SAFE AND GREEN SLOPES
THE HOLISTIC HONG KONG APPROACH

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Abstract : Most landslides in Hong Kong are caused by heavy rainfall. In the 1970s, fatal landslide incidents brought huge loss of life and damage to property in Hong Kong. The catastrophes prompted the setting up of a Slope Safety System by the Government since 1977. The administrative framework has been continuously built up in the last 28 years. During this period of time, the Government in partnership with the profession and the community, progressively and systematically reduced the landslide risk. Increased knowledge on landslides, and application of geotechnical and information technology have brought improvement to the Slope Safety System. The improvement has taken place in many areas of slope engineering and in the administrative framework such as establishing standards, use of information technology, natural terrain landslide risk management, upgrading and maintenance of slopes. In parallel, public education campaigns have been launched to improve public awareness on slope safety and slope maintenance. In recent years, in addition to safety, great effort is devoted to enhance the appearance of slopes. The Government has pioneered vegetation trials and applied the findings in the slope works. The objective is to improve the aesthetics as well as ecology of the slopes and their surroundings. Standards and guidelines on landscape treatment and bio-engineering for man-made slopes have been prepared for the local practitioners in the design and selection of suitable vegetation species on slopes. Effort has also been devoted to encourage private slope owners to provide landscape treatment to their slopes. It is now generally recognised by the Hong Kong community that the appearance of the slopes has been greatly improved. Sustained effort by the Government and private slope owners needs to continue in reducing landslide risk and enhancing the aesthetics of slopes in Hong Kong.

INTRODUCTION

Hong Kong has a population of about 6.8 million within a land area of around 1,097 square kilometres. There is a great concentration of developments on steep hillsides, resulting in the formation of many man-made slopes and retaining walls. The seasonal rainfall is high, which often triggers landslides. The challenges Hong Kong engineers are facing with regard to slope safety are unique in the world.

In the 1970s, Hong Kong experienced a number of disastrous landslides (Figures 1 to 3), notable ones being the 1972 Po Shan Road landslide and the 1972 and 1976 Sau Mau Ping fill slope failures. In the 1980s, the landslide problems were mainly associated with un-engineered squatter developments on the hillside. In the 1990s, several serious fatal landslides aroused much public attention, e.g. the 1994 Kwun Lung Lau retaining wall collapse (Figure 4), the 1995 Fei Tsui Road landslide (Figure 5) and Shum Wan Road landslide (Figure 6) and the 1999 Sham Tseng San Tsuen debris flow (Figure 7) and Shek

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Kip Mei landslide (Figure 8). Although serious landslides still occurred from time to time, the scale and severity of the landslide problems have been decreasing. Landslide fatalities have been significantly reduced in recent years (Figure 9). This is attributed to the development of a comprehensive Slope Safety System (Chan, 2000) and advancement in geotechnology and practice (Chan, 2003).

Figure 1 - 1972 Po Shan Road Landslide

Figure 2 - 1972 Sau Mau Ping landslide

Figure 3 - 1976 Sau Mau Ping landslide

Figure 4 - 1994 Kwun Lung Lau landslide

Figure 5 – 1995 Fei Tsui Road landslide

Figure 6 - 1995 Shum Wan Road landslide

Figure 7 - 1999 Sham Tseng San Tsuen debris flow

Figure 8 - 1999 Shek Kip Mei landslide

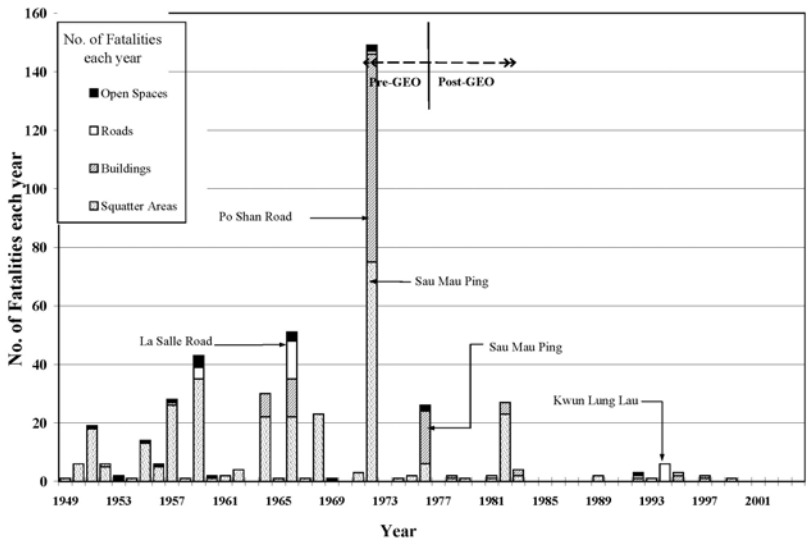

Figure 9 - Known landslide fatalities in Hong Kong

Over the years, the appearance of man-made slopes and retaining walls has been much improved through the concerted effort of the HKSAR Government and all the related professions. In the past, vegetation covers were provided only to the gentle slopes. Improvement in detailing of surface covers, involving the use of erosion control mats and steel wire mesh in soil nailed slopes, has allowed the provision of vegetation covers to slopes with steep gradients. Many more slopes can be vegetated. The proportion of vegetated surface covers on soil slopes upgraded under the Government's Landslip Preventive Measures (LPM) Programme has increased from around 50% in the past to over 70% now (Figure 10).

When the slopes cannot be vegetated for any reason and hard surface cover has to be used, hard treatment measures are provided to alleviate the visual impact of the surface protection cover. The Government has been applying findings of vegetation trials and

performance assessments to improve the ecology of slopes. Technical guidelines are promulgated to the professionals and private slope owners for their use in enhancing slope appearance.

Figure 10 – Examples of vegetated slopes and an upgraded masonry wall with wall trees preserved

HONG KONG SLOPE SAFETY SYSTEM

Many slope-safety related functions are implemented by various departments of the Government. Over the past decade, significant advances have taken place on system improvement through the formulation of a framework of the Slope Safety System by the Geotechnical Engineering Office (GEO) of Civil Engineering & Development Department (CEDD). The framework puts together the various functions in a systematic manner. It helps conveying clear messages to the administrators, the general public, geotechnical practitioners and other stakeholders what the functions are.

The Slope Safety System includes a number of key areas of work: formulating slope safety standards and regulatory framework, checking new geotechnical works, upgrading old substandard slopes, ensuring that slopes are regularly maintained, promoting public awareness and response in slope safety through public education, publicity, information services and public warnings, squatter inspection and clearance, and enhancing the appearance and aesthetics of engineered slopes.

