the length. Stakes should optimally penetrate between 500 to 600 mm into the ground. This will ensure that the live fascine has been effectively secured, and will prevent washout occurring below it. Dead stakes should be driven flush with the top of the bundle, or left protruding between about 20 and 50 mm above it.

(g) Live stakes should be installed on the downslope side of the live fascine. They should be driven against the side of the bundle, midway between the previously installed dead stakes. Optimally, the live stakes should protrude about 50 to 80 mm above the level of the final ground surface.

(h) When successive live fascines are joined, they should overlap. The growing-tip end should be placed between 500 and 750 mm over the basal end of the succeeding bundle. Additional dead stakes should be driven in the overlap zone.

(i) Following installation, loosely compacted ameliorated soil fill and other additives should be placed along the flanks of the bundle, on either side of the dead stakes, and within the

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live fascine bundle. The top of the fascine should remain partially exposed following installation.

(j) Wherever possible, moist soil should be used to ensure that the live branch cuttings, or the rooted vegetation, are protected from desiccation.

(k) The installed live fascines should be watered immediately after installation.

(l) Seeding or live staking of the areas between live fascine rows is recommended. Ideally, degradable erosion control mat should be placed over the soil surface between the live fascine trenches. Seeding should be carried out in a controlled manner, with seeds sown in a zone 150 mm below (downslope) and 300 mm above (upslope) of the installed live fascines.

Live fascines should be installed at regular intervals on the face of the slope (Table 9), either along the contour or obliquely (Figure 5), depending on the final design, which should be based on the results of the geomorphological survey. An herringbone, or chevron, configuration should be employed wherever concentrated surface water flow or strong seepage occurs (Figure 5). To improve local drainage conditions, additional live fascines in the form of pole drains (see Section 3.4.3) can be installed immediately upslope from the site.

On slopes inclined at 22° or shallower, suitable mulches and erosion control materials should be placed between live fascine trenches, whereas on steeper slopes, a degradable erosion control mat (e.g. woven coir mat) should be laid over a mulch layer (e.g. long straw mulch).

3.4.2.3 Hong Kong Field Trials

The following preliminary conclusions were drawn from the field trials. These should be reviewed in the light of future experience:

(a) *Ficus microcarpa* and *Gardenia jasminoides*, which proved to be the most hardy species and showed the best survival rates among the species tested, are recommended species for live fascines. Other *Ficus* species, which have good aerial roots, are recommended for future trials.

(b) *Salix babylomica* is recommended for future trials of live fascines. Although it was not tested in the current trials, the species performed satisfactorily in other measures that used live branch cuttings, i.e. live stakes.

(c) The performance of live fascines was found to be closely related to the time of planting, as well as the species selection. In Hong Kong, spring is the optimum time for

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planting, immediately prior to the onset of the wet season.

(d) Several live fascines, which had low plant survival rates, performed well mechanically, reducing the potential for surface erosion and shallow mass movements, as well as collecting and diverting surface and subsurface runoff.

(e) Field experience indicated that attention should be paid to ensuring that the ameliorated soil fill is placed in contact with the live branch cuttings, and that fabrication of the fascines should be closely supervised. For example, live fascines should not be tied too tightly as this will prevent the soil fill from entering the fascine. It is recommended that every second binding, originally placed at intervals of 200 to 300 mm, is removed to leave them at 600 mm intervals. Also, care should be taken to ensure that most of the leaves have been removed from the live branch cuttings. These precautions will allow the ameliorated soil fill to enter the fascine, and help to prevent the live branch cuttings from drying out.

(f) There were no signs of any further soil erosion, gully development, or mass movement in the areas where the live fascines had been installed.

(g) Natural colonisation preferentially occurred along the trenches where the live fascines had been installed, as opposed to the adjacent areas without any measures. This result suggests that the live fascines enhance natural colonisation by the surrounding plant community, particularly through their control of fluvial erosion.

3.4.3 Pole Drains

3.4.3.1 Description

A pole drain is a large-diameter live fascine, of at least 300 mm in diameter, installed in a trench. The measure is designed to both collect and redirect surface and shallow sub-surface runoff (Figure 6). This soil bioengineering measure is typically constructed along existing and potential water flow paths, and is connected to other live fascines to collect surface water, and to discharge it into adjacent natural drainage channels. Live fascine trenches should enter a central pole drain obliquely, so forming an herringbone configuration (Figure 6). Additional pole drains may be installed above the crest of the scar as an additional means of improving local drainage conditions.

(a) Applications and Effectiveness:

(i) It is recommended that pole drains are used in association with live fascines to control surface flows and seepage on the slope.

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(ii) Pole drains enhance slope drainage conditions by collecting, channelising, and redirecting surface runoff, thereby reducing surface erosion such as rilling and gullying.

(iii) Pole drains can encourage slope wash materials to be trapped and retained on the face of the slope.

(iv) Once established, pole drains can improve local slope conditions making them more favourable for colonisation by plants from the surrounding plant communities.

3.4.3.2 Construction Guidelines

(1) *Material Sizes and Preparation.* The following guidelines should be followed prior to the installation of the measures:

(a) A completed pole drain fascine is typically 300 to 500 mm in diameter. It may vary in length from 2 to 10 m, depending on site conditions and limitations on handling.

(b) The pole drain fascine should be fabricated from fresh, live branch cuttings, using plant species that root easily from cuttings.

(c) The live branch cuttings should be straight, long, flexible and well-branched.

(d) All the growing tips on the branches should be aligned in the same direction, with the growing tips arranged so that they are staggered along the length of the fascine.

(e) The live branch cuttings species and sizes should be well mixed within the bundle.

(f) The selected live branch cuttings should comprise a well-mixed range of species, diameters and ages within each fascine.

(g) Dead stakes, used to secure the bundle in the trench, should be between 1,000 to 1,500 mm long and prepared from untreated wood.

(2) *Installation.* The following procedures should be followed when installing the measures:

(a) The live fascines and live stakes should be prepared a maximum of two hours before they are installed.

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(b) Commencing at any point on the slope, a trench should be dug along the eroded gully, about 300 mm deep and 500 mm wide, slightly wider and deeper than the diameter of the live fascine.

(c) Depending upon the local conditions, the trenches can be lined with degradable erosion control mats, such as woven coir matting, to stabilise the trench. Prior to placing the fascine in the trench, a small amount of soil fill should first be placed in the base and sides of the trench, or on top of the erosion control matting. Fertilisers and other additives (e.g. root activator) can then be applied.

(d) When placing the pole drain fascines, the growing tips should be oriented upslope and when installing a pole drain 300 to 450 mm of the growing tip end should protrude from the trench.

(e) Dead stakes should be driven vertically through the pole drain fascine at intervals of 600 to 1000 mm along the length. Stakes should optimally penetrate between 500 to 600 mm into the ground. This will ensure that the live fascine has been effectively secured, and will prevent washout occurring below it. Dead stakes should be driven flush with the top of the bundle, or left protruding between about 50 and 100 mm above it.

(f) Wherever overlaps are necessary, the growing tip end should be placed 450 to 650 mm over the basal end of the adjacent live fascine. Additional dead stakes should be used at the overlapping joints.

(g) Following installation, loosely compacted ameliorated soil fill and other additives should be placed along the flanks of the fascine, within the fascine, and around the dead stakes, leaving the top of the fascine partly exposed.

(h) Moist soil should be used to protect the live branch cuttings from desiccation.

(i) The pole drain fascine should be watered as soon as the installation has been completed.

A completed pole drain is shown in Plate 16.

3.4.3.3 Hong Kong Field Trials

The following preliminary conclusions were drawn from the field trials. These should be reviewed in the light of future experience:

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(a) In common with the live fascines, *Ficus microcarpa* and *Gardenia jasminoides* achieved the best overall species survival rate among the species used for pole drains. Consequently, they are recommended for future use. Other *Ficus* species, which have good aerial roots, are recommended for future trials.

(b) Some pole drains that demonstrated low plant survival rates continued to perform well mechanically, successfully collecting surface runoff, thereby controlling slope erosion. Field inspection revealed that there were no signs of further soil erosion, gully development or mass movement in the areas where the pole drains had been installed.

(c) Performance of the pole drains was found to be closely related to the time of planting, in addition to the species selection. Spring is the optimum time for installation of the measures.

(d) Although it was not tested in pole drains during the field trials, *Salix babylomica* is recommended for use in future pole drains because of its satisfactory performance as live branch cuttings for live stakes.

(e) Field experience indicated that attention should be paid to ensuring that the ameliorated soil fill soil is placed in contact with the live branch cuttings, and that fabrication of the fascines should be closely supervised. For example, live fascines should not be tied too tightly as this will prevent the soil fill from entering the fascine. It is recommended that every second binding is removed to leave them at 600 mm intervals. Also, care should be taken to ensure that most of the leaves have been removed from the live branch cuttings. These precautions will allow the ameliorated soil fill to enter the fascine, and will help to prevent the live branch cuttings from drying out.

(f) Natural colonisation preferentially occurred along the trenches where the live fascines had been installed, as opposed to the adjacent areas without any measures. This result suggests that the live fascines enhance natural colonisation by the surrounding plant community, particularly through their control of fluvial erosion.

3.4.4 Brushlayers

3.4.4.1 Description

Brushlayers consist of live branch cuttings of adventitiously rooting plants (See

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Table 8 for recommended plant species) placed on benches, between 750 to 1000 mm wide, excavated into the slope (Figure 7 and Plates 17 to 25). Brushlayers differ from live fascines principally in the orientation of the branches, and the depth to which they are installed. Live branch cuttings are installed approximately perpendicular to the slope, thereby providing immediate shallow earth mechanical support largely as a result of the overlapping layers of the live branch cuttings.

(a) Applications and Effectiveness:

(i) Brushlayers are best suited to the remediation of shallow mass movement features that require erosion control and slope stabilisation, in locations where a thicker soil mantle occurs. This measure will be most effective in the middle to lower sections of a landslide scar, or immediately below the scarp.

(ii) The technique immediately provides mechanical support, the live branch cuttings reinforcing the soil.

(iii) Brushlayers are able to trap and retain slope wash materials on the slope face.

(iv) In common with live fascines, brushlayers sub-divide long sections of the natural hillside (or steep slope sections resulting from landsliding) into a series of shorter slope sections.

(v) The completed brushlayer terrace immediately enhances conditions for the natural colonisation by plants from the surrounding plant communities. Even brushlayers that fail to establish and grow still function mechanically and continue to offer improved conditions for natural colonisation.

3.4.4.2 <u>Construction Guidelines</u>

(1) *Material Sizes and Preparation*. The branch cuttings should be between 5 and 20 mm in diameter, and from 1 to 2 m long. Live cut branch material should be well-branched. It is recommended that the live branch cuttings be a minimum mix of three to four species, containing a range of different ages between 1 and 3 years old.

(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Brushlayers should be installed at selected intervals along the contour of the slope (Table 9).

(b) Commencing in the lower section of the site, benches 750 to 1000 mm wide should be excavated in preparation for

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placing the live branch cuttings.

(c) The treads of the benches should be inclined back into the slope at an angle of approximately 15º to 25º (front to back).

(d) On steeper slopes, the bare soil areas between the brushlayer benches may be covered with a layer of long straw mulch, overlain by erosion control mats. The erosion control mats can be continued across the back scarps and the treads of the benches.

(e) On shallower slopes that are not covered with erosion control mats, the bench tread should be scarified, and a thin layer of ameliorated soil fill, with any necessary additives, spread as required.

(f) Three successive layers of live branch cuttings should be placed on the bench tread, each layer having a different orientation. Individual layers shall be placed on the bench (angled right, left and perpendicular to the slope) with a 25mm to 50mm layer of well-compacted ameliorated soil material placed on top of each successive layer of branches. Live branch cuttings should protrude 150 to 300 mm beyond the outer edge of the bench to retard slope runoff and to filter out suspended soil. It is recommended that at least 50% of the branches should reach the back of the excavated bench, and that at least two-thirds of each branch stem is buried.

(g) The branch growing tips should be directed towards the outer edge of the bench and have a distinctive upward orientation.

(h) Excavated soil with any necessary additives should be placed over the top of the final branch layer.

(i) Moist soil should be used so that the live branch cuttings are protected from desiccation.

(j) The installation should be loosely compacted by foot to eliminate voids, and to ensure that the live branch cuttings have maximum contact with the soil.

(k) The brushlayer should be watered immediately after installation is complete.

Suitable mulches (such as long straw mulch) should be placed between the brushlayers, inclined at about 26º or less. Steeper slopes should be protected with a covering of erosion control-material (e.g. degradable erosion control mats) over the mulch layer.

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3.4.4.3 Hong Kong Field Trials

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) *Gardenia jasminoides* showed the best overall survival rate among all the species used for brushlayers.

(b) The performance of the brushlayers was closely related to time of planting and the species selected. Spring is the optimum time for installation of the measures, immediately prior to the onset of the wet season. *Gardenia jasminoides* is recommended for use in these measures.

(c) *Salix babylomica* was not been tested in brushlayers, but it is recommended because of its satisfactory performance as live stakes.

(d) Field inspection indicated that there were no signs of further soil erosion, gully development or mass movement in the areas where the brushlayers had been installed.

(e) Natural colonisation was observed to occur preferentially on the benches where brushlayers were installed, in contrast to the adjacent areas without any measures. This finding indicated that brushlayers are able to encourage colonisation from the surrounding plant communities.

3.4.5 Hedgelayers

3.4.5.1 Description

Hedgelayers are installed in a similar manner to brushlayers (Section 3.4.4), both being placed perpendicular to the slope. However, hedgelayers utilise rooted plants on excavated benches 300 to 600 mm wide (Figure 8 and Plates 26 to 32). This method enables additional plant species to be introduced to the site (See Table 8), and allows for a slightly longer installation season than for live branch cuttings, assuming that maintenance watering is an option.

(a) Applications and Effectiveness:

(i) In common with brushlayers, hedgelayers are best suited to the remediation of shallow mass movement features that require erosion control and slope stabilisation, in locations where a thicker soil mantle occurs. This measure will be most effective in the middle to lower sections of a landslide scar, or immediately below the scarp.

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(ii) In common with brushlayers, hedgelayers are able to trap and retain slope wash materials on the slope face.

(iii) In common with live fascines and brushlayers, hedgelayers sub-divide long sections of the natural hillside (or steep slope sections resulting from landsliding) into a series of shorter slope sections.

(iv) Once established, hedgelayers are capable of providing greater biodiversity on the slope.

(v) Hedgelayers immediately provide conditions suitable for natural colonisation by plants from the surrounding plant community, even in hedgelayers that fail to establish and grow.

3.4.5.2 Construction Guidelines

(1) *Material Sizes and Preparation.* Rooted plants used to construct hedgelayers should be between 300 and 1000 mm in height, long enough to allow the roots to reach the back of the excavated bench. The height of the rooted plants will govern the depth of the excavated bench. Optimally, the selected plants should be well-branched.

(2) *Installation.* The following procedures should be followed when installing the measures:

(a) Construction can commence at any location on the site where thicker soils occur.

(b) Benches 300 to 600 mm wide should be excavated into the slope. The treads of the benches should be inclined back into the slope at an angle of approximately 25º to 45º (front to back).

(c) Degradable erosion control material (e.g. woven coir mats) should be installed down the back of the bench and across the tread, with the mats extending across the slope above and below the excavation.

(d) A thin layer of ameliorated soil fill should be placed on the erosion control mat over the excavated bench.

(e) The rooted plants should be placed on the excavated bench, perpendicular to the slope face. Plants should be spaced at 100 to 500 mm intervals, depending upon their initial size and branching characteristics. On a highly visible hillside, it may be desirable to use larger, more mature vegetation that will develop rapidly.

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(f) Each plant should be carefully removed from its transportation container, and the surrounding soil and the roots loosened.

(g) The roots should be laid out on the bench in a natural configuration, with the growing tips oriented towards the outer edge of the bench, ensuring that they extend between about 150 to 300 mm above the surface depending upon the height of the plant. About 50% of the stem of the rooted plant must be buried.

(h) Careful backfilling should then be carried out using excavated soil material and soil additives as required, ensuring that the roots, stem and side branches are covered.

(i) Moist soil should be used to protect the rooted plants from desiccation.

(j) The soil backfill should be loosely compacted by foot to eliminate voids, and to ensure that the rooted plants have maximum contact with the soil.

(k) The hedgelayer should be watered immediately after completing the installation.

In Hong Kong the hedgelayers should be installed along the contour of the natural hillside, at intervals as shown in Table 9. Suitable mulches (e.g. long straw mulch) and degradable erosion control materials (e.g. woven coir mats) should be placed on the bare soil areas between the rows.

3.4.5.3 Hong Kong Field Trials

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) *Gardenia jasminoides, Duranta erecta, Raphiolepis indica, Ficus microcarpa* and *Melastoma candidum* showed the best overall survival rate among the species used for hedgelayers, hence they are recommended for future use in hedgelayers.

(b) Hedgelayer performance was shown to be less dependent upon the time of planting and species selection than other measures using live branch cuttings.

(c) Field inspection indicated that there were no signs of further soil erosion, gully development or mass movement in the areas where the hedgelayers had been installed.

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(d) Natural colonisation was observed to occur preferentially on the benches where hedgelayers were installed, in contrast to the adjacent areas without any measures. This finding indicated that hedgelayers are able to encourage colonisation from the surrounding plant communities.

3.4.6 Branchpacking

3.4.6.1 Description

Branchpacking is used to repair shallow (i.e. 750 to 1500 mm deep) landslide scars and erosion gullies that experience relatively high runoff discharges (Figure 9 and Plates 33 to 39). The measure consists of placing alternating layers of live branch cuttings of adventitiously rooting woody plant species secured by poles, possibly in combination with live rooted plants and compacted backfill, within the eroded hollow. Recommended plant species are summarised in Table 8. The stems of the live branch cuttings, or live rooted plants, and the installed wooden poles immediately increase stability by providing structural support to the reconstructed slope. The growing tips of the closely-planted and well-branched plants helps to reduce surface erosion. Development of the plant roots further increases stability by penetrating both the soil of the reconstructed slope and the underlying slope material, binding the two together into a unified mass.

Prior to installing branchpacking, a thorough site survey should be conducted to establish if concentrated surface runoff, or subsurface flows, occurs at the site. If so, appropriate remedial measures should be constructed. These would include the installation of live fascines or pole drains above the crest of the feature to capture and redirect the runoff.

(a) Applications and Effectiveness:

(i) Branchpacking is best suited to the remediation of rills and gullies on shallow landslide scars.

(ii) Additional measures such as intercepting pole drains could be constructed to reduce surface runoff.

(iii) Branchpacking provides immediate mechanical support to the soil fill.

3.4.6.2 Construction Guidelines

(1) *Material Sizes and Preparation.* The following guidelines should be followed prior to the installation of the measures:

(a) Live branch cuttings should range between 12 to 50 mm in diameter, and be sufficiently long to reach the backs of benches as well as extending 150 to 300 mm beyond the slope surface.

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(b) Live branch cuttings should be harvested from well-branched plants.

(c) Rooted plant material should meet the same length and branching criteria. Typically, rooted plants are used in shallower sites and are combined with live branch cuttings where thicker soils are present.

(d) Depending upon the depth and length of the reconstructed slope section, wooden poles between 1500 to 2500 mm long and 80 to 100 mm in diameter are also used.

(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Installation should begin at the base of the landslide scar or gully.

(b) A sub-horizontal platform should be cut in the slope, angled into the slope at between 15° and 25° when using live branch cuttings, and between 25° and 45° when using rooted plants.

(c) Beginning at the lowest point of the site, wooden poles should be driven 1000 to 1250 mm vertically into the ground. They should be arranged in a rectilinear pattern, and placed 300 to 500 mm apart.

(d) On sites with concentrated subsurface water flows, a 150 to 200 mm thick layer of rock fill should be placed along the floor of the gully or scar. Depending upon the flow conditions, the rock fill should also be placed some distance up the back of the feature to capture the flow. It is recommended that the rock fragments are wrapped in a filter fabric to prevent the migration of fines.

(e) A 100 to 150 mm layer of ameliorated soil fill should be placed directly onto the cut platform, or onto the wrapped rock fill.

(f) A 150 to 300 mm thick layer of live branch cuttings should be placed on the platform, between the vertical wooden poles. Each layer of live branch cuttings should be placed between 200 and 300 mm apart. The branches should be placed in an overlapping, criss-cross configuration (approximately perpendicular to the slope) with the growing tips directed towards the slope face and at a distinct upward angle. The basal ends of about 50% of the branches should be long enough to reach the back of the gully.

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(g) Ameliorated soil fill should be allowed to filter into each live branch cuttings layer as it is being placed. This is accomplished by walking on the live branch cuttings during placement of the soil fill.

(h) When using live rooted plants, the size and species determine the density of planting. Typically, each layer is 80 to 150 mm thick and is installed between 150 and 200 mm apart.

(i) A 200 to 300 mm thick layer of ameliorated soil should be placed over the live branch cuttings or rooted plant layers and loosely compacted by foot to ensure that the soil is in full contact with the live branch cuttings or rooted vegetation.

(j) Moist soil should be used to prevent desiccation of the live branch cuttings or the rooted vegetation.

(k) The procedure should be repeated until the entire gully has been filled with alternating layers of live branch cuttings and/or rooted plant vegetation and ameliorated soil.

(l) The branchpacking measure should be watered immediately after installation is completed.

3.4.6.3 Hong Kong Field Trials

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) *Gardenia jasminoides* showed the best overall survival rate among the species used for branchpacking.

(b) Performance of the live branch cuttings used in branchpacking was shown to be closely related to the time of planting and the species selected. Spring is the optimum time for installation of the measures, immediately prior to the onset of the wet season. *Gardenia jasminoides* is recommended for live branch cuttings used in branchpacking.

(c) Rooted species, including *Gardenia jasminoides, Duranta erecta, Raphiolepis indica, Ficus microcarpa* and *Melastoma candidum*, showed satisfactory overall survival rates for branchpacking. Therefore, these rooted species are recommended to be mixed with live branch cuttings in the branchpacking measures.

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(d) Field inspection indicated that there were no signs of further soil erosion, gully development or mass movement in the areas where the hedgelayers had been installed.

(e) Natural colonisation was observed to occur preferentially on the benches where branchpacking had been installed, in contrast to the adjacent areas without any measures. This finding suggests that branchpacking encourages colonisation from the surrounding plant communities.