Development of the Slope Safety System has been very rapid in recent years. A comprehensive new Slope Catalogue was completed in 1998. It now contains records of some 57,000 man-made slopes and retaining walls. The Slope Catalogue facilitates the planning of the slope upgrading and maintenance programmes by the provision of technical

data. The Lands Department has also established the Slope Maintenance Responsibility Information System (SMRIS) which provides the information on the parties responsible for the maintenance of each slope in the Slope Catalogue. The importance of promoting public awareness and response in slope safety and enhancing the appearance of engineered slopes is recognised, and these are now the key components of the Slope Safety System. The Slope Safety System is reviewed regularly and benchmarked internationally through a Slope Safety Technical Review Board. In order to continuously reduce landslide risk in Hong Kong, the tasks undertaken by the Government include the following:

I. Ensure That New Slopes Meet Safety Standards

(1) Improve slope safety standards, administrative and regulatory frameworks

Continuous improvement in technical standards and geotechnical control is needed to meet the changing environment and the changing public expectations on slope safety. The publication of the first edition of the Geotechnical Manual for Slopes (GCO, 1979) in 1979 and the second edition (GCO, 1984a) in 1984 marked the first step of Government to provide guidance for the standards of practice that should be adopted for the design, construction and maintenance of slopes and site formation works in Hong Kong. The Manual covers a wide range of geotechnical topics and each topic is later given full coverage in a series of Geoguides and GEO Publications, e.g. Geoguide 1 – Guide to Retaining Wall Design (GCO, 1982) and (GEO, 1993) and Geospec 1 – Model Specification for Prestressed Ground Anchors (GCO, 1984b & 1989). The main objective of publishing the Manual, Geoguides and Geospecs is to allow the profession to use a series of common, up-to-date and comprehensive geotechnical standards which are appropriate to Hong Kong conditions.

Other related technical publications include GEO Publications, GEO Reports on research and development work in the GEO, Geological Memoirs and reports on systematic investigation of major landslides in Hong Kong. Through these publications, the GEO is able to share experience, results of research and development and lessons learnt from landslides with the profession to enhance the level of geotechnical competence in Hong Kong (Chan, 1999).

Systematic investigation of landslides has brought improved understanding of the mechanism of landsliding. Areas for improvement have been identified. Enhancements have been introduced in many aspects of slope engineering and the administrative framework, including :

- Improved reliability of engineered slopes, through: adoption of more robust design measures (GEO, 2004a), improved slope detailing and drainage, and enhanced geotechnical and engineering geological input for slopes with complex ground conditions and hydrogeology.
- Improved slope safety risk management system, through: identification of slopes that warrant priority follow-up action, contribution to enhancement of slope maintenance standards via an improved Engineer Inspection process, identification of system improvement measures based on holistic reviews of slope problems, and contribution to development of natural terrain risk management strategy and approach to risk assessment and risk mitigation based on an improved understanding of natural terrain landslides.

- Enhanced public safety, through taking out-of-turn, integrated follow-up actions on about 100 slopes (and their adjoining areas as appropriate) based on the findings of landslide studies.

Geotechnical control on building and infrastructure developments also plays a key role in enhancing slope safety (Chan, 1997). The GEO has worked closely with the Buildings Department and the profession to regularly review the geotechnical control strategy and implement identified enhancement measures, such as the review of geotechnical control as part of the Slope Safety Review in 1995 (Works Branch, 1995) and the follow-up comprehensive review of statutory geotechnical controls in private slopes and developments completed at the end of 2000. Various amendments to the Buildings Ordinance have been made in the past two decades to enhance the geotechnical control of private building developments, with the key milestone of enacting the law in 2004 a register of Registered Geotechnical Engineer (RGE).

In the past, the Buildings Ordinance (BO) only required the appointment of an authorized person (AP) as the coordinator of building works and a registered structural engineer (RSE) for the structural elements of the building works. As such, the AP had to be held responsible under the law for geotechnical works although geotechnical engineers were usually engaged as sub-consultant to the AP for the design and supervision of the geotechnical works. In the last several years, the industry was consulted for the setting up of a statutory register of geotechnical engineers to undertake geotechnical engineering duties relating to private building works. As a result, the Legislative Council passed the law on 23 June 2004 to set up a register of RGE.

The Buildings (Amendment) Ordinance 2004 establishes a register of geotechnical engineers and introduces the requirement for the appointment of a RGE for the geotechnical elements of building works. The registration system has commenced operation since 31 December 2004, and the remaining provisions pertaining to RGE will commence operation 1 year later, i.e. on 31 December 2005. With effect from 31 December 2005, a RGE is required to be appointed for the geotechnical elements of building works as stipulated in section 4(1)(c) of the BO. The RGE will take up the statutory responsibility for the geotechnical elements. At that point of time, the respective responsibilities of AP, RSE and RGE in building works under the BO are mainly specified in Building (Administration) Regulation 12 with reference to the prescribed plans and documents they are required to prepare and sign.

The duties and functions of a RGE under the BO are classified into “executive role” and “advisory role” as appropriate in respect of the geotechnical elements of the building works (BD, 2004). The geotechnical tasks under the Buildings Ordinance and Regulations to be undertaken by the RGE are summarized in Table 1.

For the executive tasks, the RGE needs to prepare and sign the prescribed geotechnical plans and reports, and shall also be required to certify that the works have been carried out in accordance with the approved plans and that the works completed are geotechnically safe. For the advisory tasks, the RGE should prepare and sign the geotechnical report/supporting documentation. The signature is deemed to indicate the RGE’s acceptance of responsibility for the geotechnical report/supporting documentation.

Table 1: Geotechnical Tasks under the Buildings Ordinance and Regulations to be Undertaken by the RGE

Executive Role – Geotechnical Tasks
Ground Investigation in Scheduled Areas
Ground Investigation in Non-scheduled Areas
Site Formation
Groundwater Drainage Works in Scheduled Area 1
Water Supply and Wells
Remedial Works to Dangerous Hillsides
Long Term Monitoring (Post Occupation Permit)
Advisory Role – Geotechnical Tasks
Demolition Affecting Slopes and Retaining Walls
Geotechnical Assessment for General Building Plan where required
Foundation in Scheduled Areas Nos. 1, 2 & 4 and Designated Area of Northshore Lantau
Foundation Affecting Slope and Retaining Wall
Excavation and Lateral Support
Superstructure (Report on geotechnical design parameters)

(2) Check new slopes

With the intense building and infrastructure developments in Hong Kong, hundreds of new man-made slopes are formed each year. If uncontrolled, these new slopes could be substandard and would increase the landslide risk in Hong Kong. The GEO has been maintaining a dedicated team of professional geotechnical engineers with technical support staff to check the adequacy of all slope works, site formation works, earth retaining structures and deep excavations that are designed and constructed by the private sector, public authorities and government departments. The GEO has obtained certification to the international quality assurance standard of ISO 9001 and is maintaining this standard through regular internal and external audits and continuous quality improvements.