3.4.7 Live Gully Repair

3.4.7.1 Description

Live gully repairs can be used to repair shallow (e.g. 750 to 1,000 mm deep) landslide scars, and fluvial gullies that experience relatively low discharges (Figure 10 and Plates 40 to 47). The method consists of placing alternating layers of live branch cuttings of adventitiously rooting woody plant species, possibly in combination with live rooted plants, and compacted ameliorated backfill into erosion gullies and shallow failure scars. Recommended plant species are listed in Table 8. Live gully repairs are suitable for locations that experience persistent, low volume surface and sub-surface flows, the method serving to reduce the flow velocities by acting as a permeable barrier that allows drainage to pass through the system without creating further damage. Sediment loads are trapped in the branches, thus helping to fill the gully and also enhancing the root development of the installed live branches. Over time, stability is increased through the additional mechanical support provided by the reconstructed slope, and also by the binding action of the roots that penetrate the substrate.

Prior to commencing live gully repairs, a detailed site survey should be carried out to determine the volumes of surface, or sub-surface, runoff. Although this measure allows the percolation of a limited amount of water, unlike branchpacking, large discharges cannot be accommodated.

(a) Applications and Effectiveness:

(i) Live gully repairs are best suited to the remediation of small rills, gullies and shallow landslide scars that experience relatively low runoff discharges.

(ii) The method produces a barrier that reduces flow velocities, and also acts as a filter, trapping eroded sediments.

3.4.7.2 Construction Guidelines

(1) *Material Sizes and Preparation*. The following guidelines should be followed prior to the installation of the measures:

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(a) Live branch cuttings should range between 12 and 50 mm in diameter, and be sufficiently long to reach the bottom of the gully and extend from 150 to 300 mm above the slope surface.

(b) The live branch cuttings should comprise well-branched cuttings.

(c) Rooted plants, which may be used in combination with the live branch cuttings, should meet the same length and branching criteria. Rooted plants should not be used alone in this measure.

(d) Depending on the depth of the reconstructed slope section, dead stakes between 1,000 and 1,500 mm long should be prepared.

(e) Depending upon the width of the reconstructed slope section, wooden cross-poles between 50 and 100 mm diameter and 1,500 and 2,500 mm long, should be prepared.

(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Starting at any point along the length of the site, a 100 to 200 mm deep channel should be excavated along both sides of the gully, in preparation for installing and anchoring the first wooden cross-pole.

(b) Cross-poles should be installed horizontally at 500 to 2,000 mm intervals. Each cross-pole should be anchored into the ground on both sides of the gully using 1,000 to 1,500 mm long dead stakes driven vertically into the ground on the downslope side of the cross-pole.

(c) On sites with concentrated surface water flows, a 150 to 200 mm thick layer of rock fill should be placed on the floor of the gully, along the upslope side of the wooden cross-pole. It is recommended that the rock fragments are wrapped in a filter fabric.

(d) Live branch cuttings, alone or in combination with rooted plants, should be planted with the growing tips oriented steeply upslope, at an angle of between 60° and 75°. It is recommended that, when rooted plants are used, the number of live branch cuttings should be four- or five-times that of the rooted plants.

(e) A layer of ameliorated soil should be placed around the live branch cuttings and rooted plants, raising the ground to the level of the wooden cross-poles.

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(f) A 150 to 300 mm thick layer of live branch cuttings and rooted plants, alternating with backfill, should be placed in the gully between the horizontal wooden cross-poles. The branches should be laid in an overlapping, criss-cross configuration (approximately at right angles to the slope) with the growing tips oriented at an acute angle facing upslope. About 60% of the basal ends of the live branch cuttings and the plant roots should be long enough to reach the bottom of the gully.

(g) Ameliorated soil fill should be filtered into the live branch cuttings and rooted plant layers as they are being placed.

(h) A 150 to 300 mm thick layer of ameliorated soil should be placed on the live branch cuttings, and rooted plant, layers and compacted by foot to ensure that the soil is in contact with the branches and stems.

(i) Moist soil should be used, to avoid the live branch cuttings and the rooted plants being desiccated.

(j) The procedure should be repeated until the entire gully has been filled with alternating layers of live branch cuttings, rooted plants, and ameliorated soil backfill.

(k) The live gully repair should be watered immediately after the installation has been completed.

3.4.7.3 Hong Kong Field Trials

The conclusions of the field trials of live gully repairs are the same as those reached in the branchpacking trials, described in Section 3.4.6.3.

3.4.8 Tension Crack Repair

Tension crack repair involves filling the tension crack with ameliorated soil fill, followed by the insertion of live stakes obliquely along both sides of the crack. This soil bioengineering measure has been specifically developed for Hong Kong hillsides. The criss-cross configuration of the stakes is designed to secure the opposing faces of the tension crack (Figure 11 and Plate 48). It is anticipated that, over time, the measure will produce a living root mat along the tension crack that will stabilise the soil by reinforcing and binding the soil particles together, and by extracting excess soil moisture. Unlike the live stake method, tension crack repair offers immediate mechanical support by binding the soil mantle on both sides of the crack.

Selected species with suitable stem diameters and with the capacity to root and grow from cuttings (adventitious growth characteristics), such as *Ficus microcarpa* and *Salix babylomica,* are well suited to this technique.

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Material dimensions, material preparation, field installation techniques, and results of the field trials of live stakes are presented in Section 3.4.1.

3.4.9 Berm Construction

This technique involves the construction of an earth embankment that is designed to reduce surface erosion of the eroded site by capturing and diverting surface water flow. Live stakes and live rooted plants are placed along the constructed berm. This combination of soil bioengineering and earth mounding has been specifically developed for natural terrain sites in Hong Kong, to capture and redirect water flow entering at the crest of landslide scars (Plate 49).

It is recommended that perimeter pole drains be constructed on the upslope side of the berm to collect and divert the captured runoff (Figure 11).

Guidelines for berm construction are as follows:

(a) The berm should be constructed using ameliorated soil fill, and should be well compact well by foot to facilitate the placing of live stakes and rooted plants.

(b) The top of the completed berm should rise approximately 100 mm above the existing ground profile.

(c) Degradable erosion control mat and long straw mulch should be placed over the completed berm and secured with dead stakes.

(d) The live stakes should be tamped through the degradable erosion control mat into the soil berm at approximately 1,500 mm intervals. Details of the dimensions, preparation, installation and recommended species of live stakes are described in Section 3.4.1.

(e) Live rooted plants should be placed along the berm in the intervals between the installed live stakes.

3.4.10 Live Cribwalls

3.4.10.1 Description

Live cribwalls consist of a timber wall, constructed of overlapping timbers, that is backfilled with ameliorated soil fill. Live branch cuttings, and possibly rooted plants, are installed in the openings in the face of the cribwall, so that they are rooted in the soil fill behind the wall.

Once established, the live branch cuttings take over the structural function of the original timber members of the cribwall, which eventually decay (Figure 12 and Plates 50 to 56).

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(a) Applications and Effectiveness:

(i) This technique is generally used on the hillside where a low retaining structure is required, such as in a depression below a soil scarp.

(ii) The cribwall is not designed to resist large, lateral earth pressures.

(iii) Live cribwalls are typically limited to a maximum height of about 1,500 mm, including the foundation.

(iv) The system provides immediate erosion protection, in addition to a limited amount of toe support to the soil scarp.

(v) When fully established, the installed vegetation provides long-term stability.

(vi) The surface of the soil backfill top may also be planted with trees or shrubs to screen the soil scarp.

3.4.10.2 Construction Guidelines

(1) *Material Sizes and Preparation*. The following guidelines should be followed prior to the installation of the measures:

(a) Rock fill, wrapped in a filter fabric, should be placed below the structure and for some distance up the slope above to provide an additional drainage layer.

(b) Timber used for construction of the cribwall should be treated wood, ranging between 100 and 200 mm in diameter. The length should be consistent with the available space, which determines the size of the structure. The timber members should be secured using rebar pins of 8 to 10 mm diameter, and long enough to extend from the top to the bottom of the wall.

(c) Live branch cuttings, generally ranging between 12 and 50 mm in diameter, should be long enough to reach the excavated slope profile at the back of the cribwall, and to extend about 150 to 300 mm above the structure.

(d) The live branch cuttings should be well branched.

(e) Rooted plants should meet the same length and branching criteria as live branch cuttings.

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(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Starting at the lowest point of the slope, a 600 to 1,000 mm thick layer of loose, surface material should be removed from the slope to create a stable platform, inclined towards the slope.

(b) The back of the platform should be 200 to 400 mm deeper than the front.

(c) If additional drainage is considered to be necessary, rock fill, wrapped in a drainage geotextile, should be placed on the platform and up the back wall of the excavation.

(d) The cribwall should be erected at the front edge of the platform, with the first course of timbers placed in two rows approximately 1.25 to 2.0 m apart, parallel to the contours of the slope and to each other.

(e) The second course of internal bracing timbers should be placed over the first course, at right angles to it, and overhanging it by 100 to 150 mm. Each timber course should be secured with rebar pins.

(f) Successive courses should be placed in a stepped fashion, with each successive course of face timbers set back 100 to 200 mm from the leading edge so that the face of the structure is inclined back towards the slope.

(g) Structures over 1.5 m wide may require additional internal bracing. To extend the length of a structure, the timbers should be joined by a notched overlap, and secured with rebar pins.

(h) The spaces between the timbers of each course should be filled with ameliorated soil fill and covered with a layer of live branch cuttings, or rooted plants. These should be installed at right angles to the slope face and extend out from the cribwall. The layers of live branch cuttings or rooted plants should be covered with further ameliorated soil fill that has been loosely compacted by foot.

(i) Successive courses should be laid in a similar manner until the desired height is attained. All the timbers should be secured with rebar pins.

(j) The live cribwall should be watered immediately after completion.

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3.4.10.3 Hong Kong Field Trials

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) The overall survival rate, both for live branch cuttings and rooted plants, used in live cribwalls was much higher than for other measures that used live branch cuttings alone. A possible reason for the relatively high survival rate of the live branch cuttings is that they were installed in a thick layer of ameliorated soil fill that had a higher moisture content than the thin slope soil.

(b) *Gardenia jasminoides* and *Melastoma candidum*, which had the highest individual species survival rate among those used for live cribwalls, are recommended for future applications.

(c) The performance of live branch cuttings was closely related to time of planting, and to the species selection. Spring is considered to be the optimum time for the installation of the measures.

(d) Rooted species, including *Gardenia jasminoides, Melastoma sanquineum* and *Rhodomyrthus tomentosa*, showed excellent overall species survival rates in live cribwalls. It is, therefore, recommended that these rooted species be mixed with live branch cuttings in live cribwalls to increase the overall plant survival rates.

(e) Field evidence suggested that there were no signs of continued erosion or failures in the areas where live cribwalls had been installed.

(f) Natural colonisation appeared to preferentially occur on the top, and downslope, of the live cribwalls, compared to other areas without any measures. This observation indicates that live cribwalls enhance the process of natural colonisation by the surrounding plant community, primarily as a result of controlling fluvial erosion and providing a favourable platform for the growth of pioneer species such as *Commelina* and *Sympocoslautina*.

3.4.11 Bender Fences

3.4.11.1 Description

Bender fences are thin retaining structures composed of thin flexible boards woven between living or dead stakes, which are installed along the contour. (Figure 13 and Plates 57

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to 61). Initially, bender fences provide a stable soil surface for planting live stakes and rooted plants. Recommended plant species are given in Table 8.

This soil bioengineering measure is typically used on slopes with shallow gradients, that is less than 26°, and low to moderate surface water flows.

(a) Applications and Effectiveness:

(i) Bender fences are best suited to the remediation of shallow mass movement scars that require surface protection and shallow stabilisation. They are most effective on lower angle slopes, and on sites with thin soils where excavation would be difficult.

(ii) Initially, bender fences retain a 150 to 200 mm thick layer of soil fill that is placed on the slope behind the woven boards, which provides a stable growing platform for live stakes and rooted plants.

(iii) Bender fences restrict surface erosion by reducing the velocity of surface runoff, particularly by sub-dividing a long, straight slope into a series of short, stepped sections.

(iv) Eroded slope wash particles are trapped and retained behind the structure.

(v) Bender fences enhance the conditions for the natural colonisation by the surrounding plant community.

3.4.11.2 Construction Guidelines

(1) *Material Sizes and Preparation.* The following guidelines should be followed prior to the installation of the measures:

(a) Live stakes and rooted plants, 750 to 1,000 mm long, should be prepared immediately prior to installation.

(b) Flexible boards of non-living, treated wood of between 3 mm to 5 mm thick, 100 mm wide, and 3,000 to 6,000 mm long are required.

(c) Poles of between 1,000 to 1,400 mm long should be used to support the boards and the compacted soil benches.

(2) *Installation.* The following procedures should be followed when installing the measures:

(a) A completed bender fence is typically 150 to 200 mm high,

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although it may be up to 300 mm high. The bender fence may vary in length from 2,000 to 5,000 mm, depending on site conditions and handling limitations.

(b) Commencing in the lower section of the site, a row of wooden poles should be driven into the slope along the contour, at a slight angle towards the slope, and spaced about 300 mm apart. Depending upon the finished height of the bender fence, the wooden poles should be between about 700 to 1,000 mm long, with approximately 100 mm of the wooden pole protruding above the final wooden board. Additional poles are required at the ends as the boards, to curve the fence in towards the slope, enabling the fence to retain the soil fill.

(c) Loose compact fill should be placed behind the woven boards.

(d) The spacing of individual bender fences depends upon the slope gradient and site conditions. However, to obtain the optimum visual effect, the elevation of the top board of the first bender fence should be level with the bottom board of the bender fence above.

(e) Optimally, bender fences should be installed in a staggered configuration on the face of the slope (Figure 13).

(f) Live stakes, possibly with rooted plants, should be installed on the constructed soil bench. The live stakes should protrude between about 50 to 80 mm above the bench surface.

(g) A mixture of rooted plants can be installed about 150 to 500 mm apart. However, if they are placed between the live stakes, the spacing should be between 300 to 500 mm to prevent them stifling the growth of the live stakes.

(h) The plants should be watered immediately after construction has been completed.

3.4.11.3 <u>Hong Kong Field Trials</u>

The following lessons were learned from the Hong Kong field trials, which should be reviewed in the light of further experience in Hong Kong.

(a) Rooted plants generally performed very well in bender fences, and better than rooted plants in any other type of measure, including hedgelayers and live cribwalls.

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(b) Performance of the rooted plants in bender fences was found to be less related to time of planting and species selection, compared to live branch cuttings.

(c) Rooted species, including *Acacia confusa, Lophostemon confertus, Machilus checkiangensis, Melastoma sanquineum, Phyllanthus emblica, Raphiolepis indica, Rhodomyrthus tomentosa*, *Sterculia lancealata, Schefflera octophylla* and *Schima superba* are recommended for use in bender fences.

(d) If live stakes are to be installed in bender fences, the spacing of the installed rooted plants should not be less than 300 mm to prevent them stifling the growth of the live stakes. Recommended species for live stakes are presented in Section 3.4.1.

(e) Field observations indicated that there was no evidence of further mass movement in the areas where bender fences had been installed.

(f) Natural colonisation preferentially occurred on the downslope side of the bender fences, compared to other areas without any measures, indicating hat the bender fences enhance the process of natural colonisation by the surrounding plant communities.

3.5 Indirect Measures Installed in the Field Trials

3.5.1 Live Barriers

Live barriers are an indirect bioengineering measure, which differ from the direct soil bioengineering measures described above in several important respects. They are planted at a significant distance downslope from the areas of slope instability, to provide a natural screening barrier to protect low consequence facilities below.

Live barriers consist of a group of direct plantings arranged in a configuration that is designed to slow down, or possibly retain, moving landslide debris. The live barriers are constructed in channelised debris flow tracks, employing an open chevron pattern, in either an upslope (splitting wedge) or a downslope (collecting dam) alignment. Alternatively, they can be planted as contour belts below potential open hillside failures. This technique has rarely been used, hence there are no standard designs available.

The uppermost belts of live barriers are designed to act as sacrificial structures. An open-chevron (*en echelon*) pattern of tree belts is designed for channelised debris flow hazards, with the apex of the 'V' approaching, but not closing at the stream channel in order to not disrupt the normal stream flow. The belts can be placed in either an upslope (splitting wedge) 'V', or a downslope (collecting dam) 'V'-shaped configuration, depending upon local site conditions. The recommended gap at the apex is based on the width of the natural stream channel at that particular point, and the final orientation and alignment should be

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decided on site. For open hillside failures, contour belts should be planted. Different configurations of live barriers are shown in Figure 14. Plate 62 shows freshly planted live barriers at the trial site.

The distance that the tree belts should extend up the valley side slopes depends upon the local topography. Determining factors include the local valley cross-profile, the width of the channel, the geometry of the channel cross-profile, the boulder content of the channel, and the perceived ability of the valley to constrain, deflect, dam or facilitate debris movement.

Within each tree belt, the tree spacing and the choice of species are crucial. The optimum tree spacing is 2 m, with alternate rows planted in a staggered configuration. Minimum recommended stem diameter, measured at 1 m above ground level, is 20 mm. Recommended trees are predominantly naturalised species that are both fast growing and strong. These include *Acacia aurliformis, Ficus microcarpa, Schefflera octophylla,* and *Schima superba*. Bamboo, such as *Bambusa textilis*, is also recommended for use as an additional live barrier, being hardy, strong, flexible, and tolerant of close spacing. Zones of bamboo can provide an effective ‘debris straining’ barrier, and initial sacrificial barrier. Sturdier trees should be planted immediately downslope of the bamboo belt, to provide support to the weaker bamboo barrier.

Since most tree species require over a decade to grow to a sufficient strength to provide support to the bamboo belt, it is recommended that existing mature and sturdy trees be incorporated into the live barrier design. These trees will provide immediate additional support to both the bamboo belts and the newly planted tree belts. In cases where there is a high consequence in the event of hillside failure, more robust engineering mitigation measures, such as a concrete baffle wall system, are recommended.

3.6 Supplementary Soil Bioengineering Measures

The following supplementary soil bioengineering measures have not been tested in Hong Kong, but they are recommended for consideration in future projects.

3.6.1 Vegetated Gabions

3.6.1.1 Description

A gabion is a rectangular, mesh basket fabricated from triple-twisted, galvanised steel wire. Gabions can be made of natural materials such as bamboo. Empty gabions are assembled on site, and placed in position on the hillside. Successive gabions are wired together, then filled with rock and soil fill gathered on site before being folded shut and wired at the ends and sides. Subsequently, live branch cuttings, and possibly rooted plants, are installed on consecutive layers between the rock-and-soil-filled baskets. When the live branch cuttings and rooted plants become established, the plant roots consolidate the structure and bind it to the slope (Figure 15, Plate 63).

(a) Applications and Effectiveness:

(i) Vegetated gabions are usually placed at the base of a

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slope where a low retaining structure is required.

(ii) Vegetated gabions are not designed to resist large, lateral earth stresses.

(iii) Vegetated gabions are typically limited to about 1,500 mm high including the foundation.

(iv) Vegetated gabions provide immediate erosion protection and limited toe support to a slope.

(v) Established vegetation in the gabions provides longer-term stability.

(vi) The front face of vegetated gabions should be inclined back towards the slope, and successive gabions should be placed in a stepped fashion, each one set back between about 150 to 250 mm towards the slope from the lower gabion.

3.6.1.2 Construction Guidelines

(1) *Material Sizes and Preparation*. The following guidelines should be followed prior to the installation of the measures:

(a) Inert components include wire gabion baskets, wires for assembling and connecting the baskets, and rock and soil fill. Filter fabric should be used if the structure is placed below ground level.

(b) Live branch cuttings should range between 120 to 250 mm in diameter. They should be long enough to reach 200 to 300 mm into the soil at the back or base of the gabion, and to extend about 150 to 300 mm above the structure.

(c) Live branch cuttings should be well branched.

(d) Rooted plant material should meet the same length and branching criteria as the live branch cuttings.

(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Starting at the lowest point of the slope, a 600 to 1,000 mm thick layer of loose surface material should be removed from the slope surface to create a stable platform.

(b) The back of the finished platform should be 200 to 400 mm deeper than the front.

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(c) The fabricated wire gabions should be placed on the platform and filled with rock and ameliorated soil fill.

(d) The voids both between and behind the baskets should be filled with loosely compacted soil.

(e) Live branch cuttings or rooted plants should be placed on the wire baskets, at right angles to the slope surface and with their growing tips oriented away from the slope. They should extend 150 to 300 mm above the surface of the structure, as well as extending about 200 to 300 mm beyond the back of the structure into the soil fill. Loosely compacted soil should be placed over the vegetation layers.

(f) Successive gabions should be constructed in a similar manner until the required height is achieved.

(g) The vegetated gabion should be watered immediately after construction is complete.

3.6.2 Joint Planting

3.6.2.1 Description

Joint planting is similar in many respects to live stake installation. However, the technique involves the installation of live branch cuttings of adventitiously rooting woody species into soil-filled rock joints (Figure 15 and Plates 64 to 66). A network of joint planting creates a living root mat within the soil mantle. Eventually, joint planting stabilises the soil by binding the soil particles together and by extracting excess moisture. Selected pioneer plant species, such as *Commelina* and *Sympocoslautina*, which have the capacity to root and grow from cuttings (adventitious growth characteristics), are best suited to this technique. Joint planting is appropriate for the repair of areas affected by shallow mass movement and subject to the influx of surface and shallow subsurface flows. The technique offers immediate surface erosion control and mechanical support to the soil. Information about the selection and use of live stakes is contained in Section 3.4.1.

A detailed site survey should be carried out to determine if the conditions are suitable for the application of the technique, particularly because a sufficient thickness of suitable soil is required to enable the joint plantings to become established.

(a) Applications and Effectiveness:

(i) Joint planting method is best suited to the remediation of shallow mass movement features and areas of steeper gradient.

(ii) Joint planting can be used on sites where rockfill has been placed and a vegetation cover is desirable.

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(iii) Joint planting traps and retains slope wash materials moving down the slope face.

(iv) This approach offers immediate mechanical stabilisation, thereby allowing the plants an opportunity to establish.

(v) Once established, the joint planting enhances the conditions for natural colonisation by plants from the surrounding plant communities and provides additional mechanical support to the base upon which the rockfill has been placed.

3.6.2.2 Construction Guidelines

(1) *Material Sizes and Preparation*. The following guidelines should be followed prior to the installation of the measures:

(a) Live branch cuttings should be between 12 to 40 mm in diameter and 850 to 1000 mm long.

(b) Side branches should be cleanly removed and the bark left intact.

(c) The basal ends should be cut at an angle or sharpened for easy insertion into the soil between and below the rock. The top should be cut flat, with the buds oriented upwards.

(d) The live branch cuttings should be installed while fresh, within 4 hours of fabrication.

(e) If installed without treatment, the fabricated materials should be installed on the same day that they are prepared. Prepared live stakes may be installed immediately without treatment, or soaked in root activator solution in accordance with the manufacturer's recommendations. It is important to ensure that the stakes are kept moist from the time they are fabricated to the time that they are installed. This may be accomplished by keeping them in water, or by wrapping them in wet straw, wet burlap, hessian cloth or wet erosion control fabric.

(f) Joint plantings should be tamped into the ground at an angle of approximately 45° to the horizontal.

(2) *Installation*. The following procedures should be followed when installing the measures:

(a) Installation can begin at any point within the rock area on the slope face.

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(b) The density of live stakes should range between 3 to 5 stakes per square metre, using a triangular grid pattern.

(c) Up to 80% of the length of the live stake should be inserted into the ground, below the surface of the rock, approximately perpendicular to the slope.

(d) The joint plantings should not be split during installation.

(e) When the ground beneath the rock is hard, a steel bar or similar device, should be used to make a pilot hole in the slope surface. The diameter of the bar should be equal to the diameter of the smallest live stake.

(f) The joint plantings should be tamped into the ground with a "dead blow" hammer.

3.7 Degradable Erosion Control Mats and Long Straw Mulch

Degradable erosion control mats are generally made of woven coconut husk fibres. They are commonly installed on the slope surface, together with long straw mulch, to provide temporary soil erosion protection. Prior to installation, the areas to be covered with the degradable erosion control mats should be made reasonably smooth by localised trimming or soil filling, and be cleared of all debris. The selection criteria for erosion control mats and long straw mulch are summarised in Table 10.

Degradable erosion control mats should be placed and fixed in accordance with the manufacturer's recommended procedures. In addition, the following site-specific procedures should be followed:

(a) Prior to placement of the long straw mulch and degradable erosion control mat, the slope surface should be prepared by lightly raking the top 5 mm of the soil.

(b) Long straw mulch should be spread on the slope surface prior to the laying of the degradable erosion control mat. The long straw mulch should be evenly spread by hand to produce a layer between 25 to 35 mm thick. The mulch should not be chopped up.

(c) Degradable erosion control mat should be installed on the prepared slope, and should be dry when placed.

(d) Laying of the degradable erosion control mat should begin at the top of the slope. Adjacent mats should have an overlap of at least 300 mm, with the upslope mat overlapping the downslope mat. Overlapping sections of mat should not be located where abrupt changes of gradient occur.

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(e) Degradable erosion control mat should be secured with dead stakes at 1,000 mm centres, and every 750 mm along the upper edge and along overlapping seams.

(f) Where hard strata are encountered, steel rebar stakes may be substituted for the dead stakes. Where hard strata create local irregularities, reduced stake spacing should be adopted to ensure that the mat is in close contact with the slope surface over their entire slope surface.

(g) To ensure that the entire area of the mat is in contact with the prepared slope surface, excessive tension in the mat should be avoided.

4. SOIL BIOENGINEERING MATERIALS

4.1 Locating and Selecting Plants

The primary objectives of the soil bioengineering measures are to control surface erosion, stabilise shallow mass movement scars, restore damaged habitats, improve the appearance of scarred slopes, and to enhance colonisation from local plant communities. To achieve these objectives, native species, harvested from existing stands of living woody vegetation, are the preferred soil bioengineering plants largely because they are compatible with the local environment and are relatively inexpensive to obtain. However, the native live plants should be carefully selected, harvested, handled, transported, stored and installed. Care must be taken to choose native live plants that possess the required diversity of root systems, namely deep, laterally extensive, and strong. They should also propagate easily from cuttings.

4.1.1 Harvesting, Handling and Storage of Native Plants

Native live plants can be harvested from existing native stands growing near the project site, or within practical transporting distance. The harvesting site must contain plant species that will propagate easily from cuttings, have the required rooting and branching characteristics, and be appropriate for the project requirements, both initially and in the long term.

Harvesting sites usually require special permission, both for access and for removing the live cuttings. Large areas of native plant materials can be cut in most areas, whereas selective harvesting may be demanded in environmentally or visually sensitive areas. Therefore, in sensitive areas, it is essential that harvesting is carried out selectively, with specifically defined objectives, with strict limits to the number of cuttings removed, and under expert supervision from a suitably qualified professional. Limitations may include:

(a) controlling the proportion, or total number, of plants that may be cut from within the designated harvesting area;

(b) designating specific zones within the designated harvesting

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area, and specifying cutting patterns;

(c) specifying the particular plant species from which the cuttings may, or may not, be taken;

(d) restricting the total number of plants that may be cut from individual species.

(1) *Harvesting Tools.* Lightweight cutting tools such as pocket secateurs and hand-saws are recommended for cutting the live branches. Importantly, strict safety precautions must be followed when using these, and any other, tools. Harvesting of plants should be carried out with great care.

(2) *Live Branch Cuttings.* The branches should be cut or pruned in accordance with British Standard BS 3998:1989, to ensure minimum risk of the pruned plants suffering from subsequent bacterial or fungal attack, or physical weakness. Similarly, it is important that live branch cuttings are taken from healthy, insect-free, undamaged, and disease-free plants. The selected branches should normally be between 12 to 50 mm in diameter, and range in length from 300 to 2,000 mm. Cuts should be made at a low-angle of about 5° to 15°, and about 150 to 300 mm above the ground. Cutting this high up the stem enables the pruned plant to regenerate rapidly and in a healthy manner. Unhealthy, diseased, insect-infested and damaged plants should not be taken to the project site, but left, and preferably destroyed, at the harvesting site. Highly invasive plants should also be left at the harvesting site. Consequently, it is recommended that, prior to leaving the harvesting site, all live branch cuttings are inspected for invasive vines, or similar infestations, that may be attached to them.

Harvested sites should be left clean and tidy. It is recommended that any remaining cut plants that are either too large or too old for use in the project be arranged into low piles to provide cover for wildlife. Alternatively, they can be chopped-up and spread on either the harvesting or project site to provide fertilisation, or chopped-up and taken from the site for proper disposal. Harvesting sites may be used several times, so it is particularly important that they are left in a condition that will enhance their potential for regeneration, and possibly improving the local environmental conditions. Care should be taken to ensure that the lease or access conditions are complied with, and that the site is re-instated to the satisfaction of the landowner.

(3) *Binding.* Live branch cuttings should be bundled together and securely tied with twine before transportation. It is important that the brushy limbs are preserved and not damaged during transport. The bundles should be small enough to be easily and conveniently handled and deployed at the project site. Consequently, it is recommended that the bundles contain a specified, and consistent, branch count. For example, five to ten live branch cuttings in each bundle or a similar number that would conveniently correspond to multiples required for particular measures. In addition, the live branch cuttings in each bundle should be of the same species, to facilitate their use in particular measures.

(4) *Transporting.* Care should be taken not to damage the bundled live branch cuttings during transport to the project site. The bundles should be placed on the vehicle in an orderly manner, to prevent damage and to facilitate unloading. Importantly, the bundles should be covered with a tarpaulin during transportation to prevent the branches drying out. In some cases, wetting the branches prior to transport may be necessary.

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(5) *Handling and Storage.* The live branch cuttings should arrive at the site as fresh as possible, preferably within two hours of harvesting. Ideally, they should be installed immediately after harvesting. Live cut plant materials should be installed within twenty-four hours of being cut.

When the cuttings are not used immediately, they should be promptly placed in controlled storage conditions at the project site. This includes keeping them covered, moist and protected until they are installed. When the live cuttings are placed in storage, it is important that they are:

(a) stored in permanent shade;

(b) protected from the desiccating effects of the wind and sun;

(c) kept moist, and prevented from drying out; and

(d) protected from all forms of damage.

It is recommended that the cuttings are stored in water, sprayed with water every few hours, or placed in moist soil and covered with wet hessian cloth. Live branch cuttings that are not installed within the designated time should be properly disposed of.

4.1.2 Commercial Sources

Commercially grown plants can be used for soil bioengineering measures, although it is necessary to allow an adequate lead-in time for their sourcing, procurement and delivery. Depending upon the project objectives, suitable species should be determined from site surveys that examine the geomorphological and ecological conditions. In addition, information should be gathered about the tolerances of particular species to adverse conditions such as sediment deposition, flooding, waterlogging, drought, salt, fire and low-fertility soils. A plant specialist with experience of plant testing should be called upon to compile a list of species appropriate for a range of adverse site conditions, and to determine a reliable commercial source for their procurement.

4.1.3 Cost Comparison between Harvesting and Commercial Sources

Experience from the Hong Kong trial sites indicated that the cost of harvesting live branch cuttings from the vegetation growing around natural terrain landslide scars and purchasing them from commercial nurseries are similar. Price differences between harvested materials, for live stakes and brushlayers, and rooted commercial plants, for direct planting and hedgelayers, were minimal. These findings differ from the situation in the United States and Europe, where plants from commercial sources are generally more expensive than harvested plants. The major reason for the difference is that most of the plants in the Hong Kong trials were supplied by low-cost nurseries in Mainland China.

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4.2 Installing Plants

4.2.1 Programming

Installation of the live branch cuttings should begin concurrently with the site profiling operations. To maximise efficiency, it is recommended that all construction procedures are coordinated wherever possible. For example, soils derived from slope profiling should be used in the construction of an upper berm, or as fill for other soil bioengineering measure such as vegetated gabions or bender fences. The optimum time of year for installing soil bioengineering measures is immediately prior to the onset of the rainy season. This generally occurs between March and May in Hong Kong. Although it is impossible to forecast weather conditions, annual variations in rainfall amounts, duration, and timing should be taken into account, and changes to the programme made as necessary. These programme changes may require the project to be accelerated, necessitating the hiring of extra labourers. On the other hand, it may be necessary to postpone or delay a project for several months, or to change the species or type of plants in order to ensure the success of the project.

4.2.2 Soil Characteristics

Soil bioengineering measures require a planting medium that is free draining, that includes fines and organic material, and that is capable of supporting vigorous plant growth. Most soil bioengineering projects use on-site stockpiled topsoil as the planting medium. The material does not have to be organic topsoil, but must be able to support plant growth. Ideally, in accordance with the project philosophy of installing cost effective measures, soil should not be imported to the site. Soil trimmed from profiling the scar is the practical alternative. Therefore, it is recommended that the excavated slope materials are nutrient tested, and then appropriately ameliorated.

Soil samples for nutrient testing should be collected from the site. Imported soils should also be tested prior to planting. Nutrient testing should be carried out by an approved laboratory, and should include analyses for a full range of nutrients, including the content of metals, carbon, potassium, phosphorous, sulphur, nitrogen, and organic matter, as well as the pH value. Upon receipt of the test results, it is recommended that assistance from an horticulturalist or landscape architect is sought, for advice on interpreting the test results and suggesting appropriate fertilisers and other additives suitable for the selected plants.

Gravel is not suitable for use as fill around living plants. Muddy soils are generally unsuitable, but certainly should not be used until they have dried to a workable moisture content. Soils used as backfill around the live cuttings should be compacted to the density of the surrounding natural soils. Soil placed around the plants should be free of voids.

The volcanic soils at the Hong Kong trial sites were characteristically acidic, and infertile, being deficient in nitrogen, phosphorus, potassium, and organic matter. Aluminium toxicity was found to be a potential problem for plant growth in these acidic soils. In comparison, soil samples taken outside the landslide scars contained a relative higher level of nutrients, especially of nitrogen and potassium. Detailed soil analytical results are contained in Appendix B.

An adequate supply of fertiliser is recommended during planting, and for post-planting

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care. Ideally, planted shrubs and trees should be given 50 g of a balanced, slow-release fertiliser. When new roots appear on the planted cuttings, additional phosphorus fertiliser is beneficial to stimulate growth. Phosphorus is a useful starter fertiliser, but unfortunately its bio-availability in acidic soils is reduced due to the presence of aluminium, iron and manganese. Ideally, the acidic soils should be improved with lime, such as dolomitic limestone, in order to increase the bio-availability of phosphorus. Liming should be carried out at least one month before planting begins, but may be expensive because of technical difficulties. However, in special circumstances, and when time is available, this procedure is recommended to ensure success of the plants.

5. CONSTRUCTION INSPECTIONS AND FOLLOW-UP

5.1 Quality Control

Strict quality control throughout the installation and maintenance periods will help to ensure the success of a soil bioengineering project. To achieve these objectives, the following guidelines are recommended.

5.1.1 Pre-construction

The pre-construction works include:

(a) Selection of the appropriate plant species for compliance.

(b) Locating and securing source sites for harvesting the live cuttings, or the identification of a commercial nursery.

(c) Definition of the construction works area, and clearance of the land matters for land allocation.

(d) Fencing of the sites requiring special protection or treatment, such as those containing sensitive plants or endangered insects, amphibians or other animals, as well as those that are considered extremely dangerous.

(e) Completion and inspection of the following preparations:

- (i) Geomorphological mapping of the site, including slope angle, site dimensions, and local features such as scarps, benches and gullies
- (ii) Soil bioengineering design and preparation of design drawings
- (iii) Design and layout of the works
- (iv) Selection of a suitable harvesting area

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(v) Determination of the depth of excavations required

(vi) Preparation of the site, by clearing, grading and profiling

(vii) Disposal of excess gravel, soil and debris

(viii) Removal or preservation of existing vegetation

(ix) Stockpiling of suitable soil and rock

(x) Demarcation of storage and fabrication areas

(xi) Marking and clearance of access locations

(xii) Safety considerations

(xiii) Contract tendering

5.1.2 During Construction

Inspect every aspect of the works, at each stage of the project, paying particular attention to the following:

(a) Field layout of the measures

(b) Preparation of trenches or benches for soil bioengineering measures

(c) Selection and placement of soil fill and rock fill

(d) Laying of erosion control materials

(e) Application of fertilisers and additives

(f) Inspection of the plant storage area

(g) Plant handling and preparation

(h) Placement and orientation of the live cuttings

(i) Pruning

(j) Soil compaction

(k) Watering

(i) Ensuring that proper maintenance occurs during and after installation

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(ii) Daily quality control inspection

(l) Checking of live cuttings, removal of unacceptable materials and use of fresh stock for replacement

(m) Continuously check all items in the pre-construction and construction inspection lists

5.1.3 Post Construction

Regular inspections should be carried out after the soil bioengineering measures have been installed. The following schedule is recommended:

(a) Monthly inspections for the first 6 months, and after each heavy rainstorm or period of exceptional weather conditions that might adversely affect the site

(b) Inspections after nine months and twelve months, and after each heavy rainstorm or period of exceptional weather conditions that might adversely affect the site

(1) *First Year Inspection.* The following features should be inspected:

(a) Evidence of soil erosion, ground cracking, mass movements, or any form of soil displacement

(b) Plants affected by disease or insects, and invasion by undesirable plant species

(c) Adverse competition between herbaceous plants and woody plants

(d) Nutrient deficiencies

(e) Plant desiccation

(f) Vandalism

(g) Grazing or trampling by livestock or wild animals

(h) Damage caused by passers by, or from recreational use

(i) Fire damage

(j) Check for any off-site influences that may have negative effects

In addition to the above factors, the following information should be gathered by an experienced geotechnical engineer and an horticulturalist with knowledge of the area and of

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native plant conditions:

(a) Are the measures performing mechanically?

(i) Has the erosion ceased, or been or reduced compared with the original conditions?

(ii) Are any tension cracks or signs of failure visible?

(b) Are the installed methods properly established?

(i) Do the plants appear to be in a healthy state?

(ii) Which particular species have established, and which ones are in stress or have died?

(iii) What is the probable cause of mortality?

(iv) What is the percentage of living vegetation on each component of the measures and across the site, as a measure of survival rates?

A healthy growing state is usually based on overall leaf development, as shown in Table 11. The percentages, which are based on over 30 years of experience in North America and Europe, may not be directly transferable to Hong Kong conditions. It may be necessary to develop a set of local criteria that are modified with further local field trials, ideally over about ten years of observations.

Successful growth for the soil bioengineering measures is defined as a continuous swathe of "green" with no open spaces greater than 300 mm along the length of the installations. Spaces of 600 mm or less will fill in over time, typically do not need repair, and will not hamper the integrity of the installation.

Remedial planting is recommended in those locations that exhibit poor performance. Typical remedial installations take the form of live stakes and pit planting along the failed measures. Suggested remedial actions for the different measures are as follows:

(a) Pole drains - Install live stakes along both sides of existing pole drains at 600 mm centres

(b) Live fascines - Install live stakes at 600 mm centres along the downhill side of the live fascine, and install rooted plants at 600 mm centres along the upslope side of the live fascine

(c) Brushlayers - Install live stakes in a staggered configuration, at 300 mm centres, along the centreline of the brushlayer

(d) Branchpacking - Install two rows of live stakes at 300 mm spacing at each batter of the branchpacking

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(e) Hedgelayer - Install live stakes, and possibly rooted plants, in a staggered configuration, at 300 mm centres, along the centreline of the hedgelayer

(2) *Second Year Inspection.* Inspections should be carried out twice a year, with the following checks included:

(a) Are the measures performing mechanically?

(i) Has the erosion ceased, or been or reduced compared with the original conditions?

(ii) Are any tension cracks or signs of failure visible?

(b) Are the installed methods established properly?

(i) Do the plants appear to be in a healthy state?

(ii) Which particular species have established, and which ones are in stress or have died?

(iii) What is the probable cause of mortality?

(iv) What is the percentage of living vegetation on each component of the measures and across the site, as a measure of survival rates?

(c) Has natural colonisation from the surrounding plant community occurred within the project site?

(i) What percentage of the site is covered by natural colonisation?

(ii) Which plant species have invaded the site, and what is the total number of each species?

(iii) Will certain species have to be removed, such as exotics?

Recording of the above factors will enable the rate and progress of natural colonisation to be determined, providing a basis for future species selection, and for assessing ways of further improving the site conditions. It should be noted that items a) to j) under first year inspection are also included in the second year inspection schedule.

5.2 System Maintenance

Under normal conditions, following inspection and acceptance of the completed works, there should be little or no maintenance required. However, limited maintenance may be advisable, depending upon the final composition of the vegetation. A native shrub or mixed

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forest system commonly require some management. Additional maintenance may be necessary if the site has special features, such as a viewpoint where the height of the vegetation may need to be trimmed, or if seasonal clearance along a footpath is desirable. Mature soil bioengineering measures may, in future, become a harvesting area for future bioengineering measures.

Minimal maintenance generally consists of light pruning and the periodic removal of undesirable vegetation. Heavy pruning may be necessary to reduce the competition for light, or to stimulate new growth. Under certain circumstances, selective removal of vegetation may be required every 3 to 10 years to eliminate undesirable invading species, to create special habitat zones, or to open up a viewpoint. Importantly, vegetation inspection and assessment should be carried out by an experienced horticulturalist.

More intense maintenance may be required to repair problems created by high intensity rainstorms or other unusual weather conditions. Generally, re-establishment should take place for a 1-year period following the completion of construction, and should consist of the following:

(a) Replacement of dead measures as described in Section 5.1.3

(b) Branchpacking, placement and compacting of soil fill in rills and gullies

(c) Insect and disease control

(d) Weed control

Rilling and gullying of the slope, or damaged measures, should be repaired using healthy, live branch cuttings and rooted plant stock. Preferably, this should be installed immediately prior to, or during the early part of, the wet season. For large repairs it is recommended that the branchpacking or live gully repair method is used, and for small repairs that the live fascine and live staking methods are use.

6. GENERAL EVALUATION OF SOIL BIOENGINEERING METHODS

6.1 General

Soil bioengineering measures are not a suitable solution for all surface erosion problems and slope failures in Hong Kong. Although soil bioengineering measures have unique attributes, they are not appropriate for all sites and for all situations. In certain cases, more conventional treatment, such as grass seeding, turfing, hydro mulching or direct planting of herbaceous or woody plants, would work well and for less cost. In other cases, standard engineering structural retaining systems would be a more appropriate, and a more effective, solution, either alone or in combination with vegetation.

6.2 Constraints

The various soil bioengineering measures, alone or in combination, are suitable for a

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range of different applications in Hong Kong. These are summarised in Table 12.

6.3 Overall Cost Considerations

The cost of soil bioengineering measures are based on two main factors, the cost of the construction materials and their harvesting, and the labour costs for installation. In general, labour costs will constitute the major outlay for each scheme. Also, provision should be made for a small maintenance cost during the establishment period, which typically extends for about one year after completion of the works. Depending upon the type of measure, or its location, period maintenance such as pruning may be required (see Section 5.2 a). Typically the maintenance cost is relatively small. The relative costing of soil bioengineering measures in Hong Kong is summarised in Table 13.

6.4 Effectiveness

The effectiveness of individual soil bioengineering measures will generally depend on the specific type of problem that the measures have been installed to deal with, and the physical characteristics of the site. The effectiveness of each soil bioengineering measure in Hong Kong is shown in Table 14.

6.5 Environmental Considerations

The effect on the environment of any planned soil bioengineering measures should be considered during the planning stage. Erosion control benefits should be evaluated against factors such as the potential visual enhancement of the slope, the increase of natural surface cover and associated litter layer development, accelerated natural colonisation, improvements to the habitat, and the overall aesthetic effects. A general summary of the environmental and aesthetical considerations of soil bioengineering measures is shown in Table 15.

7. ASSESSMENT OF EFFECTIVENESS

7.1 General

Soil bioengineering measures are intended to provide an environmentally compatible method of preventing soil erosion and of stabilising shallow natural terrain landslide scars. Potentially, they can provide a self sustaining, relatively maintenance-free repair that cannot be achieved by conventional engineering solutions alone. Prior to recommending soil bioengineering measures in Hong Kong, the technical, aesthetic, ecological and economic aspects of all the available repair methods should be considered and compared, in order to determine the appropriateness, or otherwise, of the soil bioengineering approach. Importantly, prior to the commencement of design and construction, it is necessary to carry out a detailed geomorphological site survey, a vegetation survey, a soil survey, and a desk study to gather information about factors such as rainfall totals. Based on the results of these surveys, the engineer can then select the most appropriate soil bioengineering measures that meet both the long term and short term requirements of the repair, and to determine which plants and plant communities should be used to ensure compatibility with the surrounding

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vegetation communities. The following sections offer guidance on the selection of appropriate soil bioengineering measures, and their relative benefits:

7.1.1 Benefits of Soil Bioengineering Measures

7.1.1.1 Technical Benefits (after Schiechtl, 1980; Sotir, 1993)

The desirable technical benefits of soil bioengineering measures include:

(a) Collection and control of surface runoff;

(b) Protection of countryside infrastructural facilities, such as walking trails and barbeque areas, from erosional damage;

(c) Stabilisation and protection of exposed soil slopes;

(d) Mitigation of the effects of erosive forces on slopes, thereby stabilising the soil, promoting natural compaction, and averting minor slope failures;

(e) Retention of mobile surface materials, such as gravel and boulders;

(f) Filtering of fine suspended sediment and nutrients, thereby improving water quality;

(g) Immediate mechanical reinforcement of the soil by the structural members, such as wooden stakes, and longer term reinforcement through the development of a fibrous root system; and

(h) Reduction of the flooding potential at the base of the slope, with vegetation reducing surface runoff and promoting infiltration by intercepting rainfall, and by storing water on the leaves and branches.