Various initiatives have been introduced to improve the performance of the quality-assured checking system. The initiatives include – increase the number of inspections of active construction sites to improve the standard of supervision of geotechnical works, and set up a comprehensive computerized district information system to enhance the effectiveness of checking of new slopes.

(3) Enhance land use planning

In addition to geotechnical checking, the GEO also provides input at the land use planning stage by advising government town planners, land administrators and project departments on land development proposals, land use zoning and special geotechnical conditions on land allocations. The purpose is to mitigate landslide risk and facilitating safe and economic developments at the earliest possible stage.

II. Enhance the Stability of Old Man-made Slopes

(1) Upgrade old man-made slopes

Before the GEO was established in 1977, there was very limited geotechnical control of

slope formation both in the private and public sectors. Hence, the safety standards of many old man-made slopes are in doubt. About 10,500 of the 39,000 old government man-made slopes affect developments and major roads. The Government has therefore been maintaining an on-going LPM Programme to systematically rectify substandard slopes so as to progressively reduce the risk from man-made slopes which affect the community directly (Figure 11).

Figure 11 – Recompaction of granular fill in upgrading a loose fill slope

Figure 12 illustrates the proportion of risk posed from old man-made slopes in terms of facility groups (Wong & Ho, 1998). About half of the risk derives from 10% of the slope population, i.e. from those affecting buildings and major roads (facility group 1). In order to ensure that the 'right' slopes are selected, a risk-based priority classification system (Wong, 1998) utilising QRA results has been developed. The Slope Catalogue provides the necessary information for the systematic selection of substandard slopes to be rectified. The annual provision of funds under the LPM Programme for rectifying substandard slopes has increased from $107 million in 1994-95 to some $895 million in 2005-06. The total capital expenditure on the programme in the five years starting from 1994-95 to 1999-2000 amounts to $2.9 billion. The funds committed in the extended 10-year programme from 2000 to 2010 will incur capital cost of about $9 billion at March 1999 price.

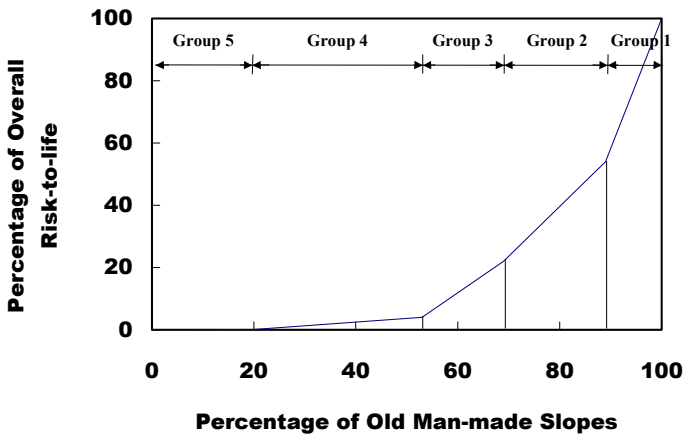

Figure 12 – Risk profile of old man-made slopes

For slopes which could affect or be affected by road and development projects, project departments will, as far as possible, adopt an integrated approach to upgrade these slopes to current safety standards as part of the implementation of the projects.

For those smaller slopes not covered by the LPM Programme, maintenance departments (e.g. Highways Department for roadside slopes, Housing Department for public housing estates, Water Supplies Department for catchwater and reservoir slopes, etc.) are taking an active role in reducing the landslide risk by improving these slopes through the use of prescriptive measures or enhanced maintenance.

(2) Promote slope maintenance

Regular maintenance is essential to the continued stability of all man-made slopes. To facilitate maintenance of man-made slopes, the GEO has published the standard of good practice for slope maintenance – Geoguide 5 in 1995, with the third edition published in 2003 (GEO, 2003). Geoguide 5 has been adopted as the minimum standard for maintenance of government slopes. The maintenance responsibility of man-made slopes in the Slope Catalogue has also been identified under the $73.6 million project – Systematic Identification of Maintenance Responsibility of Slopes (SIMAR) which was substantially complete in December 1999. There are now some 57,000 sizable man-made slopes in the Slope Catalogue. For each of the 39,000 government slopes in the Slope Catalogue, the departments responsible for maintenance are also identified. Maintenance departments have actively arranged Engineer Inspection of their slopes so that each slope has received an Engineer Inspection (EI) (comprehensive inspection by professional engineer) by September 2002. Currently some $650 million is spent on slope maintenance a year by the maintenance departments.

Government's policy is for slope owners to take care of their own slopes, i.e. Government maintains government slopes and private owners take care of private slopes. It is therefore important that private owners maintain private slopes and upgrade those which are substandard. Government, as a controlling authority on slope safety, also carries out safety-screening of private man-made slopes to establish prima facie evidence for serving Dangerous Hillside Orders (DHO) to private owners under the provisions of the Buildings Ordinance. Private owners are statutorily required to investigate and carry out necessary slope upgrading works for discharging the DHO. Similar statutory actions are also taken to require owners to repair their underground drains and water pipes which may affect the stability of adjacent slopes.

Under the present system, maintenance of private slopes requires voluntary actions from private owners. The GEO has completed a review of private slope maintenance and it has been recommended that the Government to encourage and facilitate owners to take up their responsibility for slope safety through public education, publicity and information services. Mandatory slope maintenance should be taken as a last resort.

(3) Provide information services

Although private owners are becoming more aware of their slope maintenance responsibilities, but as laymen, many of them may not possess the required information, knowledge and expertise in slope improvement or maintenance works. The GEO has

therefore provided the public with free comprehensive information on slopes through a computerized Slope Information System which contains information of some 57,000 man-made slopes in the Slope Catalogue. The information is also available on the Internet in the Hong Kong Slope Safety Website (http://hkss.cedd.gov.hk). Parties responsible for maintenance of each slope in the Slope Catalogue are also available from SMRIS in the Website of the Lands Department (http://www.slope.landsd.gov.hk/smris/).

III. Mitigate Natural Terrain Landslide Risks

About 60% of the land area of Hong Kong has not been significantly modified by human activities and can be referred to as 'natural' (Figure 13). Much of this natural terrain is steeply sloping and is covered by a mantle of weak saprolitic and residual soils derived from many thousands of years of weathering, as well as colluvial soils, which are the product of past landslides and erosion processes. So far, the present slope safety plan has focused primarily on substandard high-priority man-made slopes, which in the past have posed a relatively high landslide risk to the community in Hong Kong. As a result, there has been a significant reduction in landslide risk, as the high-priority man-made slopes are systematically dealt with as described above. Meanwhile, landslide risk from natural hillsides is on the rise due to encroachment of more developments closer to steep hillsides.