7.1.1.2 Ecological Benefits (after Schiechtl, 1980; Sotir, 1993)

The desirable ecological benefits of soil bioengineering measures include:

(a) Benefits to the hillslope hydrology as a result of the increased interception of rainfall;

(b) Improved balance between soil water retention during the dry season, and soil water loss through transpiration during the wet season;

(c) Improvements to soil drainage;

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(d) Moderation of air pollution and water temperatures in streams and reservoirs;

(e) Stabilisation of temperatures in the soil, and in the air layers close to the soil surface;

(f) Improved shading and wind protection to produce favourable micro-climates for plant growth;

(g) Improvement to the soil texture by plant root action;

(h) Increase of soil nutrients through the addition of decaying plant matter, and by symbiosis (especially N-fixation), thus improving the local ecosystem and assisting the soil flora and fauna;

(i) Creation of connected wildlife corridors, feeding, nesting and associated habitats for wildlife such as birds, animals, reptiles, butterflies, and insects; and

(j) Improvements to terrestrial, riparian and aquatic habitats.

7.1.1.3 Aesthetic Benefits (after Schiechtl, 1980; Sotir, 1993)

The desirable aesthetic benefits of soil bioengineering measures include:

(a) Concealing unsightly natural and anthropogenic scars on natural terrain hillsides in Hong Kong;

(b) Concealing structures to blend them in with the natural landscape;

(c) Screening of unsightly construction activities that are unsightly and visually disruptive in a natural setting;

(d) Enrichment of the Hong Kong landscape by using natural form and colour; and

(e) Reconstruction, preservation and enhancement of upland catchments and associated streams, rivers, and wetlands.

7.1.1.4 Economic Benefits (after Schiechtl, 1980; Sotir, 1993)

The desirable economic benefits of soil bioengineering measures include:

(a) Reduced construction costs in comparison to conventional engineering methods;

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(b) Reduced long-term maintenance costs;

(c) An ancillary system to support and enhance conventional engineering installations on hillsides;

(d) Enhancement of upland recreation areas in Hong Kong;

(e) Enhance the quality of the environment for Hong Kong residents;

(f) Reduction in the number and size of artificial drainage measures and related structures; and

(g) Support property values by improving the aesthetic appeal of the district.

7.1.1.5 Educational Benefits (after Sotir, 1993)

The desirable educational benefits of soil bioengineering measures include:

(a) Ensure the continuance of local plant successions and ecological systems on natural hillsides for educational purposes;

(b) Protection of important cultural, historical and natural resources; and

(c) Provide a stimulus for research into natural systems.

In order to meet the foregoing objectives, high quality specifications prepared specifically for the site are essential. Implementation and construction should be supervised by full-time, appropriately qualified professionals. They should be familiar with both soil bioengineering measures and the broader project objectives.

To achieve long-term success, the projects require the collection of appropriate site data, careful layout, and skilful planning by experienced staff. Only in this way can workable construction contracts be compiled, tendered, and managed. Soil bioengineering sites should also be carefully monitored after construction, with any necessary remedial planting and minor maintenance carried out promptly before the site deteriorates.

7.2 Evaluation Criteria

Evaluation of the success of a soil bioengineering project requires that several factors are taken into consideration, including effectiveness of the measures in controlling soil erosion, the development and health of plants, and the extent of natural vegetation succession. About one year after installation, the Hong Kong trial sites showed a significant increase in the vegetated area, ranging between 50% to 80% (MGS, 2006a). Table 16 shows the percentage change of vegetation cover after the installation of soil bioengineering measures.

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The criterion used to assess healthy growing characteristics was the percentage of leaf development, as detailed in Section 5.1.3.

The following factors should be assessed as part of the evaluation (initial evaluation criteria are presented in Section 5.1.3 - Post Construction):

(a) Have the installed systems controlled the erosional processes that originally caused the damage?

(b) Have the following problems being reduced or removed?

    (i) Fluvial erosion processes (e.g. sheet and gully erosion).

    (ii) Shallow mass movements (e.g. scars and debris trails).

    (iii) Tension cracks.

(c) Are the installed measures well established, and is natural succession occurring as a result of colonisation from the surrounding native plant community.

(d) Has a completely diverse plant cover established, a permanent, self-sustaining plant community approaching the natural climatic climax vegetation of shrubs and small trees.

(e) In parallel with the establishment of the plant community, has the condition and nutrient content of the soil improved?

8. FUTURE STUDIES

Based on the lessons learned from the field trials, several recommendations for further studies can be summarised as follows:

(a) A major deficiency that was encountered in the Hong Kong field trials was the lack of information about the rooting characteristics of Hong Kong plants. Further studies should be carried out, preferably in association with suitably qualified specialists, to further investigate rooting depths, root morphology, root density, and root strength.

(b) Soil bioengineering measures that use live branch cuttings, such as brushlayers, live fascines and pole drains, should be trialled using a mixture of rooted plants species together with the harvested live branch cuttings to investigate if this would increase the overall survival rates.

(c) When installing pole drains and live fascines, the twines used for tying the bundles of live branch cuttings should be

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removed at 600 mm intervals, along with most of the leaves. This will test the assumption that ameliorated soil filling voids within the trench facilitates rooting of the live branch cuttings and prevents drying out.

(d) Further studies of woody upland species and their propagation from cuttings could be carried out. *Ficus microcarpa, Gardenia jasminoides* and *Salix babylomica* are recommended species based on the field trials. Testing of other *Ficus* species that have good aerial roots is also recommended.

(e) A cost-benefit analysis of advanced soil treatment, or amelioration, of the highly acid upland soils could be carried out. Species that can tolerate low soil pH conditions may also be tested.

(f) Special consideration should be given to the possibility of installing special forms of soil bioengineering measures on steep sites.

(g) Information obtained from Hong Kong horticultural experts suggests that a 30-month period, or longer, is required for the establishment of native species. Therefore, it is considered that longer-term continuous monitoring is required before any final conclusions can be reached about the performance of the various soil bioengineering measures installed in the Hong Kong field trials.

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Table 1 - Comparison of Costs Per Unit Area of Soil Bioengineering Works Versus Conventional Slope Repair Works

Type of Measures	Descriptions	Rate (HK$ per unit sq. m)
Conventional Slope Repairs	Mat for erosion control of Polyamide type plus hydroseeding with grass seed and tree seed mix	{80[1] + 15[2] + 12.5[3] + 3680[4]} x 128%[5] x 145%[6] = 199 per sq. m + 6830[4]
	Mat for erosion control of Polyethylene type plus hydroseeding with grass seed and tree seed mix	{60[1] + 15[2] + 12.5[3] + 3680[4]} x 128%[5] x 145%[6] = 162.4 per sq. m + 6830[4]
	Mat for erosion control of Polypropylene type plus hydroseeding with grass seed and tree seed mix	{50[1] + 15[2] + 12.5[3] + 3680[4]} x 128%[5] x 145%[6] = 143 per sq. m + 6830[4]
	Grade 20 sprayed concrete with one layer of A252 mesh - 75 mm thick, plus colour pigment	275 x 128%[5] x 145%[6] = 510.40 per sq. m
	Grade 20 sprayed concrete with one layer of A252 mesh - 100 mm thick, plus colour pigment	310 x 128%[5] x 145%[6] = 575.36 per sq. m
	Grade 20 sprayed concrete with one layer of A252 mesh - 150 mm thick, plus colour pigment	400 x 128%[5] x 145%[6] = 742.40 per sq. m
Soil Bioengineering Measures	Simple soil bioengineering measures[7] (excluding direct planting)	261 per sq. m
	Simple soil bioengineering measures[7] (including direct planting)	278 per sq. m
	Comprehensive soil bioengineering measures[8]	391 per sq. m

Notes:
(1) Unit rate of erosion control mats given in schedule of rate for LPM.
(2) Unit rate of hydroseeding with grass seed and tree seed mix given in schedule of rate for LPM.
(3) Unit rate of preparation works given in schedule of rate for LPM.
(4) Rate of establishment of equipment for hydroseeding given in schedule of rate for LPM.
(5) Additional percentage for horizontal inaccessibility given in SOR contract for LPM. From experience of the field trials, average inaccessible horizontal distance is over 200 m. Therefore, additional of 28% is adopted.
(6) Additional percentage for vertical inaccessibility given in SOR contract for LPM. From experience of the field trials, average inaccessible vertical distance is over 60 m. Therefore, additional of 45% is adopted.

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Table 2 - Preliminary Selection of Vegetation Species for Soil Bioengineering (Sheet 1 of 2)

Species	Chinese Name	Form	Status native (n), naturalized (nz) or exotic (e)		Comparative Rooting Depths(1)
Acacia auriculiformis	耳果相思	Tree	Common	e	Moderate
Acronychia pedunculata	山油柑	Tree	Common	n	Moderate
Aporusa chinensis	銀柴	Shrub	Common	n	Moderate
Aquilaria sinensis	牙香樹	Tree	Common, Protected in China (Class II)	n	Moderate
Archidendron lucidum	亮葉猴耳環	Tree	Common	n	Moderate
Ardisia crenata	朱砂根	Shrub	Common	n	Moderate
Baeckea frutescens	崗松	Herb	Very common	n	Moderate
Breynia fruticosa	黑面神	Shrub	Very common	n	Moderate
Bridelia tomentosa	土蜜樹	Tree	Common	n	Uncertain
Canthium dicoccum	魚骨木	Shrub or tree	Common	n	Uncertain
Celtis sinensis	朴樹	Tree	Very common	n	Uncertain
Cinnamomum camphora	樟樹	Tree	Very common	n	Deep
Cratoxylum lligustrinum	黃牛木	Shrub	Very common	n	Moderate
Croton crassifolius	雞骨香	Shrub	Common	n	Moderate
Ficus hirta	粗葉榕	Shrub	Common	n	Moderate
Ficus hispida	對葉榕	Tree	Common	n	Moderate
Ficus microcarpa	細葉榕	Tree	Very common	n	Shallow to Moderate (560 mm depth)(2)
Ficus variolosa	白肉榕	Shrub	Common	n	Uncertain
Gardenia jasminoides	白樿	Shrub	Common	n	Shallow to Moderate (range: 450 to 700 mm)(2)
Glenichenia cantonensis	粵裏白	Herb	Restricted	n	Shallow
Glochidion eriocarpum	毛果算盤子	Shrub	Common	n	Moderate
Glochidion lanceolarium	艾膠算盤子	Shrub	Common	n	Moderate
Glochidion zeylanicum	香港算盤子	Shrub	Common	n	Moderate
Gordonia axillaris	大頭茶	Tree	Common	n	Shallow
Ilex asprella	梅葉冬青	Shrub	Very common	n	Moderate
Itea chinesis	鼠刺	Shrub or Small Tree	Common	n	Moderate
Lespedeza formosa	美麗胡枝子	Shrub	Common	n	Uncertain
Liquidambar formosana	楓樹	Tree	Very common	n	Deep
Litsea cubeba	山蒼樹	Tree	Common	n	Moderate
Litsea glutinosa	潺槁樹	Shrub	Very common	n	Uncertain
Litsea rotundifolia	豺皮樟	Shrub	Very common	n	Moderate

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Table 2 - Preliminary Selection of Vegetation Species for Soil Bioengineering (Sheet 2 of 2)

Species	Chinese Name	Form	Status native (n), naturalized (nz) or exotic (e)		Comparative Rooting Depths[(1)]
Macaranga tanarius	血桐	Tree	Very common	n	Moderate
Machilus breviflora	短花楠	Tree	Common	n	Moderate
Machilus checkiangensis	浙江潤楠	Tree	Common	n	Moderate
Mallotus paniculatus	白楸	Tree	Very common	n	Moderate
Melastoma candidum	野牡丹	Shrub	Common	n	Shallow
Melastoma sanguineum	山棯	Shrub	Common	n	Moderate
Melia azedarach	苦楝	Tree	Introduced, common	e	Deep
Melicope ptelefolia	三椏苦	Shrub	Common	n	Moderate
Phyllanthus cochinchinensis	越南葉下珠	Shrub	Very common	n	Moderate
Phyllanthus emblica	油柑子	Shrub	Very common	n	Deep (1000 mm depth) [(2)]
Psychotria rubra	山大都	Shrub	Common	n	Moderate
Raphiolepis indica	車輪梅	Shrub	Common	n	Shallow to Moderate (range: 400 to 650 mm depth) [(2)]
Rhamnus crenata	長葉凍綠	Shrub	Common	n	Moderate
Rhodomyrtus tomentosa	崗棯	Shrub	Very common	n	Moderate
Rhus chinensis	鹽膚木	Shrub	Very common	n	Moderate
Rhus succedanea	野漆	Tree	Very common	n	Moderate
Sapium discolor	山烏桕	Tree	Very common	n	Moderate
Sarcandra glabra	草珊瑚	Shrub	Very common	n	Shallow
Schefflera octophylla	鴨腳木	Tree	Very common	n	Shallow to Moderate (range: 300 to 700 mm) [(2)]
Schima superba	木柯	Tree	Common	n	Moderate
Sterculia lancealata	假蘋婆	Tree	Common	n	Moderate
Syzygium buxifolium	赤楠	Shrub or Small Tree	Common	n	Moderate
Syzygium jambos	蒲桃	Tree	Introduced, common	e	Deep
Zanthoxylum avicennae	勒欓	Shrub	Common	n	Moderate

Notes: (1) The classes of rooting depths are defined as:
(a) Shallow - not exceeding 600 mm depth;
(b) Moderate - exceeding 600 mm depth but not exceeding 900 mm;
(c) Deep - exceeding 900 mm depth.
(2) The estimated rooting depths were determined under the Root Investigation of the Field Trials in 2005.

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Table 3 - Harvested Live Branch Cuttings for Soil Bioengineering Field Trials

Species	Chinese Name	Form	Status native (n), or exotic (e)		Comparative Performance[1]
Acacia confusa	台灣相思	Tree	Common	e	Poor
Baeckea frutescens	崗松	Herb	Very Common	n	Poor
Duranta erecta	假連翹	Shrub	Common	e	Fair
Ficus microcarpa	細葉榕	Tree	Very Common	n	Moderate
Gardenia jasminoides	白樿	Shrub	Common	n	Moderate
Ilex asprella	梅葉冬青	Shrub	Very Common	n	Poor
Lophostemon confertus	紅膠木	Tree	Common	e	Poor
Macaranga tanarius	血桐	Tree	Very common	n	Fair
Melastoma candidum	野牡丹	Shrub	Common	n	Moderate
Melastoma sanquineum	山棯	Shrub	Common	n	Poor
Phyllanthus emblica	油柑子	Shrub	Very Common	n	Poor
Raphiolepis indica	車輪梅	Shrub	Common	n	Poor
Rhodomyrtus tomentosa	崗棯	Shrub	Very common	n	Poor
Salix babylomica	柳	Tree	Common	n[2]	Moderate
Sterculia lanceolata	假蘋婆	Tree	Common	n	Poor
Schefflera octophylla	鴨腳木	Tree	Very common	n	Poor

Notes:
(1) The comparative performance of the species is referred to report "Performance Assessment of Vegetation at the Pilot Sites in the Main Phase" (MGS, 2006a) and defined as follows:
- (a) Excellent - average species survival rate exceeding 80%;
- (b) Good - average species survival rate higher than 50% but not exceeding 80%;
- (c) Moderate - average species survival rate higher than 30% but not exceeding 50%;
- (d) Fair - average species survival rate higher than 10% but not exceeding 30%;
- (e) Poor - average species survival rate not exceeding 10%.

(2) *Salix babylomica* is very common and a native species in Guangdong.

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Table 4 - Container Nursery Plants for Soil Bioengineering Field Trials

Species	Chinese Name	Form	Status native (n), or exotic (e)		Comparative Performance[1]
Acacia confusa	台灣相思	Tree	Common	e	Excellent
Cratoxylum cochinchinensis	黃牛木	Tree	Common	n	Excellent
Duranta erecta	假連翹	Shrub	Common	e	Excellent
Ficus microcarpa	細葉榕	Tree	Very Common	n	Excellent
Gardenia jasminoides	白樿	Shrub	Common	n	Excellent
Gordonia axillaris	大頭茶	Tree	Common	n	Excellent
Lophostemon confertus	紅膠木	Tree	Common	e	Excellent
Melastoma candidum	野牡丹	Shrub	Common	n	Moderate
Machilus chekiangensis	浙江潤楠	Tree	Common	n	Excellent
Melastoma sanquineum	山棯	Shrub	Common	n	Moderate
Phyllanthus emblica	油柑子	Shrub	Very Common	n	Good
Raphiolepis indica	車輪梅	Shrub	Common	n	Excellent
Rhodomyrtus tomentosa	崗棯	Shrub	Very Common	n	Excellent
Sterculia lanceolata	假蘋婆	Tree	Common	n	Excellent
Schefflera octophylla	鴨腳木	Tree	Very Common	n	Good
Schima superba	木柯	Tree	Common	n	Excellent

Notes: (1) The comparative performance of the species is referred to report "Performance Assessment of Vegetation at the Pilot Sites in the Main Phase" (MGS, 2006a) and defined as follows:

(a) Excellent - average species survival rate exceeding 80%;
(b) Good - average species survival rate higher than 50% but not exceeding 80%;
(c) Moderate - average species survival rate higher than 30% but not exceeding 50%;
(d) Fair - average species survival rate higher than 10% but not exceeding 30%;
(e) Poor - average species survival rate not exceeding 10%.

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Table 5 -Light Standard Trees and Bamboo for Live Barriers for Field Trials

Species	Chinese Name	Form	Status native (n), or exotic (e)		Comparative Performance[1]
Bambusa textilis	青皮竹	Bamboo	Very Common	n	Excellent
Acacia auriculiformis	耳果相思	Light standard tree	Common	n	Good
Ficus microcarpa	細葉榕	Light standard tree	Very Common	n	Excellent
Schima superba	木柯	Light standard tree	Common	n	Good
Schefflera octophylla	鴨腳木	Light standard tree	Common	n	Good

Notes: (1) The comparative performance of the species is referred to report "Performance Assessment of Vegetation at the Pilot Sites in the Main Phase" (MGS, 2006a) and defined as follows:

(a) Excellent - average species survival rate exceeding 80%;
(b) Good - average species survival rate higher than 50% but not exceeding 80%;
(c) Moderate - average species survival rate higher than 30% but not exceeding 50%;
(d) Fair - average species survival rate higher than 10% but not exceeding 30%;
(e) Poor - average species survival rate not exceeding 10%.

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Table 6 - Recommended Plants Species for Soil Bioengineering

Species	Chinese Name	Form	Status native (n), or exotic (e)		Live Branch Cutting/Pit Planting
Acacia confusa	台灣相思	Tree	Common	e	Pit Planting
Cratoxylum cochinchinensis	黃牛木	Tree	Common	n	Pit Planting
Duranta erecta	假連翹	Shrub	Common	e	Pit Planting
Ficus microcarpa	細葉榕	Tree	Very Common	n	Live Branch Cutting &Pit Planting
Gardenia jasminoides	白樿	Shrub	Common	n	Live Branch Cuttings & Pit Planting
Gordonia axillaris	大頭茶	Tree	Common	n	Pit Planting
Lophostemon confertus	紅膠木	Tree	Common	e	Pit Planting
Melastoma candidum	野牡丹	Shrub	Common	n	Live Branch Cutting and Pit Planting
Machilus chekiangensis	浙江潤楠	Tree	Common	n	Pit Planting
Melastoma sanquineum	山棯	Shrub	Common	n	Pit Planting
Phyllanthus emblica	油柑子	Shrub	Very Common	n	Pit Planting
Raphiolepis indica	車輪梅	Shrub	Common	n	Pit Planting
Rhodomyrtus tomentosa	崗棯	Shrub	Very Common	n	Pit Planting
Salix babylomica	柳	Tree	Common	n	Live Branch Cutting
Sterculia lanceolata	假蘋婆	Tree	Common	n	Pit Planting
Schefflera octophylla	鴨腳木	Tree	Very Common	n	Pit Planting
Schima superba	木柯	Tree	Common	n	Pit Planting

Notes: (1) The above recommendation list is based on the performance results given in Tables 3 and 4.