During the wet season, these slopes are subject to frequent intense rainstorms, so landsliding on natural terrain is a common occurrence (Figure 14). In the past, such landsliding has not been of great consequence, as it has occurred in relatively remote areas and hence has not posed a significant threat to life or property. Also, unlike man-made slopes, there have been no recorded fatalities in planned developments (i.e. excluding squatter areas) resulting from landsliding on natural terrain. In contrast, over the past 50 years, more than 470 people have died as a result of failures of man-made slopes and retaining walls. However, development has been continuing to extend into areas close to steep natural terrains, thereby increasing the risk (Figure 15). Indeed, there have been some 'near miss' cases involving landslides on natural terrain in which the consequences could have been very serious if the existing or planned developments below had been in use or occupied at the time when the landslides occurred (Chan, 1998).

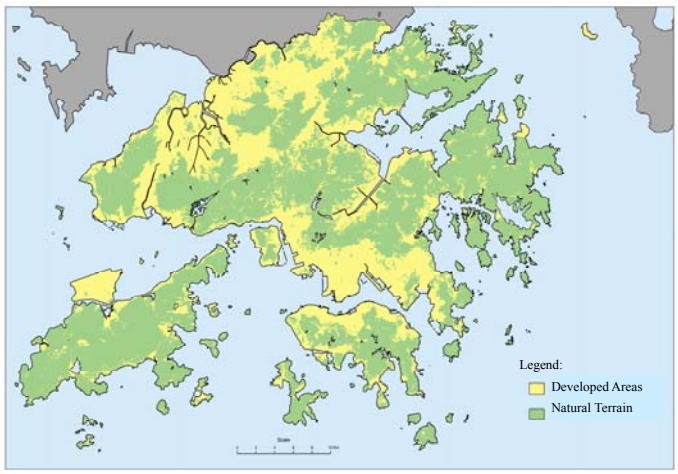

Figure 13 – About 60% of the land area in Hong Kong is "natural terrain"

Figure 14 – The Tsing Shan debris flow in 2000

Figure 15 – A 20 m^3 landslide in 1998 resulted in damage to property

To prepare for the potential risk posed by natural terrain, many research and development activities have been carried out in Hong Kong since early 1990s. Amongst these, detailed study of natural terrain landslides, such as the landslides on the natural terrain of Lantau Island due to the heavy rainstorm in November 1993 (Wong & Lam, 1997), greatly enhanced the understanding on the type, mechanism and mobility of natural terrain landslides. A comprehensive inventory of landslides on natural terrain has been set up. The inventory, which is called the Natural Terrain Landslide Inventory (NTLI), contains data on the location of the landslide crowns, the path of the resulting debris trail, the approximate date of the landslide, the width of the landslide scar and the vegetation cover. Up to the year 2000, the NTLI contains some 30,000 landslides, about 19,000 and 11,000 of which are considered recent and relict landslides respectively. Recent landslides in the NTLI refer to those that occurred within the period of comprehensive aerial photograph coverage, typically after 1950s.

The Government adopts the following principles in dealing with the natural terrain landslide hazards:

- For new developments, contain the increase in overall risk through studying the natural terrain hazards and undertaking any necessary mitigation actions where such hazards could occur. Avoid new developments on sites that are subject to severe natural terrain hazards.
- For existing developments, undertake mitigation actions urgently where there exists an immediate and obvious danger. Study natural terrain hazards where there is reason to believe that a dangerous situation could develop, such as persistent landslides affecting an existing development, and undertake mitigation actions when considered necessary.

As not all development sites are affected by natural terrain hazards, Ng et al (2003) established a set of simple guidelines on the basis of the runout distance of landslide debris and the likely consequence to assist planners, land administrators, project managers, etc. in identifying whether a site may be subject to natural terrain hazards. Where a site may be affected by natural terrain hazards, guidelines are also available for deciding whether it is more appropriate to consider relocation of the site or to undertake a natural terrain hazard study (NTHS) to identify any mitigation measures required (Chan, 2003). Ng et al (2003) also developed guidelines on how to conduct an NTHS. The guidelines highlights the

merits and limitations of and makes recommendations for three different approaches for the evaluation of natural terrain hazards, viz., factor of safety, QRA and design event (Chan, 2003).

Apart from hazard assessment, there has been substantial advancement in the design of mitigation measures. Lo (2000) reviewed typical mitigation measures applied in Hong Kong and established guidelines on the design of debris-resisting barrier. Various kinds of mitigation measures including insitu stabilisation, boulder fences, check dams, landslide debris barriers, etc (Figure 16 and 17) have recently been used in Hong Kong and the experience gained has provided much better understanding of the effectiveness and practicality of these measures (Tse et al, 2003). Other measures like bio-engineering are being tried (Campbell et al, 2005).

Over the years, significant advances have been made in information and related digital technologies. The technologies have become more readily accessible with improved capability and reduced cost (Wong et al, 2005). The GEO plays a key role in a number of areas of geo-informatics, including compilation and dissemination of geo-informatics datasets such as geological maps, Slope Catalogue, landslide data, ortho-rectified historical aerial photographs and digital elevation model; application of geo-informatics involving Geographic Information System (GIS), remote sensing and engineering analytical techniques; and development and promulgation of application of geo-informatics. In the last few years, development and applications of GIS expanded the capability of the GEO in natural terrain landslide management. The advances include advanced GIS search, browsing, editing and publication; GIS analysis; GIS modeling; mobile-location-based application; 3-D visualization and virtual reality application; and integration with remote sensing (Figure 18 and 19).

Figure 16 – Check dam built in Sham Tseng San Tsuen

Figure 17 – Boulder fence at Mid-levels

(a) Uploading GIS data to the mobile mapping system

(b) On-site navigation, data retrieval and mapping using the mobile mapping system

(c) Orthoimage, topographical map, ground features and GPS location displayed on a pocket computer

Figure 18 –Geotechnical mobile GIS mapping system

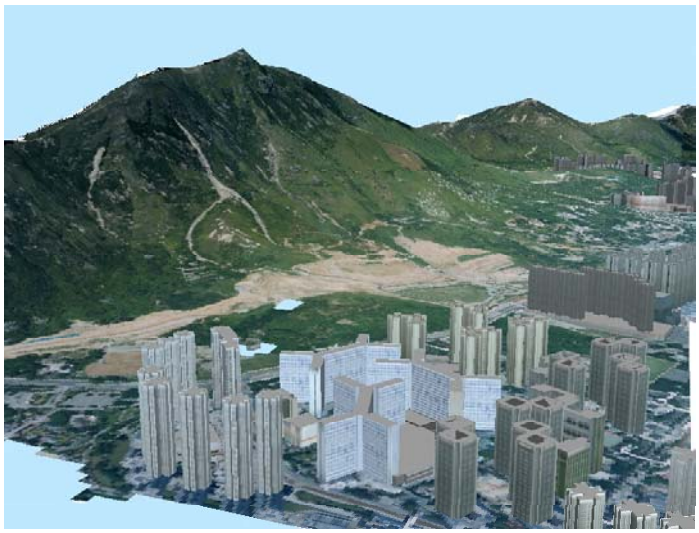

Figure 19 – 3-D virtual reality model of Tsing Shan Foothills in Hong Kong

With the above advances, it can be more systematic, consistent and rational in assessing and dealing with the rising landslide risk from natural hillsides.