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Table 7 - Summary of Species Selected for the Root Investigation

	Plant-ID	Species	Status native (n) or exotic (e)	Nature	Stem System: Dia. measured 0.15m above ground surface	Stem System: Dia. measured 1m above ground surface	Stem System: Top Growth Condition	Root System: Max. Root Depth	Root System: Left Extent	Root System: Right Extent	Root System: Overall Cross Section	Root System: Range of Root Diameters	Root System: Root Growth Condition
Selected plants from the trial sites	1	*Ficus microcarpa*	n	Live stake	25 mm	nil	Healthy, vigorous	120 mm	0.98 m	1.39 m	2.37 m	1.5 mm to 5.5 mm	Health, vigorous and fibeous
	2	*Ficus microcarpa*	n	Live stake	33.8 mm	nil	Healthy, vigorous	200 mm	0.47 m	0.9 m	1.37 m	1.0 mm to 3.0 mm	Health, vigorous and fibrous
	3	*Ficus microcarpa*	n	Direct planting	12.5 mm	3.0 mm	Healthy, vigorous, sparse foliage. No infection	560 mm	0.3 m	0.67 m	0.97 m	2.0 mm to 6.4 mm	Health, vigorous
	4	*Melastoma sanguineum*	n	Hedgelayer	32.7 mm	6.7 mm	Good, dense foliage, no sign of infection, fruiting	660 mm	0.9 m	0.88 m	1.78 m	4.6 mm to 13.6 mm	Good, adventitious root enlarge to serve other function
	5	*Gardenia jasminoides*	n	Branchpacking	5.7 mm	nil	Fair, sparse foliage, leaves damaged by pest	250 mm	0.25 m	0.27 m	0.52 m	1.5 mm to 2.0 mm	Good, multi adventitious generated from node
	6	*Gardenia jasminoides*	n	Brushlayer	8.5 mm	nil	Fair, sparse foliage, leaves damaged by pest	150 mm	0.38 m	0.28 m	0.66 m	1.0 mm to 3.0 mm	Good, multi adventitious generated from node
	7	*Schefflera octophylla*	n	Direct planting	18.7 mm	1.05 mm	Healthy, vigorous, dense foliage, no sign of infection	500 mm	1.0 m	0.9 m	1.9 m	3.0 mm to 10.3 mm	Healthy, vigorous with circling root
	8	*Schefflera octophylla*	n	Direct planting	37 mm	12.2 mm	Healthy, vigorous, dense foliage, no sign of infection	700 mm	0.78 m	1.8 m	2.58 m	6.6 mm to 21.5 mm	Healthy, vigorous with circling root
	9	*Acacia confusa*	e	Direct planting	29.5 mm	12.0 mm	Healthy, vigorous, dense foliage, leaves damaged by pest	750 mm	1.88 m	1.58 m	3.46 m	9.6 mm to 16.2 mm	Healthy, vigorous and fibrous
	10	*Phyllanthus emblica*	n	Hedgelayer	24.9 mm	3.6 mm	fair, deciduous, leaves falling, no sign of infection	1000 mm	1.78 m	1.48 m	3.26 m	4.5 mm to 23.1 mm	Healthy, vigorous and fibrous
Selected plants from the surrounding natural terrain	11	*Gardenia jasminoides*	n	Existing Shrub	12.3 mm	3.3 mm	Healthy, vigorous, sparse foliage, no sign of infection	700 mm	0.55 m	0.64 m	1.19 m	2.2 mm to 8.7 mm	Healthy, vigorous
	12	*Gardenia jasminoides*	n	Existng Shrub	25 mm	13 mm	bark damaged, dense foliage, fruit infected by pest	450 mm	1.06 m	1.07 m	2.13 m	2 mm to 10.5 mm	Fair, in contact with rock, tap choked by heart root
	13	*Machilus checkiangensis*	n	Existing Tree	70 mm	35 mm	Healthy, vigorous, dense foliage, no sign of infection	100 mm	3.35 m	2.06 m	5.41 m	13 mm to 33.8 mm	Healthy, vigorous, cross root found
	14	*Raphiolepis indica*	n	Existing Shrub or Small Tree	25 mm	15.8 mm	Fair, sparse foliage, no sign of infection	400 mm	1.1 m	0.62 m	1.72 m	3.25 mm to 24.4 mm	Fair, in contact with rocks
	15	*Raphiolepis indica*	n	Existing Shrub or Small Tree	23.5 mm	15.8 mm	Fair, sparse foliage, no sign of infection	650 mm	1.31 m	1.4 m	2.71 m	1.43 mm to 17 mm	Fair, root collar sitting on boulder, Cicadas larva found
	16	*Schefflera octophylla*	n	Existing Tree	65 mm	40 mm	Healthy, vigorous, dense foliage, no sign of infection	300 mm	1.7 m	1.4 m	3.1 m	20 mm to 46 mm	Healthy, vigorous, grub found
	17	*Schefflera octophylla*	n	Existing Tree	38 mm	27 mm	Healthy, vigorous, dense foliage, no sign of infection	300 mm	1.13 m	0.9 m	2.03 m	9.3 mm to 17.5 mm	Healthy, vigorous

Notes: (1) The above information is extracted from report “Root Investigation Study Report” (MGS, 2006b).

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Table 8 - Recommended Plants Species for Different Types of Soil Bioengineering Measures

Soil Bioengineering Measures	Form	Recommended Plants Species
Live stakes	Live branch cutting	*Ficus* microcarpa, *Salix babylomica*
Live fascines		*Ficus microcarpa, Gardenia jasminoides*
Pole drains		*Ficus microcarpa, Gardenia jasminoides*
Brushlayers		*Gardenia jasminoides, Melastoma candidum*
Branchpacking		*Gardenia jasminoides, Melastoma candidum*
Live gully repairs		*Gardenia jasminoides, Melastoma candidum*
Hedgelayers	Rooted plant	*Duranta erecta, Gardenia jasminoides, Melastoma candidum, Melastoma sanguineum, Phyllanthus emblica, Raphiolepis indica*
Live cribwalls		*Gardenia jasminoides, Melastoma sanquineum, Phyllanthus emblica, Rhodomyrtus tomentosa*
Bender fences and Direct plantings		*Acaia confuse, Cratoxylum cochinchinensis, Duranta erecta, Gordonia axillaris, Lophostemon confertus, Melastoma candidum, Machilus checkiangensis, Melastoma sanquineum, Phyllanthus emblica, Rhodomyrtus tomentosa, Sterculia lancealate, Schefflera octophylla, Schima superba*
Live barriers		*Acacia auriculiformis, Ficus microcarpa, Schima superba, Schefflera octophylla* and *Bambusa textilis*

Notes: (1) The recommendations list is based on the performance assessment result extracted from report “Performance Assessment of Vegetation at the Pilot Sites in the Main Phase” (MGS, 2006a) and the findings extracted from report “Root Investigation Study Report” (MGS, 2006b).

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Table 9 - Suggested Spacing for Installation of Different Type of Soil Bioengineering Measures on Natural Terrain Landslide Scars

Soil Bioengineering Measures	Slope Steepness (horizontal:vertical)	Distance between Trenches (mm)	
		Along Contour	On Incline
Live Fascines	1:1 to 1.5:1	1000 - 1250	600 - 1000
	1.5:1 to 2:1	1250 - 1750	1000 - 1500
	2:1 to 2.5:1	1500 - 2000	1250 - 1750
	2.5:1 to 3:1	1750 - 2750	1500 - 2000
	3:1 to 4:1	2500 - 3000	1750 - 2500
	4:1 to 5:1	2750 - 3750	2000 - 2750
Brushlayers	1:5 to 2:1	1250 - 1500	-
	2:1 to 2.5:1	1500 - 1750	-
	2.5:1 to 3:1	1750 - 2500	-
	3:1 to 4:1	2000 - 3000	-
Hedgelayers	1:5 to 2:1	1250 - 1500	-
	2:1 to 2.5:1	1500 - 1750	-
	2.5:1 to 3:1	1750 - 2500	-
	3:1 to 4:1	2000 - 3000	-

Notes: (1) The above are extracted from Sotir & Gray (1992).

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Table 10 - Selection Criteria on Mulch and Erosion Control Material

Material	Selection Criteria	Material	Selection Criteria
Degradable erosion control mats	• Coir geotextile type mat of minimum 500g/m^2 • At least 70 weft threads per linear metre and a corresponding greater density of warp threads. • The open area of the fabric should be at least 50%. • The tensile strength per linear metre should be 0.50 kN/m dry, in warp and 0.24 kN/m in weft, and 0.38 kN/m wet, in warp and 0.18 kN/m in weft.	Long straw mulch	• Comprise long natural straw stems ranging from between 100 mm and 1000 mm in length.

Table 11 - Evaluation Criteria of Overall Leaf Development for Healthy Growing Soil Bioengineering Measures

Soil Bioengineering Measures	Range of Evaluation Criteria of Overall Leaf Development(1)
Live stake	40% - 60%
Live fascine	20% - 30%
Pole drain	20% - 40%
Brushlayer	30% - 50%
Branchpacking	10% - 30%
Live gully repair	20% - 30%
Hedgelayer	40% - 60%
Bender fence	70% - 80%
Live cribwall	40% - 70%
Joint planting	30% - 40%
Vegetated Gabion	10% - 30%

Notes:
(1) Percentage of overall leaf development is defined as a percentage of project area of overall leaf development to area of the installed soil bioengineering measures.
(2) The above is extracted from Sotir & Gray (1992).
(3) Tension crack repair and berm construction are in form of live stakes, i.e. the criteria is same as that of live stakes.

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Table 12 - Suitability of Different Soil Bioengineering Measures for Slopes Based on Soil and Site Conditions

Factor or Failure Process	Intensity or Type of Condition	Soil Bioengineering Measure									
		Live Stakes	Live Fascines/ Pole Drains	Bender Fences	Live Gully Repair	Brush-layers	Hedge-layers	Branch-packing	Live Crib-walls	Joint Plant-ing	Veg Gabions
Slope Gradient	Steep		•		•			•	•		•
	Moderate	•	•	•	•	•	•	•	•	•	•
	Gentle	•	•	•	n/a	n/a	n/a	n/a	•	•	•
Slope Height	High	•	•		•	•	•				
	Low	•	•	•		•	•	•	•	•	•
Soil Depth	Deep	•	•		•	•	•	•	n/a	•	n/a
	Moderate	•	•	•	•	•	•	•	n/a	•	n/a
	Shallow		•	•	•						
Soil Permeability	High					•		•	n/a	n/a	n/a
	Moderate	•	•	•	•	•	•	•	n/a	n/a	n/a
	Low	•	•	•	•	•	•	•	n/a	n/a	n/a
Soil Erodibility	High		•		•	•			n/a	•	n/a
	Moderate		•	•	•	•	•	•	n/a	•	n/a
	Low	•	•	•	•		•	•	n/a		n/a
Soil Strength	Moderate	•	•	•	•	•	•	n/a	n/a	•	n/a
	Low	n/a		•		•	•	n/a	n/a		n/a
Moisture	Sub-surface	•	•		•	•	•	•	•	•	•
	Surface		•	•	•	•	•				
Surficial Erosion	-	•	•	•	•	•	•			•	
Mass Movement	Shallow	•	•	•		•	•	•	•	•	•
	Moderate					•		•	•	•	•

Legend:

• Recommended soil bioengineering measures
n/a Not applicable

Notes:
(1) The above is extracted from Gray & Sotir (1996).
(2) Tension crack repair and berm construction are modified soil bioengineering measures in form of live stake and pole drain respectively.

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Table 13 - Relative Order of Cost for Construction and Maintenance of Soil Bioengineering Measures in Hong Kong

Measure	Construction Costs	Maintenance Costs
Live Stakes	Very Low to Low	Low
Live Fascines/Pole Drains	Low to Moderate	Low
Bender Fences	Moderate	Moderate
Brushlayers	Moderate	Low
Hedgelayers	Moderate	Low to Moderate
Branchpacking	Moderate to High	Low
Live Gully Repairs	Moderate	Low
Live Cribwalls	High	Low to Moderate
Vegetated Gabions	High	Moderate
Joint Planting	Low to Moderate	Low

Notes: (1) The above is extracted from Gray & Sotir (1996).
(2) Tension crack repair and berm construction are modified soil bioengineering measures in form of live stake and pole drain respectively.

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Table 14 - Suggested Effectiveness of Soil Bioengineering Measures

Measure	Excavation	Specific Problem Types	Comments & Restrictions
Live Stakes	No	Shallow surface erosion	Small, simple erosion problems - used with other systems including erosion control mats
Live Fascines/ Pole Drains	Yes	Shallow surface erosion, gullies, subsurface & surface runoff	Moderate to severe shallow erosion, gullies; & drainage feature. Mixed rock & soil
Bender Fences	Yes/No	Shallow surface erosion	Low to moderate shall are erosion on gentle to moderate slopes 2 - 3 H to V or flatter
Branchpacking	Yes/No	Local slump; gullies formed by	Repair of small gully sites
Brushlayers	Yes	Shallow failures and surface erosion	Moderate 300 - 600 mm deep
Live Gully Repairs	Yes/No	Rills	Repair of small to large rill sites
Hedgelayers	Yes	Shallow failures and surface erosion	Moderate 150 to 300 mm deep Over time retains slope wash materials
Live Cribwalls	Yes (toe)	Local slump; toe	Provides immediate resistance to sliding, erosion & washouts & requires gravity type wall
Vegetated Gabions	Yes (toe)	Local slump; toe	Provides immediate resistance to sliding, erosion & washouts & requires gravity type wall
Joint Planting	No	Toe erosion or shallow slope failure	Gentle to moderate slopes 2 -3 H to 1V or flatter.

Notes:
(1) The above is extracted from Sotir (1999).
(2) Tension crack repair and berm construction are modified soil bioengineering measures in form of live stake and pole drain respectively.

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Table 15 - Environmental and Aesthetic Slope Enhancement Evaluation of Soil Bioengineering Measures

Soil Bioengineering Measures	Enhancements				
	Surface Cover / Canopy	Natural Colonization	Faunal Habitat	Litter Layer Development	Aesthetic(1)
Live Stakes	Fair to very good(2)	Good to very good	Fair to good	Fair to very good	Good to very good
Live Fascines	Good to very good	Good to excellent	Good to very good	Good to very good	Good to very good
Bender Fences	Good	Good to very good	Good	Fair to very good	Good
Brushlayers	Good to excellent	Good to excellent	Good to excellent	Good to excellent	Good to excellent
Hedgelayers	Good to excellent	Good to excellent	Good to excellent	Good to excellent	Very good to excellent
Branchpacking	Negligible	Fair	Negligible to fair	Negligible to fair	Fair to good
Live Gully Repair	Negligible	Fair	Negligible to fair	Negligible to fair	Fair to good
Live Cribwalls	Negligible	Fair	Fair	n/a(3)	Good to very good
Vegetated Gabions	Negligible	Fair	Fair	n/a(2)	Good to excellent
Joint Planting	Fair to good	Fair to good	Fair to good	Fair	Good to excellent

Notes:
(1) Visual/Subjective
(2) Develop over time
(3) Not applicable
(4) The above is extracted from Sotir (1999).
(5) Tension crack repair and berm construction are modified soil bioengineering measures in form of live stake and pole drain respectively.
(6) Vegetation to support the system is located, protected and maintained. Over time, all systems, having been constructed entirely for natural materials, are intended to fit into the natural surrounding landscape and mitigate visual impacts.

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Table 16 - Vegetation Re-growth on the Trial Sites

Landslide Site Nos.(1)	Vegetation Re-growth Area	Location	Year of Aerial Photographs					
			2000(2)	2001(3)	2002 (Oct)	2003 (Nov)	2004 (Nov)	2005(4)
CHN-01	Percentage of Re-vegetation (%)	Source	-	5	10	10	0	60
		Trail	-	10	80	95	50	100
CHN-02	Percentage of Re-vegetation (%)	Source	-	5	10	15	0	35(5)
		Trail	-	40	60	65	60	80
CHN-03	Percentage of Re-vegetation (%)	Source	-	5	10	15	5	95
		Trail	-	20	50	65	55	100

Notes:
(1) Landslide sites which were installed with soil bioengineering measures in 2004.
(2) Landslide scars are not visible on February 2000 aerial photographs.
(3) Landslide site CHN-01 and 02 are first observed on February 2001 aerial photographs. Landslide site CHN-03 is first observed on September 2001 aerial photograph.
(4) 2005 aerial photographs are not available yet. The percentages are based on the visual assessment of field inspection.
(5) The vegetation coverage at the source of Landslide Site CHN-02 is less than other sites, since the former is rocky in materials.
(6) List of Aerial Photographs reviewed:

- 16.2.2000 - 20,000' -CN26087-8
- 15.2.2001 - 8,000'- CN29731
- 31.5.2001 - 4,000' - CW31376
- 24.9.2001 - 4,000' - CW33604
- 19.11.2001 - 8,000' - CW35256-7
- 8.10.2002 - 8,000' - CW44573-4
- 1.6.2003 - 4,000' - CW48205
- 25.9.2003 - 8,000' - CW49530-1
- 25.11.2003 - 4,000' - CW53503-4
- 18.11.2004 - 4,000' - CW61316-7

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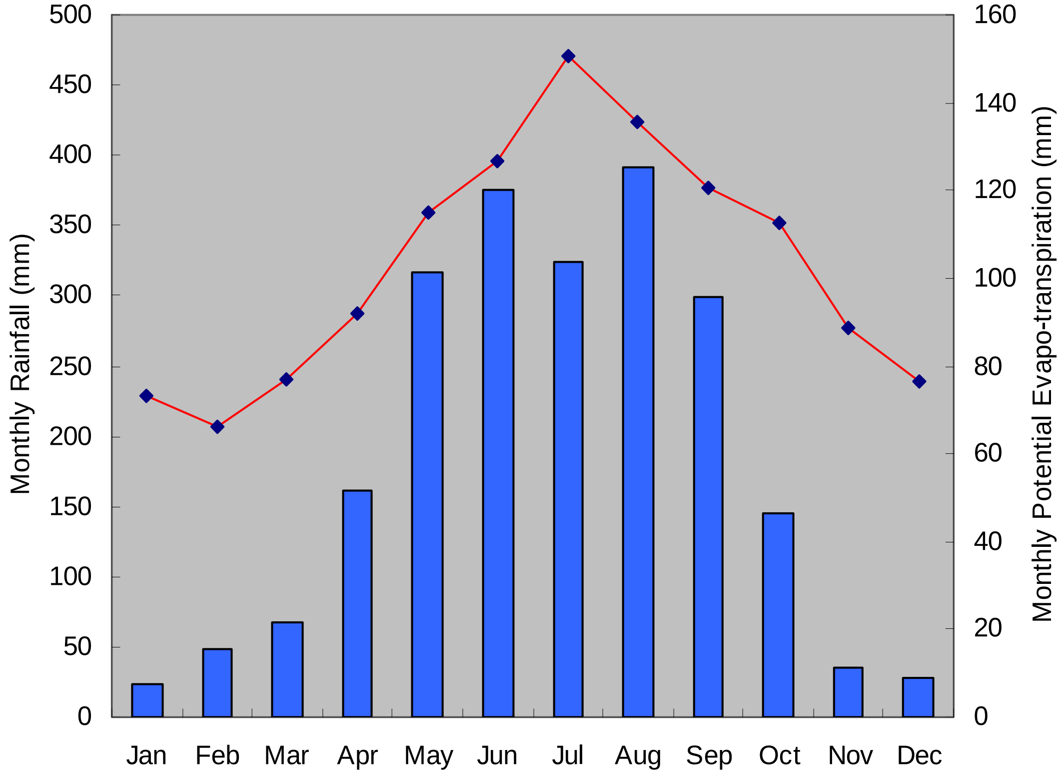

Legend:

Average Monthly Painfall

Average Monthly Potential Evapo-transpiration

Note: The data are the average values between 1961 and 1990 recorded by Hong Kong Observatory.

Figure 1 - Graph of Meteorological Observations in Hong Kong

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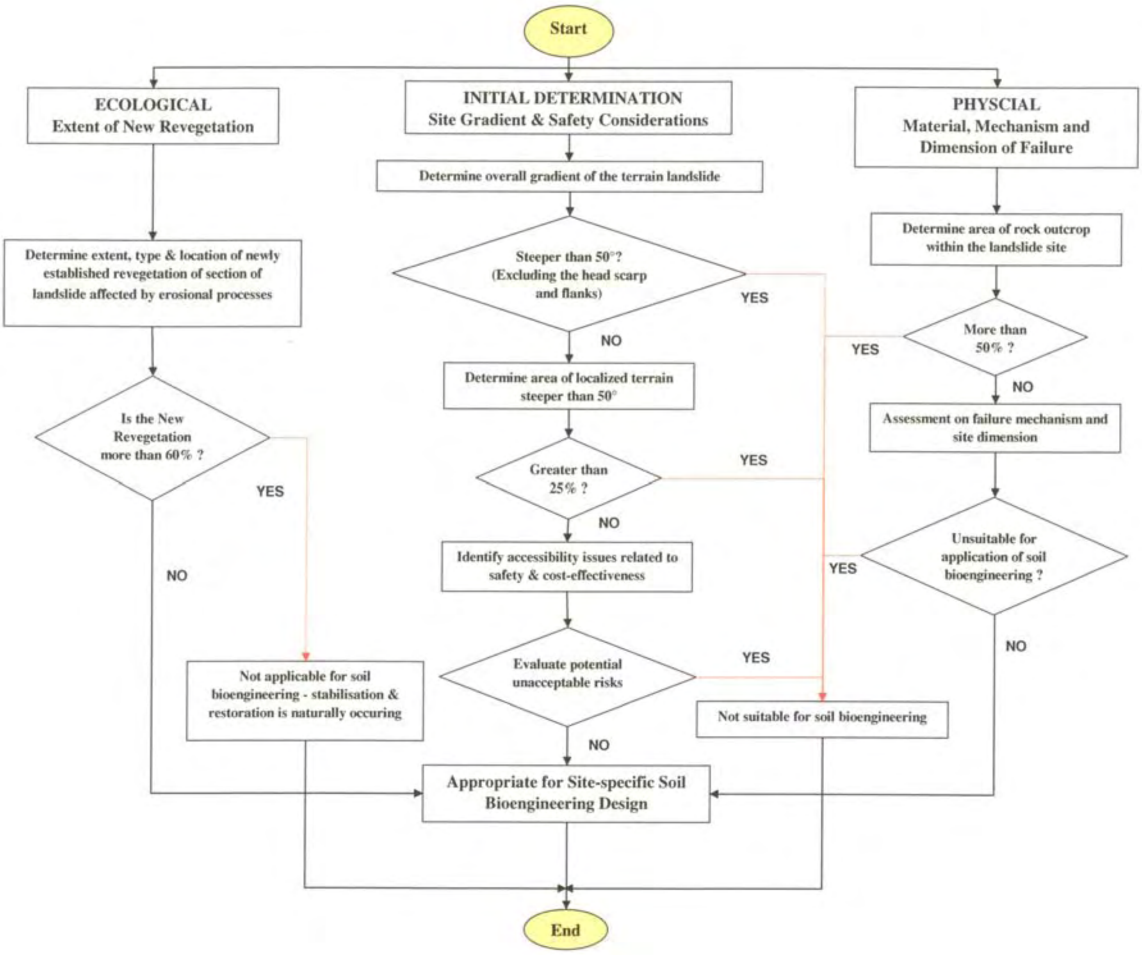
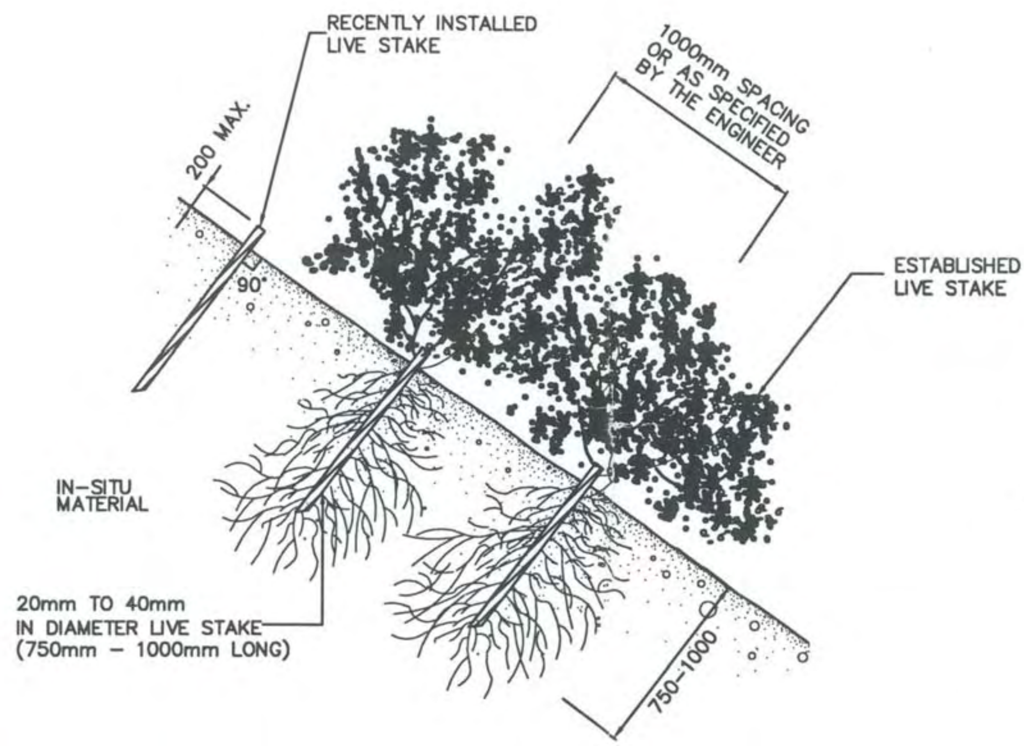


Note: For details of the selection criteria, refer to Section 2.2.1.