IV. Minimize Damage Caused by Landslides

(1) Develop a Landslip Warning System

Most landslides in Hong Kong are caused by heavy rainfall. By using a combination of real-time rainfall data and rainfall forecasts from the Hong Kong Observatory (HKO), the Government is able to issue Landslip Warning through the media. The purpose of the Landslip Warning is to alert the public to reduce their exposure to possible danger from landslides. The issuing of the Landslip Warning also triggers an emergency system within government departments that mobilizes staff and resources to deal with the aftermaths of landslide incidents. The Landslip Warning is issued when it is predicted that numerous (more than about fifteen) landslides will occur.

The GEO operates an extensive network of automatic raingauges (Figure 20) providing real-time rainfall data to the Landslip Warning System. This network, which dates back to 1984, was upgraded in 1999 to improve coverage in the new development areas. The network now comprises 86 raingauges located throughout Hong Kong.

The data capture, control and processing system, which was also upgraded in 1999, receives data from the 86 GEO raingauges and from an additional 24 automatic raingauges operated by the HKO (Figure 21). The system is now being upgraded with General Packet Radio Services (GPRS) for data transmission, replacing the telephone lines for the raingauges. At the completion of the upgrade with GPRS, data transmission can be enhanced and can become more cost-effective.

Figure 20 – Automatic raingauge

Figure 21 – Locations of the automatic raingauges in Hong Kong

The number of landslides in recent years has been low. The public perceives that as an indication of the slope safety problem in Hong Kong having been solved, when in fact the lower landslide activity could have partly been the result of less severe rainstorms in recent years. The GEO developed an index called the Landslide Potential (rainstorm) Index (LPI) in 2002 to measure the relative severity of a rainstorm with respect to its potential to cause landslides. The landslide potential in Hong Kong is a function of four factors namely: the intensity of rainfall; the size of the area affected by rainfall; the number of slopes in the rainfall area and whether the slopes affected can remain stable under such rainfall. The index can be used to communicate the severity of rainstorms in causing landslides to the public in order to raise their awareness. The concept of LPI can also be used to normalise the effect of rainfall in evaluating the performance of slopes. Evaluation of rainfall severity using this index was tried out in year 2003 and 2004 for internal reference (Figure 22).

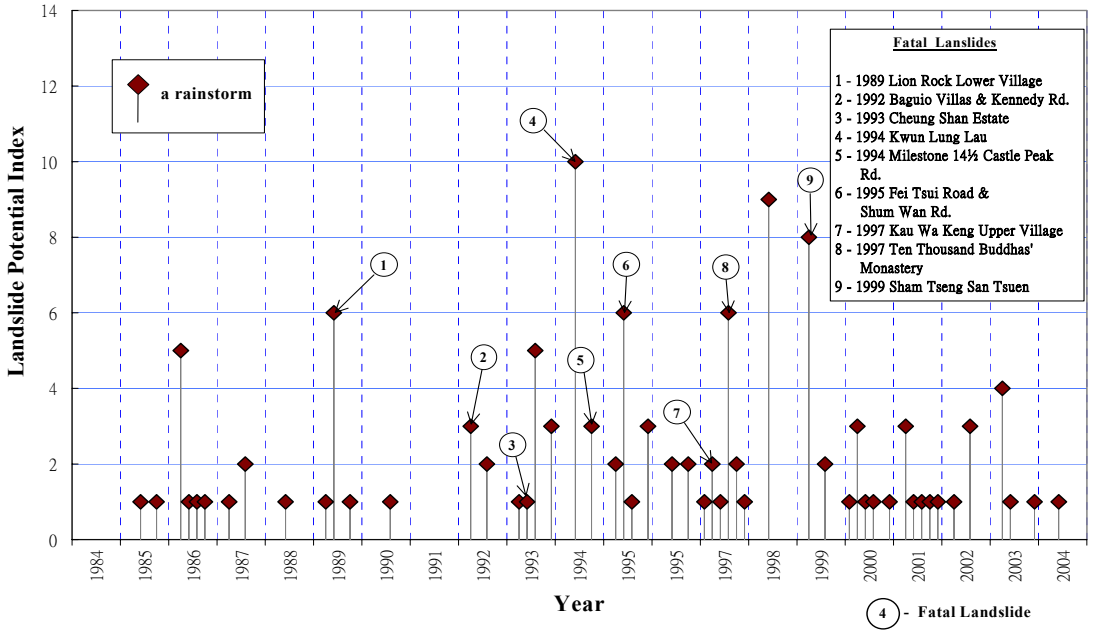

Figure 22 – Chart showing rainstorms since 1984 that resulted in the issue of Landslip Warning

(2) Provide emergency service

Most of the landslides in Hong Kong occur in the rainy season between May and September each year. There are 300 landslides on average reported to the GEO each year. The GEO maintains a 24-hour, year-round service to provide geotechnical advice to government departments on actions to be taken in case of danger arising from landslides. The service includes advice on closure of roads, evacuation of buildings and urgent slope repair works. The primary objective of the emergency service is to protect the general public from landslide hazards and to assist government departments to restore as soon as possible services to the public which have been disrupted by landslides. Where a high demand for emergency service is anticipated, such as when a Landslip Warning is in force and/or tropical cyclone signal number 8 or above is hoisted, the Emergency Control Centre (ECC) in the Civil Engineering and Development Building at Homantin is manned by 13 emergency teams on a rotational basis, working in approximately 8-hour shifts. The team controller of the ECC (a senior geotechnical engineer) receives landslide reports and dispatches geotechnical engineers promptly to landslide sites to provide necessary advice to other government departments. More senior GEO staff are available on call to give advice to geotechnical engineers in dealing with difficult or serious cases. A Crisis Management Planning Committee has been set up since 2004 to oversee the planning and preparedness for crises, including landslide crisis, and the improvements needed to the GEO Emergency System and Crisis Management System.

The GEO makes use of the advances in information technology and has enhanced the uploading of landslide information reported to the GEO in the Intranet. The system, called Integrated Landslip Information System (ILIS) has been successfully implemented. Staff can access details of each landslide reported to the GEO in the ILIS from their own computers.