Figure 2 - Flow Chart of Preliminary Site Selection Criteria



Notes: (1) Extracted from Sotir (1996).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 3 - Details of Live Stake

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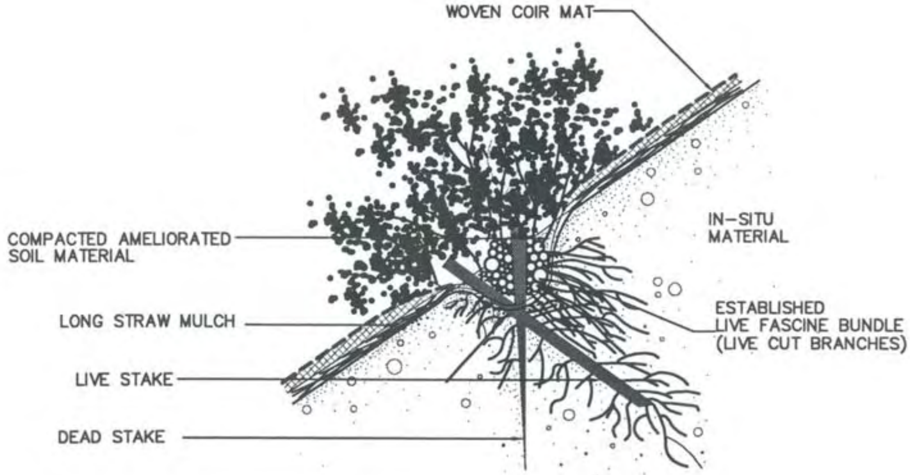
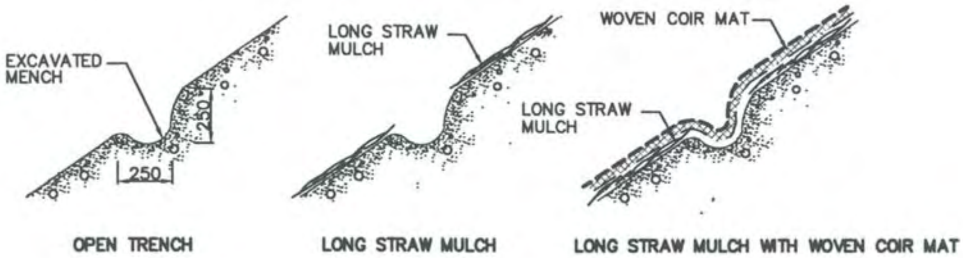
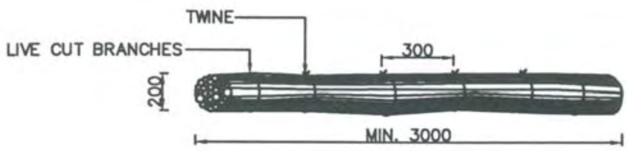


Details of Live Fascine (Cross Section)



Excavation of Live Fascine Trench (Cross Section)



Live Fascine Bundle

Notes: (1) Extracted from Sotir & McCaffrey (1997).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 4 - Details of Live Fascine

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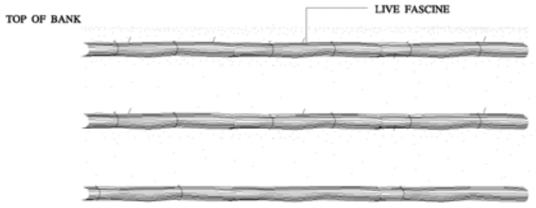
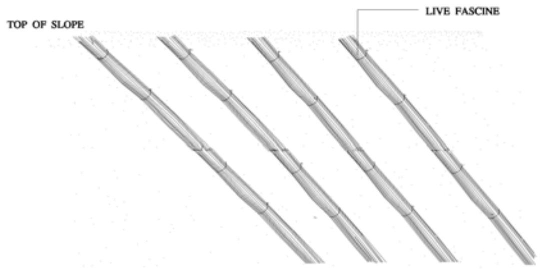
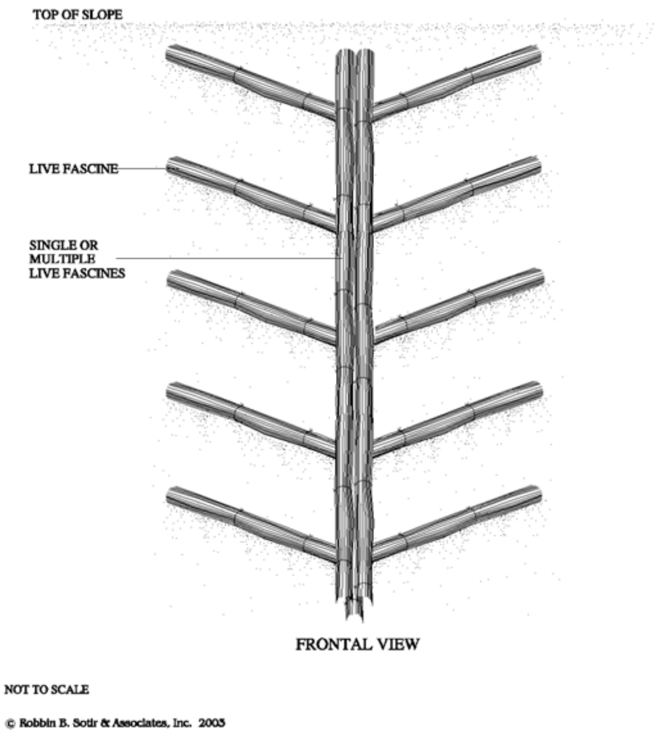


Live Fascine along Contour



Live Fascine on Incline



Herringbone Configuration

Note: Extracted from Sotir & McCaffrey (1997).

Figure 5 - Configuration of Live Fascine

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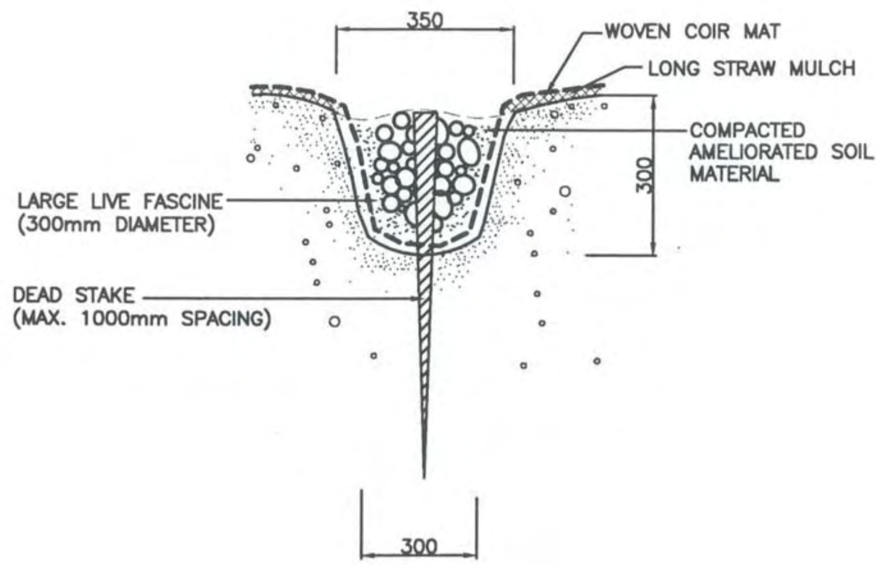
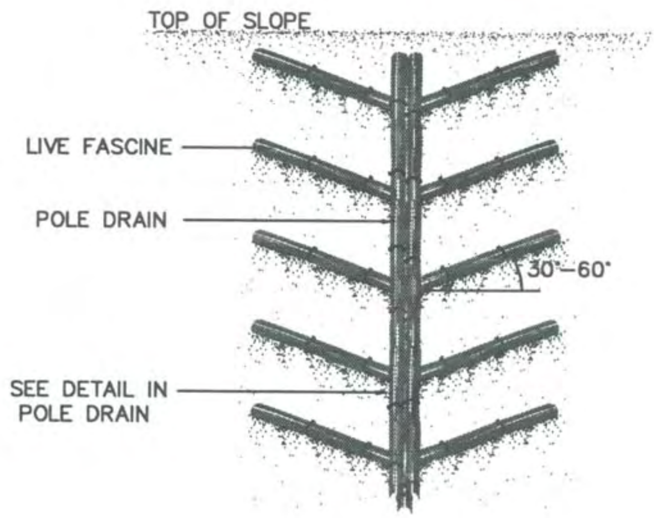


Section of Pole Drain



Herringbone Configuration

Note: Extracted from Sotir (1999).

Figure 6 - Details of Pole Drain

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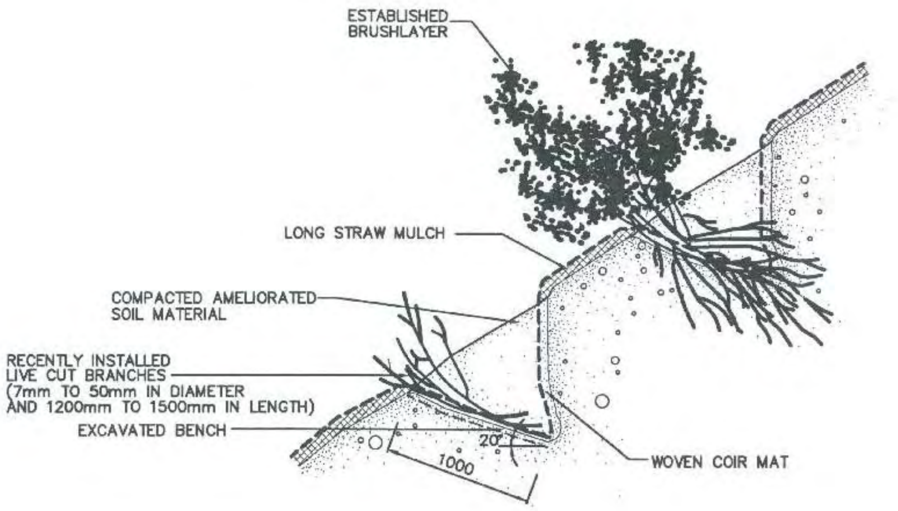
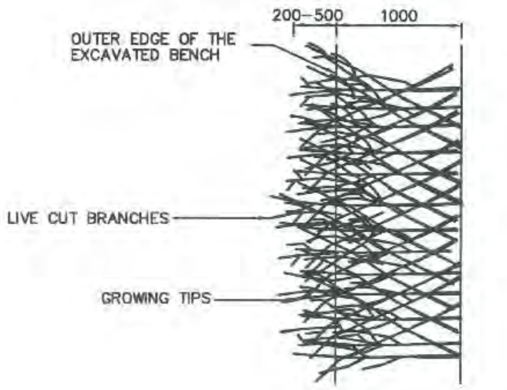


Details of Brushlayer (Cross Section)



Details of Brushlayer (Plan View)

Notes: (1) Extracted from Sotir & McCaffrey (1997).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 7 - Details of Brushlayer

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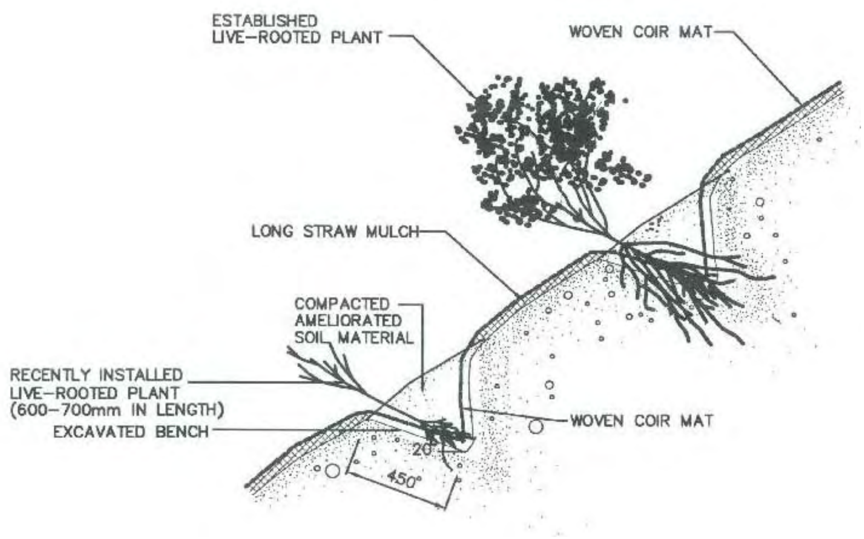
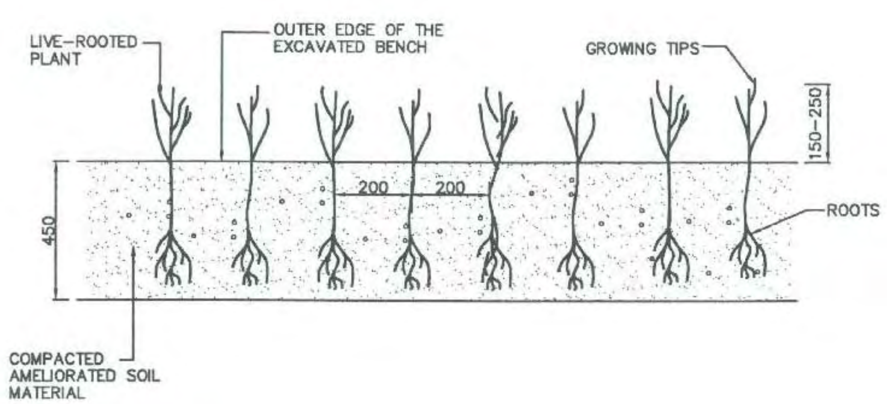


Details of Hedgelayers (Cross Section)



Details of Hedgelayers (Plan View)

Notes: (1) Extracted from Sotir & McCaffrey (1997).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 8 - Details of Hedgelayer

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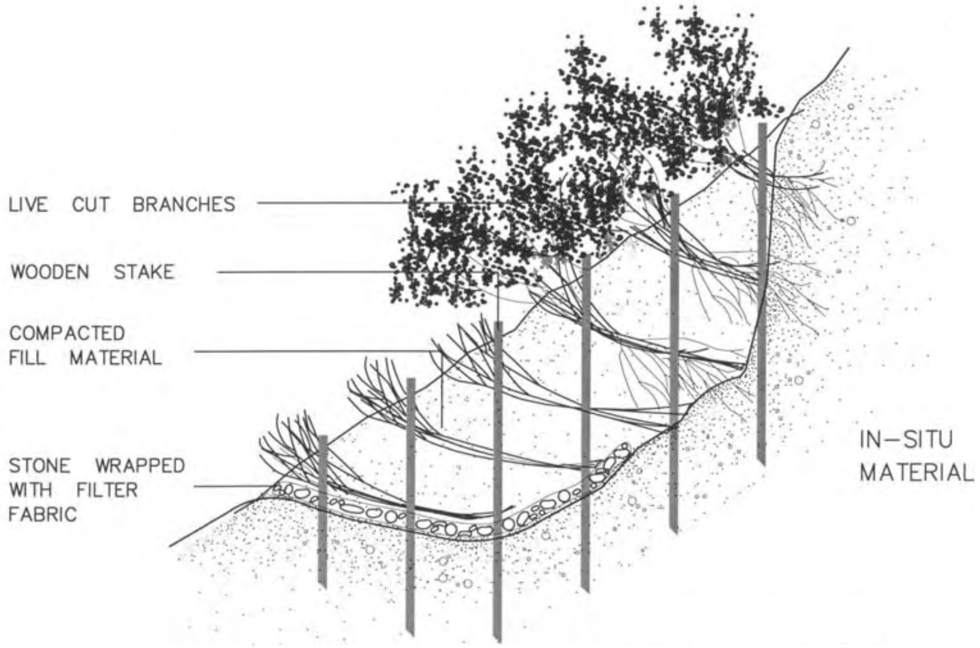
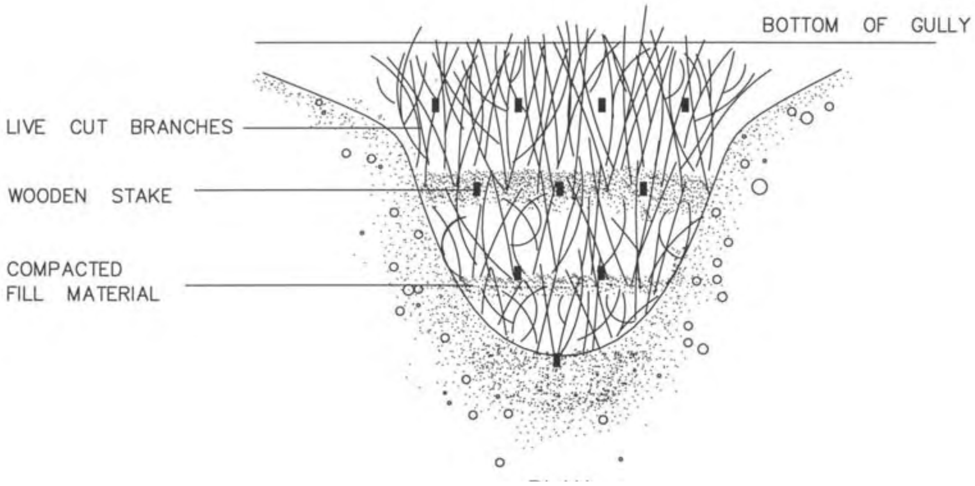


Cross Section



Plan

Notes: (1) Extracted from Sotir & McCaffrey (1997).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 9 - Details of Branchpacking

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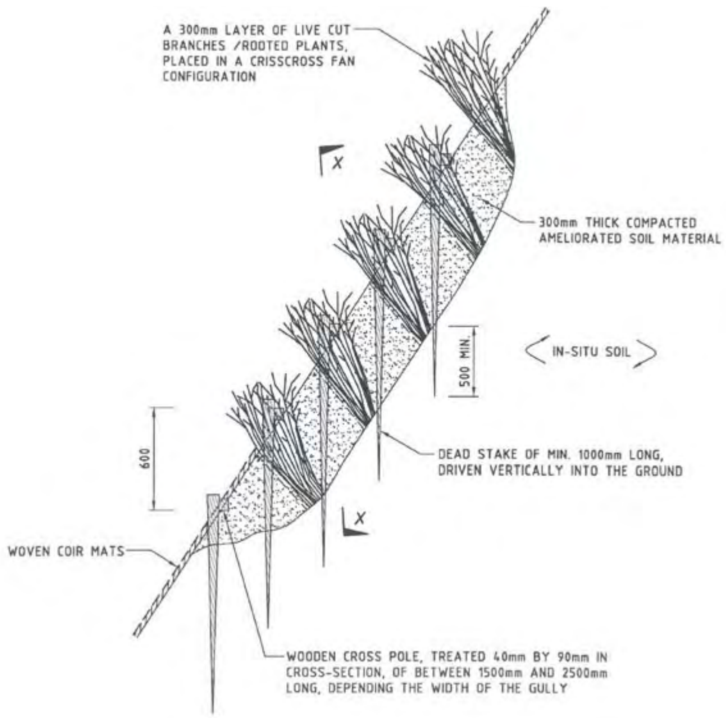
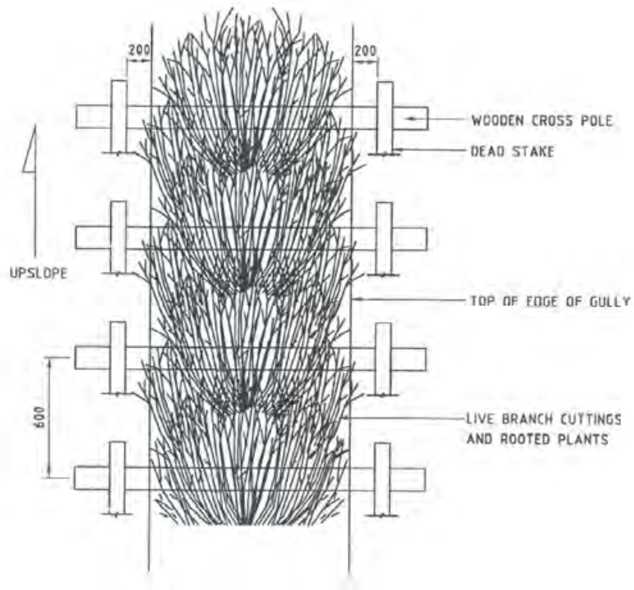


Details of Live Gully Repair



Elevation of Live Gully Repair

Note: Extracted from Schiechtl (1980).

Figure 10 - Details of Live Gully Repair

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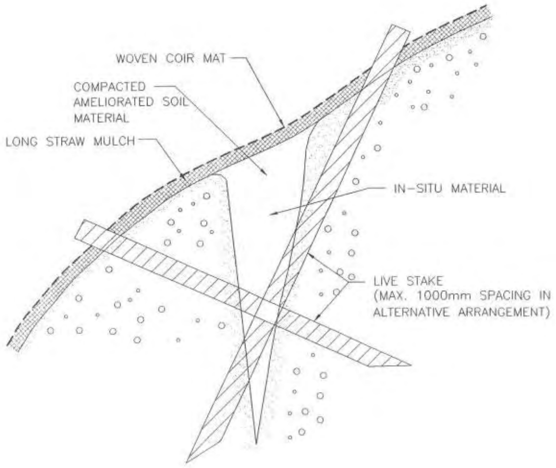
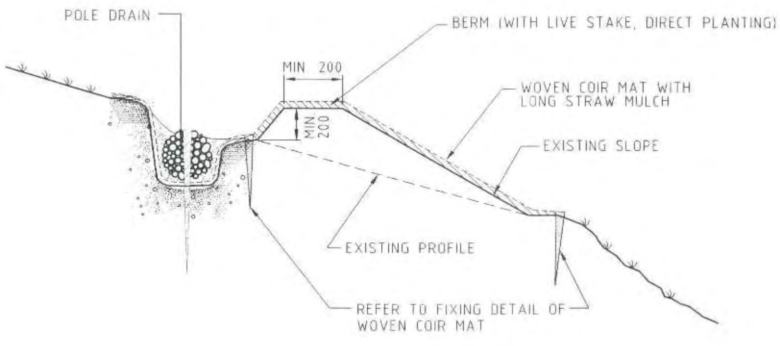


Details of Tension Crack Repair



Details of Berm Construction

Figure 11 - Details of Tension Crack Repair and Berm Construction

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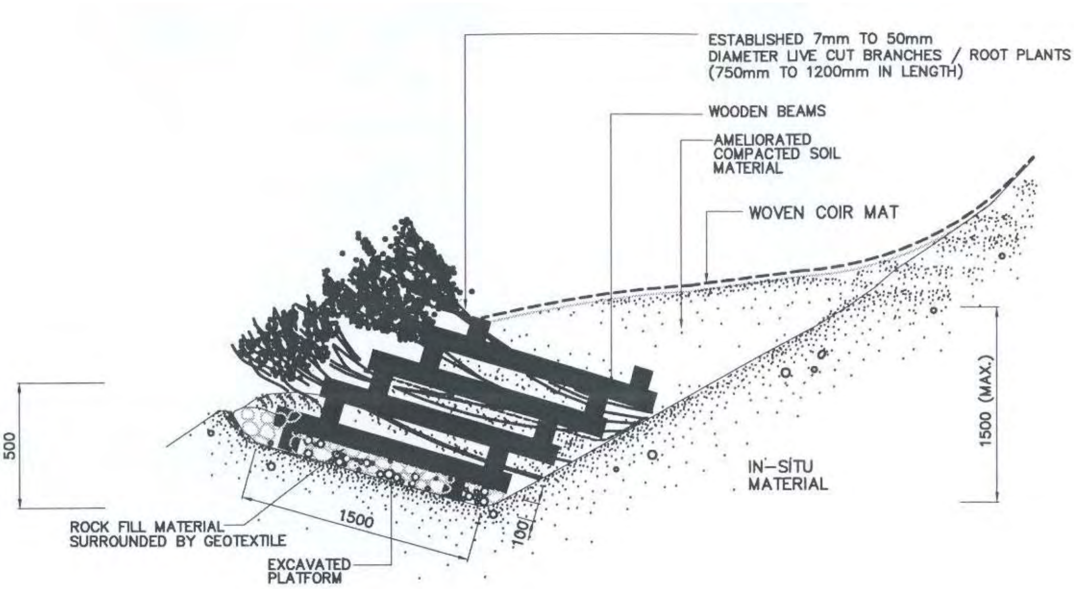
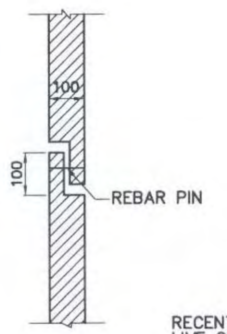
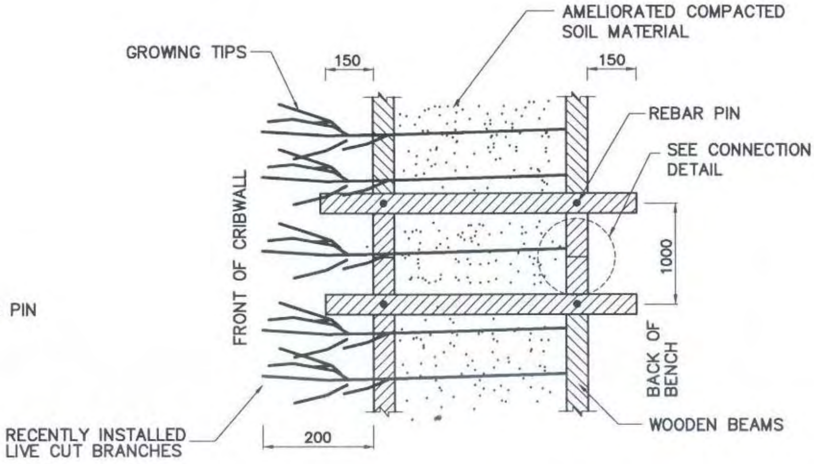


Details of Live Cribwall (Cross Section)





Connection Detail
(Side View)

Details of Live Cribwall
(Plan View)

Notes: (1) Extracted from Sotir (1998).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 12 - Details of Live Cribwalls

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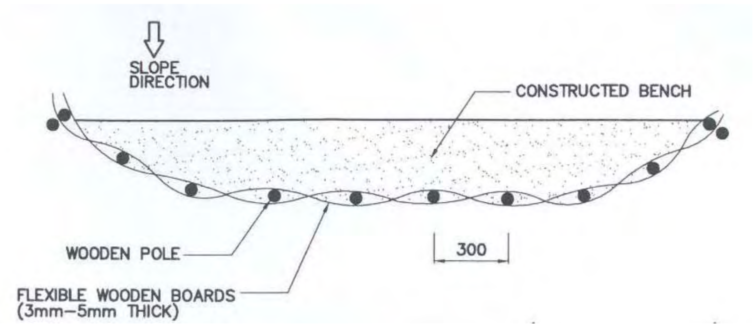
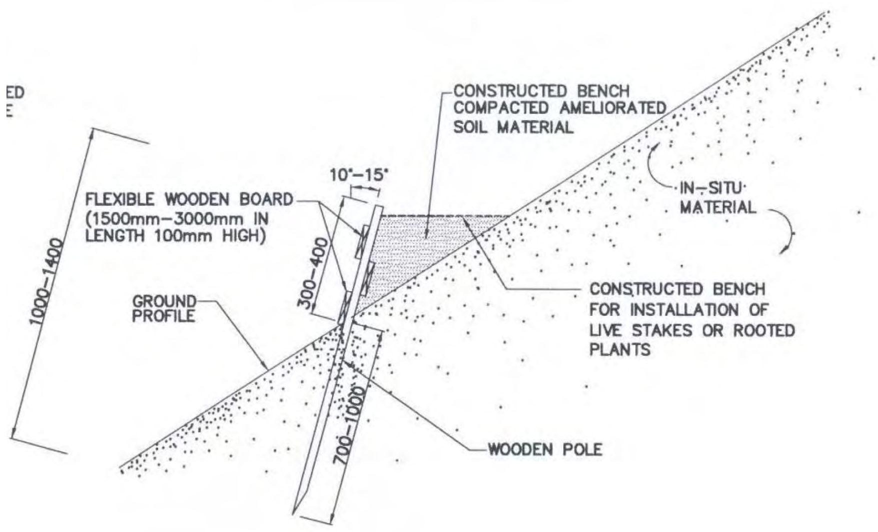
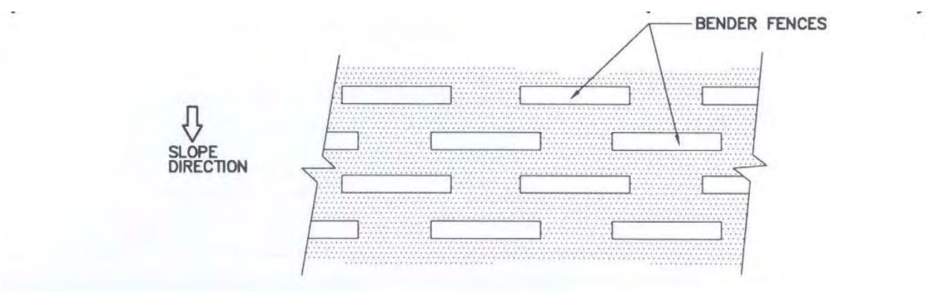


Details of Bender Fence (Plan View)



Details of Bender Fence (Cross Section)



Front Elevation of Standard Bender Fence Layout

Note: Extracted from US Force Service (2000).

Figure 13 - Details of Bender Fences

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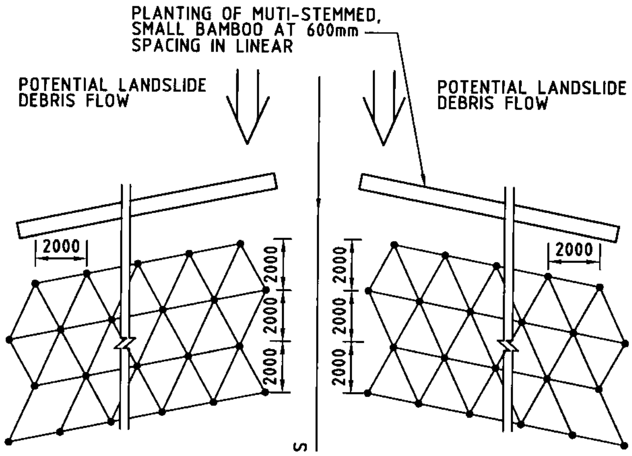
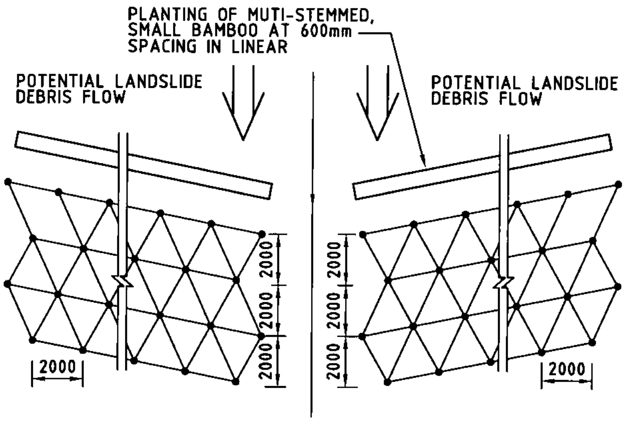
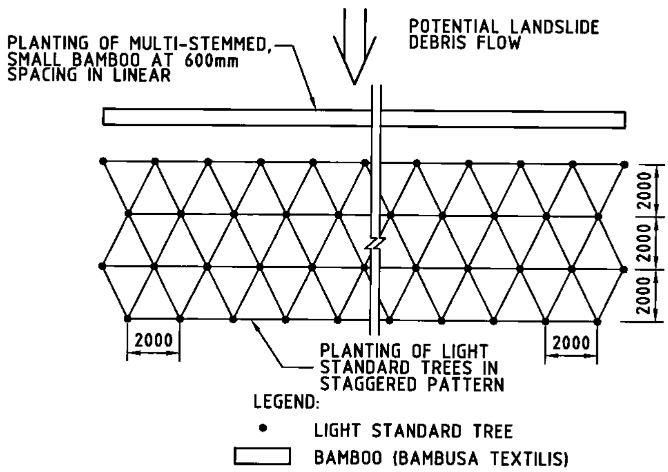


Upslope (Splitting Wedge) V-configuration of Live Barriers



Downslope (Collecting Dam) V-configuration of Live Barriers



Contour Belts Configuration of Live Barriers

Figure 14 - Alternative Configurations for Live Barriers

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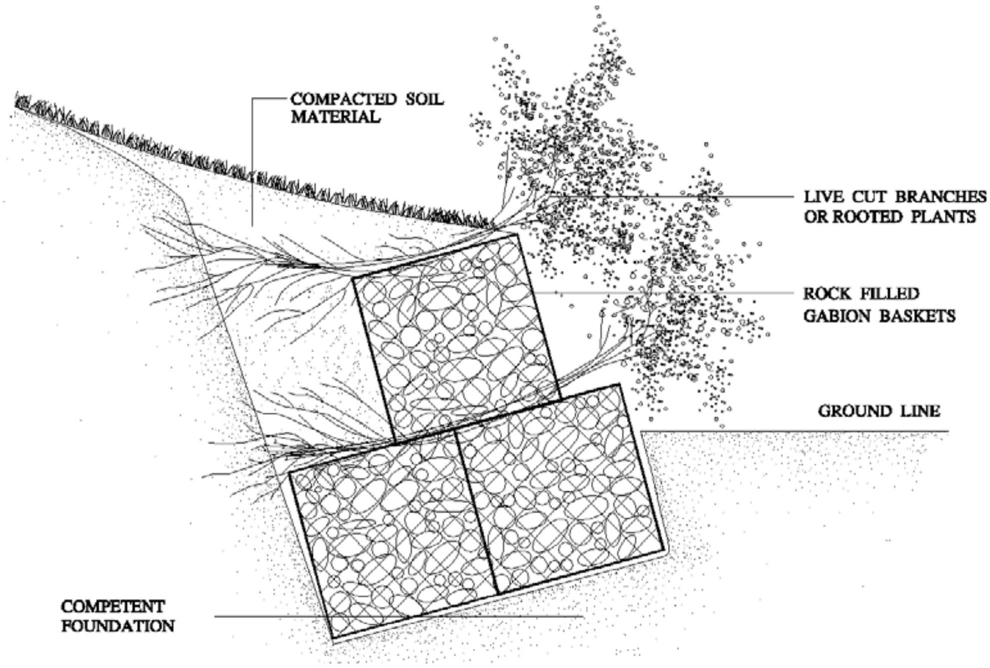
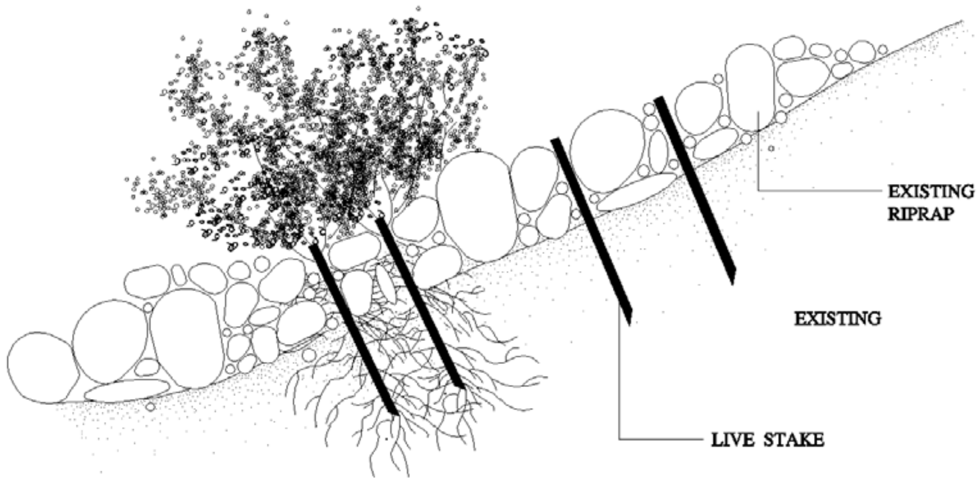


Details of Vegetated Gabion



Details of Joint Planting

Notes: (1) Extracted from Sotir (1998).
(2) Rooted/leafed condition of the plant material is not representative at the time of installation.

Figure 15 - Details of Vegetated Gabions and Joint Planting

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Plate 1 - Live Stakes Soaking in Root Activator Solution (Cloudy Hill)

Plate 2 - Driving a Steel Bar to Ream a Hole for a Live Stake (Cloudy Hill)

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Plate 4 -Installed Live Stake (Cloudy Hill)

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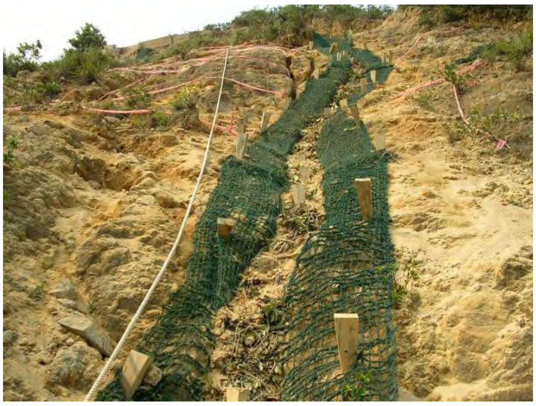

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APPENDIX A

GLOSSARY OF TERMS AND BIBLIOGRAPHY

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A.1 GLOSSARY OF TERMS

Amelioration 改善	The improvement of acidic, or otherwise unsuitable, soils by the addition of soil conditioners (e.g. compost, water retention crystals, slow release fertilisers), suitable soil, myccorrhiza, or other additives that may be necessary to meet the specifications for plant growth.
Bench 坡級	An elongate horizontal surface, or step, cut in a slope.
Bender fence 級式土柵	A retaining structure installed along the contour, comprising flexible boards interwoven between living or dead posts, and forming a series of narrow terraces across the slope. These structures typically retain ameliorated soil material, and are commonly planted with seedlings and/or live stakes.
Berm construction 護道建造	An artificial earth embankment placed to prevent surface erosion by reducing surface water flow velocities down a landslide scar, and by diverting these flows.
Biotechnical 生物科技	The use of vegetation, such as herbaceous or woody plants, in association with inert structural members, such as retaining structures and revetments. The structural members are intended to remain as the main structural support for the design life of the structure.
Branchpacking 剪枝填塞	A method for repairing gullies or small failures, using alternating layers of live branch cuttings of adventitiously rooting woody plant species and/or rooted plant materials and compacted ameliorated soil backfill. Wooden poles are installed across the gully, and live cut branches and/or rooted plants are installed perpendicular to the slope face with growing tips directed out of the slope.
Brushlayers 掃式排枝層	Live branch cuttings, pruned from a designated harvesting area, installed along constructed benches. The live branch cuttings are laid in criss-cross fashion on the benches, perpendicular to the slope face, between successive lifts of soil. The growing tips should be directed out of the slope.
Cribwall 框格式擋土牆	A timber retaining structure consisting of overlapping timbers, that is backfilled with ameliorated soil fill.
Cutting 剪枝	A branch or stem pruned from a living plant, the lower ends of which produce roots.
Dead stake 死扦插樁	Non-living, untreated, sawn wooden post, approximately 40mm x 90mm in cross-section and 900mm long, which is cut diagonally at the tip.

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Degradable erosion control mat
可分解防沖刷蓆
A cover, made of bio-degradable fibre such as woven coconut husk, that is laid on a soil slope to provide temporary erosion protection.

Exotic
外來植物
Plants that do not occur naturally in the project region. Non-native plants that originate from another part of the world.

Faunal habitat
野生動物生態
The area, or environment, where a living organism or ecological community normally lives or occurs.

Gabion
框式擋土牆
A mesh basket, made of wire or natural materials such as bamboo, which is filled with rock and soil, and used as a retaining or erosion protection structure. They can be placed individually or in multiples.

Grade control
坡度控制
The establishment and maintenance of a gentle, non-eroding gradient on a watercourse or land surface. This is a usually accomplished by means of structural measures or by regrading (lengthening) the slope.

Herbaceous species
草本植物
A type of plant, known commonly as herbs, that has a soft green stem and little woody growth. They may be annual, the plants dying after one year of growth, and are usually propagated from seed. Alternatively, they may be produced annually by new shoots that develop from dormant roots.

Joint planting
石縫種植
The installation of live branch cuttings of adventitiously rooting woody species into soil-filled rock joints. The technique creates a living root mat within the soil mantle.

Legume
莢豆類植物
An erect or climbing bean or pea plant of the family *Leguminosae*, which bears its seeds in a thin case or pod that splits into two valves, with the seeds attached to one edge of the valves.

Live barriers
活擋阻欄
Indirect bioengineering measures that are planted at a significant distance downslope from the areas of slope instability to provide a natural screening barrier. They consist of a group of direct plantings, in channelised debris flow tracks or as contour belts, arranged in a configuration that is designed to slow down, or possibly retain, moving landslide debris.

Live branch cuttings
活扦插枝
Living, freshly-cut branches of woody shrub and tree species, which root easily from cuttings, that propagate when embedded in the soil.

Live cribwalls
活框格式擋土牆
A timber retaining structure consisting of overlapping timbers, that is backfilled with ameliorated soil fill and into which live branch cuttings, and possibly rooted plants, are installed in the openings in the face of the cribwall, so that they are rooted in the soil fill or in the natural soil behind the wall.

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Live fascines 活側疏水束	Elongate bundles of live cut branches that are bound together, placed in shallow trenches, partly covered with soil, and staked with living and dead stakes. The trenches are constructed either along the contour, or at an angle to the contour. The measure provides surface protection and shallow slope stabilisation by mechanically reinforcing the soil mantle, and can also be used as a drainage system when installed along the bottom of a pole drain.
Live gully repair 活沖溝修補	The method consists of placing alternating layers of live branch cuttings of adventitiously rooting woody plant species, possibly with live rooted plants, and compacted ameliorated backfill into erosion gullies and shallow failure scars.
Live stakes 活扦插樁	Branches or plant stems that have been cut or pruned from living plants that root readily from cuttings. All side branches are typically removed prior to installation. They are placed in the ground, where they eventually root and grow.
Mass movement 重力遷移	The downslope displacement, under the influence of gravity, of soil and rock, which may be saturated with water.
Native 原生植物	Plants that live or occur naturally in the project region.
Pioneer plant 先鋒植物	The first species to enter a barren area, and one that successfully establishes itself to start an ecological cycle of life. Because they usually establish quickly and grow rapidly to maturity, they are selected to form an initial vegetative coverage that modifies the micro-climatic conditions to favour slower growing native plants.
Pole drain 主疏水束	Trenches designed to intercept and redirect surface and shallow sub-surface water flows, typically incorporating a large (300mm in diameter) live fascine.
Rock 岩石	A naturally occurring, hard geological material that cannot be broken by hand. The definition excludes more friable, tropically weathered rock.
Rooted plant 有根植物	A species that has growing roots. It may be grown from seed, from cutting or lifted from the ground on-site.
Seedling 幼苗	A tree that is less than two years old, has a single stem, a well-developed root system, and is between 150 mm and 900 mm high.
Soil bioengineering 土壤生物工程	A technique that combines mechanical, biological and ecological principles and practices for the protection, enhancement, and repair of shallow mass movement and erosional features on slopes. Comprises ‘living’ (the use of herbaceous and woody plants) and ‘structural’ (e.g.