(3) Improve the safety of squatters

A large proportion of landslide fatalities took place in squatters (Figure 23). Special non-development clearance (NDC) studies have been carried out by the GEO since 1982 to identify squatter structures which are especially vulnerable to landslide danger. Once squatter structures are identified as especially vulnerable to such danger, the Government will offer rehousing to the affected squatters. Since the mid 1980s, some 75,000 persons living in tolerated squatter structures on steep hillsides have been rehoused and the affected structures cleared. Some 58,000 of those cleared to date have been from the urban areas of Hong Kong and Kowloon. The GEO has also been carrying out inspection of tolerated squatter structures in the New Territories since the mid-1980s. Up to the end of 2003, inspections have been made of about 400 squatter areas and their nearby isolated structures, covering the more vulnerable parts of the squatter areas in the New Territories, and including dwellings adjacent to stream courses that might be subject to hazard from debris flows. This NDC inspection programme was completed in September 2003. From 1992 to September 2003, the GEO has recommended clearance for some 20,000 persons. Housing Department, Lands Department and Buildings Department are implementing the clearance recommendations. About 9,800 of these persons are yet to be rehoused. The GEO issues warning letters to squatters who have been recommended for clearance on slope safety grounds. Since 1998, the GEO has also been erecting warning signs in squatter areas where clearance recommendations are being processed. Squatters are advised to follow the safety advice given pending action for rehousing. When the Landslip Warning

is issued or during periods of heavy rain, temporary shelters are provided by District Offices to accommodate squatters or any members of the public in need.

Figure 23 – Landslides in August 1995 affecting the Lei Yue Mun Squatter Area

(4) Launch public education and publicity on slope safety

Since 1992, the GEO, with the assistance from Information Services Department, has been undertaking a systematic publicity campaign on slope maintenance to convey the following two key messages to the public, i.e. (a) inspection and maintenance are needed to keep slopes safe; and (b) action lies with the owners. To enhance and reinforce private owners' acceptance of their responsibility for slope safety, the GEO has set up a Community Advisory Unit since April 1999 to hold seminars/talks and meet-the-public sessions on slope safety and to meet with Owners' Corporations and individual private owners who have received Dangerous Hillside Orders. The feedbacks have been positive.

With the assistance of the universities and research organisations, the GEO has been conducting annual public opinion surveys to gauge the effectiveness of the campaign. The survey results in 2002 indicated that, 88% of the public were aware of the importance of slope maintenance and the owners' obligation to maintain their slopes. Recent results of the survey in 2003 indicated that there was a 10% drop to 78%, and the percentage rose slightly in 2004 to 81%. Regarding the public's concern on slope safety, the percentages dropped from 73% in 2002 to 63% in 2003, and further reduced to 59% in 2004. The reduction in awareness is likely due to an absence of serious landslides in recent years, leading to the general complacency on landslide risk.

The GEO commenced in 1996 an ongoing public education campaign on slope safety including personal precautionary measures to be taken in times of heavy rain. School education and student participation have been identified as important areas for effective promotion of slope safety. In conjunction with the Chinese University Press, the GEO prepared an education toolkit on slope safety for use by schools when teaching the subject on landslides and slope safety which has been included as part of the secondary school geography curriculum. A major exhibition was held in April 2004 at the Hong Kong Central Library on Hong Kong's history of landslide disasters to arouse the public awareness of landslide risk. To sustain the public education effort to raise awareness, the GEO in collaboration with HKO, Drainage Services Department, Security Bureau, Information

Services Department and Hong Kong Red Cross, launched a major event, "Safer Living – Reducing Natural Disasters" in March 2005. The objectives of the programme are to promote public understanding of the natural hazards, including landslides, facing the community and to raise the community's preparedness for and resilience to natural disasters, leading to safer living in Hong Kong. The whole event will last for about one year. The launching ceremony was held on 5 March 2005 (Figure 24), followed by an exhibition. A series of activities will then be arranged, leading up to a one-month major exhibition at the Hong Kong Science Museum in April 2006. The planned activities include exhibition, lectures, and seminars, slogan and bookmark competition, tropical cyclone name nomination contest, TV documentary series and rescue drill demonstration, etc.

Figure 24 – Launching ceremony by the group of officiating guests and the Campaign Ambassador aiming to raise public awareness on natural disasters

Risk assessment calculations indicate that the overall landslide risk arising from old substandard man-made slopes to the whole community of Hong Kong has been reduced to about 50% of the risk that existed in 1977. The Government is now sustaining its effort to further reduce the landslide risk from old man-made slopes to below 25% of the 1977 level by the year 2010.

ENHANCEMENT OF SLOPE APPEARANCE

Government Policy on Greening and Use of Shotcrete

The Government has committed to making man-made slopes look as natural as possible, blending them with the surroundings and minimising their visual impact. Guidance has been promulgated through technical circulars, e.g. WBTC No. 25/93 (Work Branch, 1993), and Policy Objective booklet on Slope Safety for All from 1998 to 2000 in the Policy Address of the HKSAR Government (Works Bureau, 2000). Wherever possible, vegetation is provided as slope surface cover. The GEO has the target of providing vegetation cover to at least 70% of the slopes upgraded under the LPM Programme. Over the last three years, this target has been achieved (GEO, 2004c). The use of chunam or shotcrete on slopes should only be considered as a last resort and only after other techniques have been explored and found not practical. WBTC No. 17/2000 (Works Bureau, 2000b) and CEDD TC No. 15/2004 (CEDD, 2004) stipulate that consideration may be given to introduce some graphic or wall painting design on slopes where the use of chunam or shotcrete is unavoidable to minimize the visual impact. The use of hard surface cover is controlled through the Departmental Vetting Committee on Slope Appearance for slope works under the LPM Programme.

For slope maintenance works, the maintenance departments aim to progressively replace any existing hard surface covers on Category 3 slopes, if geotechnically acceptable, with a vegetated surface covers. Aesthetic aspects of slope works are included in the scope of slope maintenance audits conducted by the GEO.

Engineers are now more knowledgeable in landscape design concept than before in blending such slopes with the surrounding environment. The commonly used methods are masonry block facing, ribbed or other patterned finishes, toe planters, colouring and planter holes, coupled with suitable retention of existing vegetation (Figure 25). More fancy techniques such as decorative artwork and artificial rock are occasionally used. Figure 26 shows the methods of providing vegetation and landscape treatment for slopes of different gradients.