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the use of crib walls and inert materials such as rock, wood, and geosynthetics) approaches. The measures are designed to provide additional mechanical support to soil, and to act as hydraulic drains, barriers to earth movement, and hydraulic pumps or wicks.

Shallow mass movement 坡面重力遷移	The downslope displacement, under the influence of gravity, of a thin, near-surface layer of soil and rock, which may be saturated with water.
Shrub 灌木	A low-growing, woody, perennial plant with a bushy habit that has several stems arising near the base.
Tension Crack Repair 張力裂隙修補	The filling of open ruptures in a slope with ameliorated soil fill, followed by the insertion of live stakes obliquely along both sides of the crack. The stakes are placed in a criss-cross configuration to secure the opposing faces of the rupture.
Vegetative cuttings 植物剪枝	Cut stems and branches of living plants that will root naturally when inserted in the ground.
Vegetated gabions 植物石籠牆	A mesh basket, made of wire or natural materials such as bamboo, which is filled with rock and soil, and used as a retaining or erosion protection structure. Live branch cuttings and rooted plants are installed on consecutive layers between the rock-and-soil-filled baskets. When the plants become established, they consolidate the structure and bind it to the slope.

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APPENDIX B

BRIEF SOIL TEST REPORT FOR TRIAL SITES

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B.1 BACKGROUND

In late June 2004, prior to the commencement of the soil bioengineering works, eight soil samples were collected from the three trial sites selected for the Main Phase of Bioengineering Repair Works. Representative soil samples were taken from two locations on the undisturbed natural hillside immediately above the landslide crowns (samples 1/2 and 3C), and from the bare scars from which the original topsoil had been removed by the failures (samples 1A, 1B, 2A, 2B, 3A, and 3B). Consequently, it is important to point out that, samples 1/2 and 3C were taken from the "A" horizon of the pedological profile of an immature upland soil, whereas the other six samples were taken from the undifferentiated, parent "C" horizon from which the topsoil had been eroded. The soil sampling locations are summarised in Table B.1 and shown on Figure B.1. A second set of test samples was taken at the same locations in early February 2006 to assess the soil properties about 1 year after completion of the soil bioengineering works.

A range of laboratory tests of the physical and chemical properties of the samples was carried out. The tests comprised the determination of organic matter content, moisture content, mass loss on ignition, pH value, total sulphate content, water-soluble chloride content, total nitrogen, total phosphorous, exchangeable potassium, electrical conductivity, and particle size distribution.

B.2 SOIL ANALYSES PRIOR TO THE COMMENCEMENT OF THE WORKS

B.2.1 Texture

Table B.2 shows the textural composition of the soils interpreted from the particle size distribution curves.

Overall, samples 1/2, 2A and 2B are more gravelly (10 to 18%) than the other soils (1-6%). The percentages of particles <2mm in these three soils are also lowest (82 to 90%). Samples 3A, 3B and 3C contained a higher percentage of the finer fractions (clay and silt) than the other soils, and were less sandy.

As would be expected, the soil texture showed a close relationship with moisture content (i.e. the finer the soil texture, the higher the water content) as shown in Table B.2. It is, however, premature to conclude that the water retention capacities of samples 3A, 3B and 3C were greater than the remaining soils because water release characteristics were not determined in this study.

B.2.2 Moisture Content

Table B.2 shows the moisture content of the soils determined gravimetrically at 105^{o}C. The samples were taken in late June 2004 when the weather was hot. The moisture content varied substantially between the soils, ranging between 18.4 and 31.3%, which is comparable to most agricultural soils in Hong Kong (Marafa & Chau, 1996). The moisture content of soil samples 2A and 2B (18.4-18.9%) was substantially lower than the other samples, while soil sample 3A yielded the highest moisture content (31.3%).

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Soil moisture increased with clay content of the soils. It was lowest in samples 2A and 2B (13-14%) and highest in sample 3A (24%)(Table B.2). Other factors being equal, the water-retention capacity of sample 3A was potentially greater than the others.

B.2.3 Reaction pH, Organic Matter, Loss on Ignition (LOI), Sulphate and Chloride Content

All the samples were strongly acidic, with a pH ranging between 4.2 and 4.8 (Table B.2). These values are comparable to most hill soils in Hong Kong (Marafa & Chau, 1996), due to the combined effect of acidic parent materials and intense leaching of the base elements (K, Na, Ca and Mg).

Several problems are commonly associated with strongly acid soils, including aluminum toxicity, low phosphorus bio-availability and low base saturation. These problems can affect normal plant growth unless remedial action is taken. The sites are dominated by a mixture of shrubs, ferns and grasses, including *Baeckea frustecens*, *Rhodomyrtus tomentosa*, *Eurya chinensis* and *Dicranopteris linearis*, plants that indicators of strongly acid soils in south China.

Organic matter affects the biological, chemical and physical properties of soils. It is also the storehouse for nitrogen, phosphorus and sulphur in unfertilised systems. An ideal soil should contain between 3 and 5 % organic matter. The organic matter content was, understandably, highest in the samples from the undisturbed soils, being 2.63% in sample 3C and 2.8% in sample 1/2, which is considered low to moderate compared to the average soils in Hong Kong (Marafa & Chau, 1996). Organic matter content in the soils from the scars ranged between 0.16% in sample 2A and to 1.75% in sample 3B. Samples 2A and 2B contained the lowest organic matter content (0.16 to 0.20%) compared with the highest in samples 3A and 3B (1.23 to 1.75%). Organic matter content correlates quite closely with the moisture contents and textures of the soils. The finer-textured samples 3A, 3B and 3C are characterised by higher organic matter and higher moisture contents.

Loss on ignition (LOI) measures the losses of organic matter, moisture and volatile substances during heating of the soils in a furnace. LOI is regarded as an estimate of organic matter only when the value cannot be accurately determined. The LOI value is thus higher than the actual organic matter content, because the soil moisture and other volatile substances are included in the result. Nevertheless, LOI closely correlated with organic matter content.

The soils contained very low levels of acid-soluble and water-soluble sulphates and chlorides, which partly accounted for specific conductance of the soils (Table B.4). These salts should have no adverse effects on the growth of the planted vegetation.

B.2.4 Nitrogen, Phosphorus, Potassium and Specific Conductance

Nitrogen, phosphorus and potassium are the three most important macro-nutrients needed for plant growth. The tests showed that the soils are deficient in these nutrient elements.

The soils contained low to moderate levels of nitrogen, a pattern similar to most hill soils in Hong Kong (Marafa & Chau, 1996). Unsurprisingly, relatively higher nitrogen

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levels were recorded in the undisturbed soils above the scars (i.e. samples 1/2 at 0.2%, and 3C at 0.15%), while the soils on the scars yielded between 0.02 and 0.10% nitrogen (Table B.2). An ideal soil should contain 0.2% or more nitrogen, thus this may be a limiting factor to plant growth at these sites. Nitrogen levels showed a close correlation with the levels of organic matter in the soils (Table B.2).

The soils contained very low levels of available P_2O_5 (<1.0 mg/100g) and K_2O (1.62 to 3.91 mg/100g), again comparable to the average hill soils in Hong Kong (Marafa & Chau, 1996). The undisturbed soils above the scars (samples 1/2 and 3C) contained higher levels of K_2O than the soils on the scars. Under acid soil conditions, large amounts of aluminum, iron and manganese in the soil are rendered soluble and they react with phosphorus to form insoluble compounds that are not available to plants. Also, Hong Kong has an average rainfall of 2,250 mm per annum, which facilitates rapid leaching of potassium.

The soils are non-saline, as shown by the low levels of electrical conductivity (0.06 - 0.12 mS/cm^2). Specific conductance is a concern to plant growth when the value reaches 4 mS/cm^2 or above.

B.2.5 Summary of Soil Test Results

The major properties of the soils are summarised below:

(a) Overall, the soils are strongly acidic, contain low levels of organic matter, and are largely deficient in nitrogen (N), phosphorus (P) and potassium (K). Samples taken from undisturbed soils outside the scars contained a relatively higher level of nutrients (especially nitrogen and potassium) than those on the eroded scars.

(b) Aluminum toxicity is a potential problem to plant growth in these acid soils.

(c) The soils are non-saline, hence salts are not a problem to plant growth.

(d) The soil at Landslide TPCHN-02 was sandier and had the lowest organic matter content.

(e) The textures of the soils were generally acceptable for plant growth, especially samples from Landslide TPCHN-03. The finer-textured samples from Landslide TPCHN-03 are characterised by higher organic matter and higher moisture contents. However, this does not indicate that the available water content is adequate in the soils.

B.3 PLANTING RECOMMENDATIONS

Based on the soil test results, the following recommendations can be made:

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(1) Environmental Considerations The major problem affecting plant growth on the eroded surface of a landslide scar is the general absence of soil, most of which was removed by the failure. In addition, the steep slopes, rapid runoff, lack of surface protection, and unstable ground give rise to problems such as concentrated surface runoff, rilling and gullying, drought, thin and patchy soils, and sedimentation on the lower slopes. These problems must be addressed prior to planting new vegetation on the slope. Several measures are recommended:

(a) interception and diversion of surface runoff to protect the exposed soil surface

(b) provision of measures to prevent soil erosion

(c) restoration of a vegetative cover

(d) other appropriate engineering measures capable of stabilising the ground

(2) Soil Management The soil test results clearly indicate that the soils are characteristically acidic and deficient in organic matter. Ideally, suitable soil should be imported to the site to facilitate plant growth. However, this process is expensive and not in keeping with the project philosophy of cost-effective measures. Re-profiling of the back scarp and use of the trimmed soils in the soil bioengineering measures is the practical alternative. Amelioration of the nutrient-deficient soils should also be carried out.

Further erosion of the remaining soils can be minimised by laying degradable erosion control mats in combination with direct planting. Plant roots help to bind the loose soil particles, and also to replenish organic matter in the soil. Following planting, a gradual improvement of the soil properties and micro-climatic conditions will further enhance the growth of local or introduced species and encourage colonisation.

Appropriate applications of fertiliser is recommended prior to tree planting and for post-planting care. Ideally, planted shrubs and trees should be given 50 g of a balanced slow-release fertiliser, and the newly-planted seedlings should be irrigated. When this is not possible, planting should be carried out in the rainy season.

When new roots appear on the planted cuttings, additional phosphorus fertiliser is needed to stimulate growth. Phosphorus is a starter fertiliser, but unfortunately the bio-availability of phosphorus in reduced acid soils due to the presence of aluminium, iron and manganese. Ideally, the acid soils should be ameliorated with lime, such as dolomitic limestone, to increase the bio-availability of phosphorus. However, because of technical difficulties, this procedure is expensive. Also, it should be carried out more than a month before the planting works commence.

(3) Vegetation Selection To improve the survival rate of shrubs and trees, it is important to plant only species that can tolerate low pH and aluminium toxicity. In this regard, members of the *Theaceae* and *Myrtaceae* families are particularly suitable, such as *Gordonia axillaris* and *Rhodomyrtus tomentosa*.

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Even though soil bioengineering measures are installed, it is worthwhile planting established shrub and tree seedlings on the site to accelerate the recovery of woodland. This should be done before the onset of the wet season.

B.4 COMPARISON OF SOIL TEST RESULTS BEFORE AND AFTER THE WORKS

In order to assess any change in soil properties several months after completion of the soil bioengineering works, in early February 2006, a second set of soil test samples was taken from the same locations as previously. The test results are tabulated in Table B.3.

B.4.1 Moisture Content

Table B.3 shows that the moisture content of the soil samples taken after the soil bioengineering works were slightly lower, averaging 15.06%. The samples were taken in early February 2006 when the weather was particularly dry and the air relative humidity ranged from 58% to 85%. Thus, the lower moisture content of the soil samples may be explained by the weather conditions.

B.4.2 Texture

Table B.3 shows the textural composition of the soil samples were similar to those recorded before the soil bioengineering works. Samples taken from Landslide TPCHN-02 are also more gravelly in general (12%) compared to the others.

B.4.3 Reaction pH, Organic Matter, Loss on Ignition (LOI), Sulphate and Chloride Content

The soil samples were still very acidic, with a pH ranging between 4.0 and 4.6. There is no significant change in acidity of the soil comparing to the previous soil test results (4.2 to 4.8).

The organic matter content of the soil samples varied from 0.6% in sample 2B to 3.4% in sample 3C, which is shows no change from the previous test results. Samples 2A and 2B contained the lowest organic matter content (0.6% - 1.3%) compared with the highest in samples 3A, 3B and 3C (1.8% to 3.4%), as in the previous tests.

Loss on ignition (LOI) value correlated closely with organic matter content.

The soil samples shows that the soils contained very low level of acid-soluble sulphates (0.01% - 0.03%), which showed a slight increase, but the values are still very low. The chloride content (<0.01%) was the same as the previous test results. A water-soluble sulphates content test was not available.

B.4.4 Nitrogen, Phosphorous, Potassium and Redox Potential

The nitrogen, phosphorus and potassium content of the soil samples, the three most

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important macro-nutrients needed for plant growth, increased more than 10-fold compared to the previous tests (N: 0.02-0.10%, P_2O_5<1.0mg/100g, K_2O: 1.62-3.91mg/100g), especially the level of phosphorus (ranging between 8.7 and 22mg/100g). Fertiliser application in March 2005 was possibly the major source of this nutrient content.

Determination of redox potential was conducted *in lieu* of the determination of specific conductance since the latter test is not available in Hong Kong. The value of redox potential of the soils varied from 230mV to 310mV.

B.5 REFERENCE

Marafa, L. & Chau, K.C. (1996). Morphological and chemical characteristics of upland volcanic soils along a vegetation gradient affected by hillfire in Hong Kong. Hong Kong Geologist, Vol. 2 (Autumn), pp 67-79.

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Table B.1 - Soil Sampling Locations

Sample No.	Landslide Site [(1)]	Location [(2)]
1A	CHN-01	On the eroded scar
1B	CHN-01	On the eroded scar
2A	CHN-02	On the eroded scar
2B	CHN-02	On the eroded scar
1/2	Between CHN-01 & 02	On undisturbed terrain
3A	CHN-03	On the eroded scar
3B	CHN-03	On the eroded scar
3C	Above CHN-03	On undisturbed terrain
Notes: (1) Landslide scars on which soil bioengineering measures were installed in 2004 (2) For locations of the samples, refer to map Figure B.1		

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Table B.2 - Results of Soil Sampling before Soil Bioengineering Works

Sample ID	Moisture Content (%)	Particle Size Distribution (%)				
		Gravel	<2mm	Sand	Silt	Clay
1A	23.7	5	95	43	32	20
1B	22.4	6	94	50	25	19
2A	18.9	10	90	56	20	14
2B	18.4	12	88	49	26	13
1/2$^{\blacktriangle}$	24.1	18	82	44	22	16
3A	31.3	1	99	37	38	24
3B	25.8	5	95	35	38	22
3C$^{\blacktriangle}$	24.8	5	95	39	36	20
Sample ID	pH	Organic Matter (%)	LOI (%)	Acid-soluble sulphate (%)	Water-soluble sulphate (%)	Chloride (%)
1A	4.8	0.26	2.1	0.01	<0.01	<0.01
1B	4.8	0.22	2.1	0.01	<0.01	<0.01
2A	4.7	0.16	2.1	0.01	<0.01	<0.01
2B	4.8	0.2	1.9	0.01	<0.01	<0.01
1/2$^{\blacktriangle}$	4.4	2.8	4.2	0.01	<0.01	<0.01
3A	4.3	1.23	3.5	0.01	<0.01	<0.01
3B	4.2	1.75	3.6	0.01	<0.01	<0.01
3C$^{\blacktriangle}$	4.4	2.63	4.9	0.01	<0.01	<0.01
Sample ID	Nitrogen (%)	Available P_2O_5 (mg/100g)	K_2O (mg/100g)	Specific conductance (mS/cm²)		
1A	0.03	<1.0	1.62	0.09		
1B	0.1	<1.0	3.16	0.09		
2A	0.02	<1.0	2	0.08		
2B	0.02	<1.0	1.8	0.07		
1/2$^{\blacktriangle}$	0.2	<1.0	3.55	0.07		
3A	0.08	<1.0	1.81	0.06		
3B	0.02	<1.0	1.77	0.12		
3C$^{\blacktriangle}$	0.15	<1.0	3.91	0.11		

Notes: (1) Samples 1/2$^{\blacktriangle}$ and 3C$^{\blacktriangle}$ are from the A horizon of undisturbed soil profiles.
(2) All other samples are from the B or C horizon of eroded landslide scars.

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Table B.3 - Results of Soil Sampling of 1 Year after Soil Bioengineering Works

Sample ID	Moisture Content (%)	Particle Size Distribution (%)				
		Gravel	<2mm	Sand	Silt	Clay
1A	17.2	12	88	46	27	15
1B	13.6	16	84	42	27	15
2A	10.6	12	88	37	36	15
2B	13.6	12	88	50	22	16
1/2▲	11.4	6	94	48	25	21
3A	18.4	9	91	37	37	17
3B	8.6	11	89	38	31	20
3C▲	12.0	5	95	43	32	20

Sample ID	pH	Organic Matter (%)	LOI (%)	Acid-soluble sulphate (%)	Water-soluble sulphate (%)	Chloride (%)
1A	4.5	1.7	3.15	0.01	Not Available	<0.01
1B	4.4	1.6	3.06	<0.01	Not Available	<0.01
2A	4.6	1.3	2.46	0.02	Not Available	<0.01
2B	4.6	0.6	1.8	0.02	Not Available	<0.01
1/2▲	4.2	1.7	3.21	0.02	Not Available	<0.01
3A	4.1	1.8	3.47	0.03	Not Available	<0.01
3B	4.0	2.0	3.22	0.02	Not Available	<0.01
3C▲	4.1	3.4	5.38	0.01	Not Available	<0.01

Sample ID	Nitrogen (%)	Available P_2O_5 (mg/100g)	K_2O (mg/100g)	Redox Potential (mV)	Bulk Density (Mg/m^3)	Relative Compaction (%)
1A	0.70	22	23	230	1.54	78
1B	0.82	18	13	290	1.59	85
2A	0.51	16	25	310	1.63	87
2B	0.30	15	13	290	1.55	82
1/2▲	0.70	15	18	240	1.52	81
3A	0.51	11	10	260	1.64	84
3B	0.82	8.7	5	250	1.55	82
3C▲	1.40	16	20	250	1.57	85

Notes: (1) Samples 1/2▲ and 3C▲ are from the A horizon of undisturbed soil profiles.
(2) All other samples are from the B or C horizon of eroded landslide scars.

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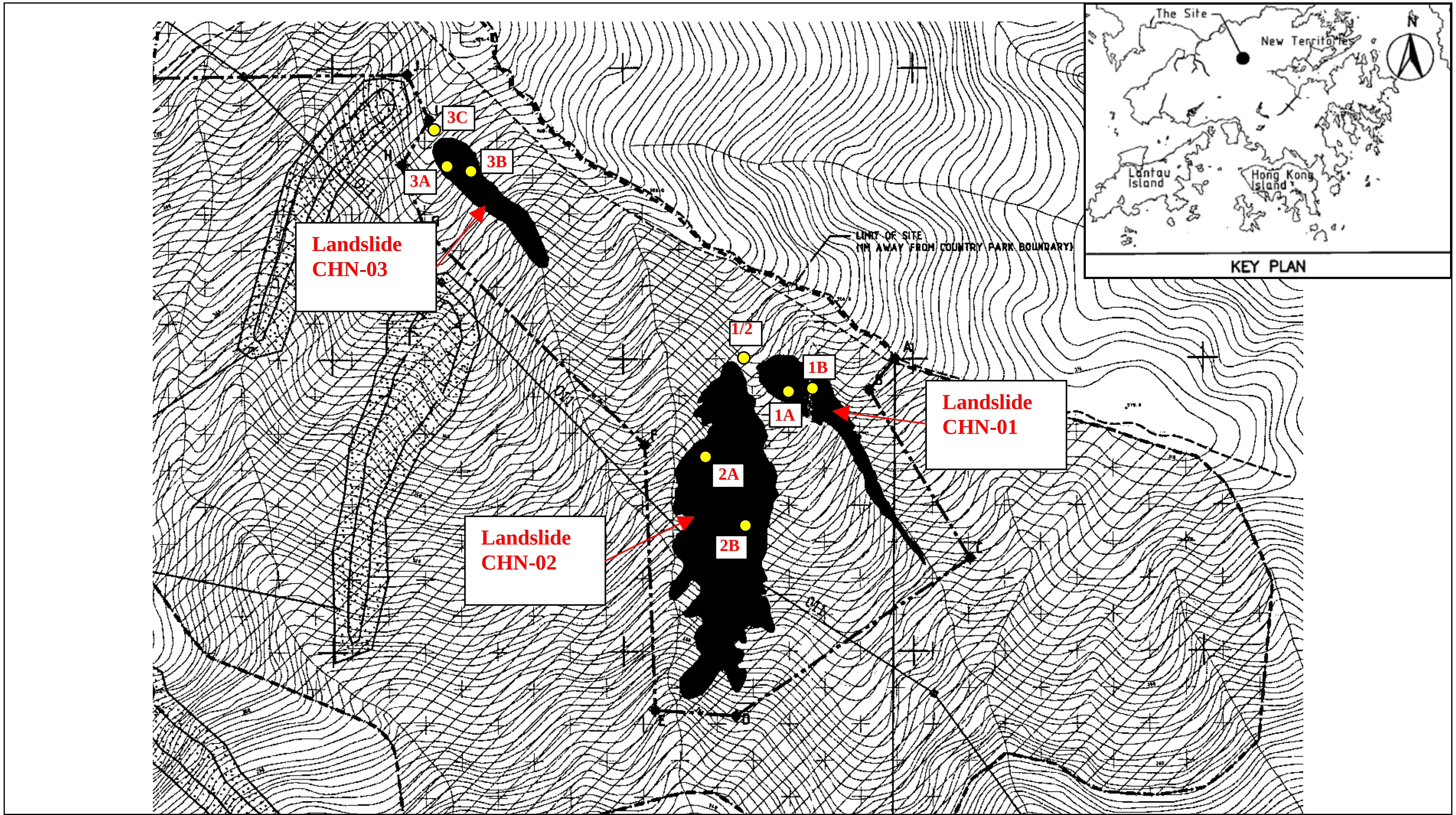

Legend:

3A sample — Location of soil

Figure B1 - Soil Sampling Locations

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Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

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