Figure 25 – A slope with landscaped treatment implemented during upgrading

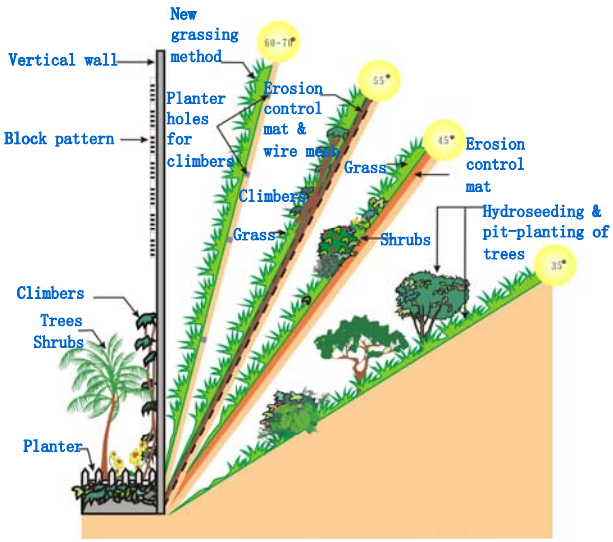

Figure 26 – Common methods of vegetating slopes

Technical Standards/Guidelines and Research

The role of vegetation in slope works was first promoted in 1984 when the technical guidelines on the use of grass, shrubs and trees for slope surface protection were published in the second edition of the Geotechnical Manual for Slopes. In 1999 a set of interim guidelines was stipulated in the revised GEO Report No. 56 (Wong et al, 1999) for prescriptive use of vegetation for soil cut slope up to 55°. In 2000, the GEO Publication No. 1/2000 – Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2000a) was promulgated, providing comprehensive technical guidance for use by the professionals in the planning, design, construction and maintenance of slope appearance enhancement measures. The publication was a pioneer document of the kind in the world. In recognition of its contribution to enhancement of the built environment, the publication received the Grand Award in the "Outstanding Green Project Awards 2000" organised by Leisure and Cultural Services Department in association with the Hong Kong Institute of Landscape Architects and the Society of Horticulture, Hong Kong. Another publication, Highway Slope Manual (GEO, 2000b) provides guidance on good practice on planning, investigation, design, construction and maintenance of highways slopes, covering both engineering and landscape aspects of slope design. GEO Report No. 116 (Halcrow China Ltd., 2001) presents a review of local

and international practice into reduction of visual impact of slopes and gives administrative and technical recommendations and proposals for further studies. Since 2002, a database called "Greening Methods on Slopes" was set up to consolidate updates of the information on the different new greening techniques that have been tried on government slopes.

On especially steep cut slopes, many new greening systems have been tried out. These systems are mostly proprietary products and generally involve the use of thick soil mulch, soil filled panels anchored onto the slope, planter-grillage system, or fibrous soil. In the past few years, more than twenty new greening systems have been applied to over 200 slopes in Hong Kong.

In the past few years the GEO in collaboration with the Kadoorie Farm and Botanic Garden has pioneered the research and study into the area of landscape treatment and bio-engineering on man-made slopes, including slopes with poor soil nutrition condition. Recently, the GEO has completed a planting trial of the use of native small tree and shrub species on steep slopes (Choi & Chau, 2004). The GEO has also completed a study (Lui & Shiu, 2004) in conjunction with the Department of Ecology & Biodiversity of the University of Hong Kong, on the review of the performance of different greening techniques and identification of vegetation that can successfully establish and self-sustain on steep man-made slopes. Based on the results of the planting trial and the study, guidelines on the selection of vegetation species for use on man-made slopes and suggested improvement to detailing and specification of the greening techniques were promulgated in 2004 under TGN No. 20 (GEO, 2004b). In this Annual Seminar, detailed findings of the planting trial at Yuen Tun (Hau et al, 2005), and the assessment of the growth condition of vegetation on slopes where the greening techniques have been applied, and evaluation of the engineering performance of the techniques (Lui et al, 2005) are described.

As part of the continuous improvement initiatives for achieving sustainability in slope greening works, the GEO is undertaking a further study on the application of various vegetation species on man-made slopes, aiming to expand the range of suitable vegetation species for landscape use in slope works. To promote the use of eco-friendly stabilization measures, the GEO is carrying out trial applications of bio-engineering measures for repairing natural terrain landslide scars, using predominantly native vegetation species. For preserving the appearance of old masonry walls and the wall trees, the GEO has embarked on a study to review the current practice and to identify improved measures in stabilization of old masonry walls.

Yuen Tun Vegetation Trial

To study the performance of vegetation establishment on steep man-made slopes, the GEO carried out a planting trial of eight native small tree and shrub species (Figure 27) at Yuen Tun, Tai Lam Country Park in collaboration with the Kadoorie Farm & Botanic Garden Corporation. Seedlings of 8 native species were planted on slopes with gradient of about 50° following hydroseeding. The trial commenced in July 2001 and monitoring of the vegetation growth has been carried out on a yearly basis.

According to the monitoring results, the survival rate of the plants is over 70% and the seedlings have grown over 100% from its original size. At places with more favourable soil and environmental conditions, some seedlings have become small trees. Among the eight species used in the trial, *Zanthoxylum avicennae* (Prickly Ash, 簕欓), *Schefflera*

heptaphylla (Ivy Tree, 鴨腳木) and *Gordonia axillaris* (Hong Kong Gordonia, 大頭茶) show better performance in terms of growth.

Figure 27 – Native vegetation species in Yuen Tun trial site

One observation of the vegetation trial at Yuen Tun is that the vegetation in the trial site is still mainly comprised of grass. The seedlings plants have not grown to create dense foliage cover to protect the slope surfaces. Although most of the seedlings have flowers and produce fruits, regeneration of the species from seed has not yet been observed. Other naturally recruited vegetations have invaded the trial panels to improve biodiversity of the vegetation system. A natural and sustainable vegetation system that requires minimum long-term maintenance can be anticipated. Based on the findings of the study, a number of recommendations for greening man-made slopes are being developed, with a view to establishing robust, cost-effective, and eco-friendly vegetation covers on man-made slopes.

Ecological Considerations

In addition to ensuring public safety, minimizing disturbance to the community during construction and enhancing slope appearance, the GEO is also very mindful of the ecological impact of slope works. In the past, the number of tree species commonly chosen for planting on man-made slopes is small. These include *Acacia confusa* (台灣相思), *Casuarina equisetifolia* (木麻黃), *Eucalyptus robusta* (大葉桉), *Eucalyptus citriodora* (檸檬桉), *Pinus elliottii* (愛氏松), *Tristania conferta* (紅膠木) and *Melaleuca leucadendron* (白千層). Very often, two to three of the above exotic species tend to dominate the slope cover. Dense canopy of exotic trees hinders the process of natural invasion of native species growing adjacent to the man-made slopes. Native plant species, which provide food and shelter are more suitable for local wildlife than exotic species. A biodiversified vegetation cover is ecologically stable and hence more sustainable. Establishing a sustainable vegetation cover on man-made slopes has been one of the long-term goals in slope greening. Ecological considerations play an important role in slope greening, as revealed by studies on the performance of vegetation establishment on man-made slopes.

The GEO is now making efforts to achieve ecological enhancement by adopting native species for restoring vegetation covers as far as possible, and protecting any rare plant species found on or in close proximity to the slopes to be upgraded under the LPM Programme. Ecological surveys are carried out where needed. GEO Information Note 16/2004 and GEO Information Sheet 17 (GEO, 2004d) promulgate the ecological enhancement in slope works.

The effort in preserving and protecting the native vegetation can be demonstrated in the following LPM projects in which rare plant species have been identified during ecological surveys.

- Project 1 – Slope upgrading works along South Lantau Road between Mui Wo and Pui O, Lantau: Wild orchids were identified on the slopes. Cages were provided to protect the orchids (Figure 28) during construction.

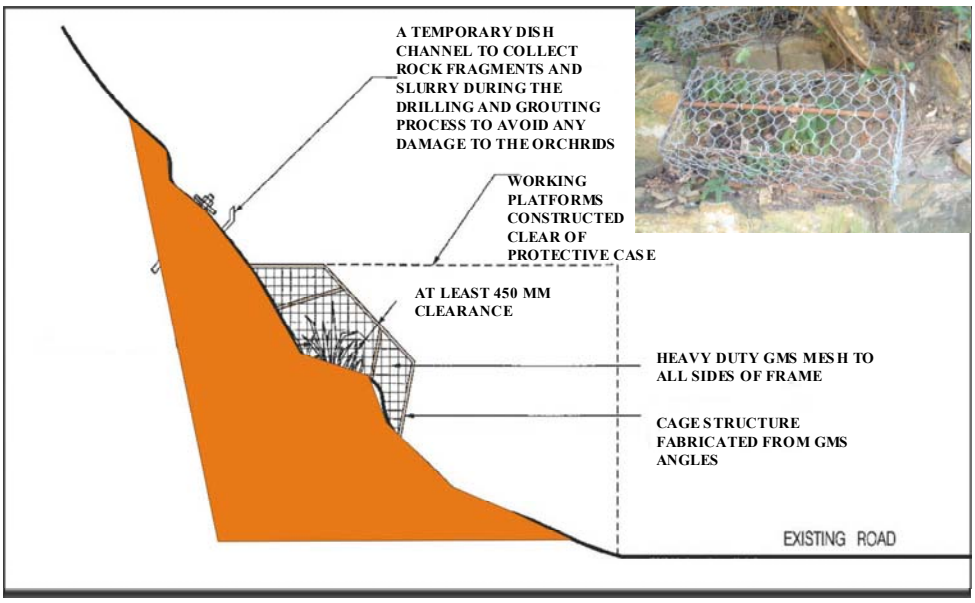

Figure 28 – Measures for protecting wild orchids in slope upgrading work sites

- Project 2 – Slope upgrading works along Keung Shan Road and South Lantau Road near Shek Pik Reservoir, Lantau: Chinese New Year flowers (Enkianthus quinqueflorus) (Figure 29) were identified. These flowers were classified as locally protected species found on a slope feature at Keung Shan. For those not affected by the works, the flowers were protected by chain link fence. If the flowers were affected by the works, the flowers were transplanted by a specialist landscape contractor.

Figure 29 – Chinese New Year flowers identified in a slope upgrading work site

Application of Bio-engineering Measures in Repairing Natural Terrain Landslide Scars

There are numerous natural terrain landslide scars in Hong Kong. In 2003, the GEO commenced a project to study and put on trial some soil bio-engineering measures to repair landslide scars on natural terrain (Campbell et al, 2005). The project was designed to identify measures with the potential to minimize natural slope deterioration, reinforce the soil mass, and improve resistance to debris movement. Five sites were identified to test the applicability and performance of the selected measures. Soil bio-engineering measures were designed and applied in various combinations at the Cloudy Hill North pilot site. Campbell et al (2005) describes these measures and presents some initial results. The findings are being documented to provide guidance on how to apply soil bio-engineering measures to other sites in Hong Kong.

Involve Private Slope Owners and Partnership with the Community

As one of the public education initiatives, the Layman's Guide to Landscape Treatment of Man-made Slopes and Retaining Walls was published in 2002 (GEO, 2002) for use by the general public. Following the publication of the Layman's Guide, a Slope Landscaping Kit was distributed to the Owners' Corporations, Mutual Aid Committees and Property Management Companies in the same year. To arouse the public's interest in enhancing slope appearance, the 'Best Landscaped Slope Awards' competition was organized jointly by the then Civil Engineering Department, the Professional Green Building Council, the Hong Kong Association of Property Management Companies, and the Hong Kong Institute of Landscape Architects in 2003. The response from the slope owners was overwhelming with 55 entries involving 90 slopes and retaining walls. The Awards Ceremony was held in February 2004 with the Champion slope awarded to Lung Tak Court, Stanley (Figure 30).

The enhancement in slope appearance has been made possible by promulgation of new technical guidelines, sharing of experience amongst practitioners and getting specialist advice from landscape experts where needed. Comprehensive technical guidelines on landscape treatment and bio-engineering for man-made slopes and retaining walls are now given in GEO Publication No 1/2000 (GEO, 2000a) described earlier.

Figure 30 – Best Landscaped Slopes Awards Prize Presentation Ceremony in February 2004 to promote enhancement of slope appearance and the champion slope at Lung Tak Court, Stanley

CONCLUSIONS

The overall landslide risk from old substandard man-made to the community of Hong Kong has been reduced significantly in the past two decades through the concerted effort of the HKSAR Government, the geotechnical profession and the private slope owners. A comprehensive Slope Safety System is in place to deal with the landslide problems. The scale and severity of the landslide problems in Hong Kong have been much reduced. Rapid development and advancement in technology will continue and that can open up more opportunity for its application in geotechnical engineering. Rising landslide risk from natural hillsides deserves increasing attention as more developments encroach closer to steep hillsides. On top of safety, the aesthetics of slopes are being enhanced, by integrating slope upgrading works and the provision of landscape treatment and bio-engineering at the design and construction stages. There is still much room for development and application. The Government has taken the lead in pioneering research and application of landscape treatment and bio-engineering in man-made slopes, and has started to extend its application to repair natural terrain landslide scars. Continuing joint efforts by the Government, the profession and the public need to be maintained so as to reduce the landslide risk, and to further enhance our surrounding environment – to make Hong Kong a safe and green place to live.

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ACKNOWLEGEMENTS

This paper is published with the permission of the Director of Civil Engineering & Development, Government of the Hong Kong Special Administrative Region.