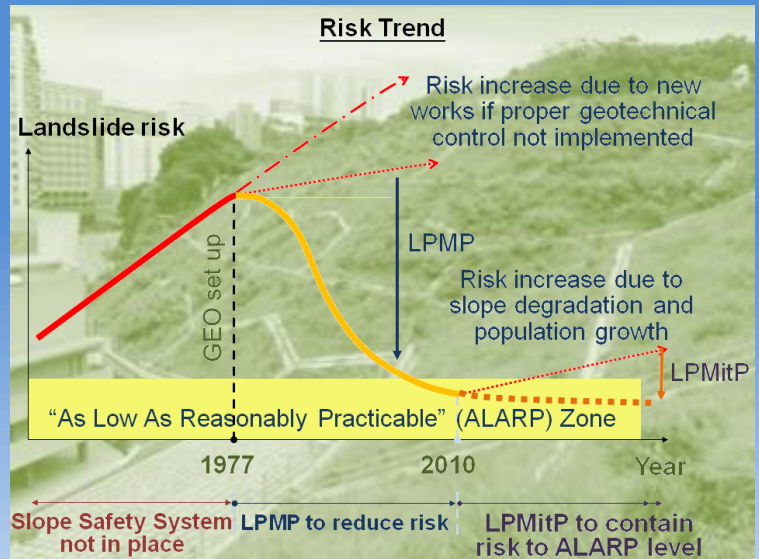
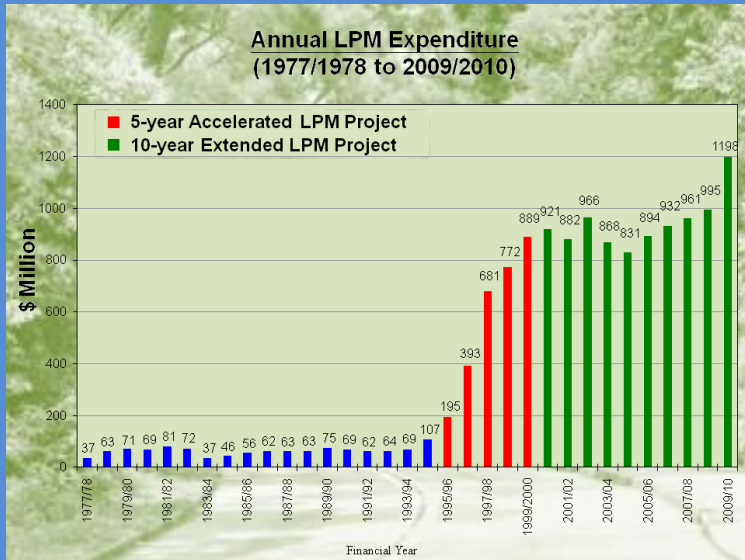


# Landslide Risk Reduction through Works

## *35 Years of Landslip Preventive Measures Programme and Beyond*

20 May 2011, Hong Kong



Jointly organised by



**Geotechnical Division**  
**The Hong Kong Institution of Engineers**



**The Hong Kong Geotechnical Society**

**Proceedings of the 31st Annual Seminar  
Geotechnical Division, The Hong Kong Institution of Engineers**

**Landslide Risk Reduction through Works:  
thirty-five years of landslip preventive measures  
programme and beyond**

**20 May 2011  
Hong Kong**

**Jointly organised by :  
*Geotechnical Division, The Hong Kong Institution of Engineers  
Hong Kong Geotechnical Society***

**Captions of Figures on the Front Cover**

Top-left: Annual LPM expenditure  
Top-right: A road-side slope in Lantau upgraded under LPM Programme in 2003  
Bottom-left: A 100 m high cut slope overlooking Sai Wan Estate in Kennedy Town  
being upgraded under LPM Programme in 2007  
Bottom-right: Landslide risk in Hong Kong

(By courtesy of the Geotechnical Engineering Office, Civil Engineering and  
Development Department)

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## Foreword

Landslide risk reduction through works to upgrade old man-made slopes is an important part of the slope safety efforts made by the Hong Kong Government since 1977. This was largely done through the Government's Landslip Preventive Measures (LPM) Programme. Starting from 2010, the LPM Programme is replaced by the Landslip Prevention and Mitigation Programme (LPMitP) to expand the scope to cover natural terrain landslide risk and the remaining man-made slopes. On this background, it is timely that the Organising Committee has chosen the topic on "Landslide Risk Reduction through Works: thirty-five years of landslip preventive measures programme and beyond" for this annual seminar.

Given the important role played by the geotechnical profession in Hong Kong in implementing the LPM Programme and the LPMitP, this seminar is for the geotechnical profession in Hong Kong to record and consolidate our experience in reducing landslide risk through works on upgrading of man-made slopes and to look ahead on challenges and means of meeting them. In addition to presentations on project management, technological and system improvement, challenges in construction, etc., we are honoured to have Ir Raymond Chan, the Head of the Geotechnical Engineering Office, to take us through the evolution of the LPM policy. I am confident that the Seminar will achieve its objectives and we will be better equipped in tackling further challenges ahead.

I would like, on behalf of the Geotechnical Division, to take this opportunity to thank Mrs Carrie Lam, our Guest of Honour; Ir Raymond Chan, our Keynote Lecturer; Ir M C Tang, our Invited lecturer; as well as presenters and authors of papers for their support. The contributions of the sponsors are also gratefully acknowledged. Lastly, I am grateful to the Organising Committee, under the leadership of Ir Y C Chan, and our activity supporters for their commitment and hard work in making this event a success.



Ir Ringo Yu

Chairman, Geotechnical Division (2010/11 Session)

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May 2011

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## TABLE OF CONTENTS

|    | <b>Keynote Lecture</b>                                                                                                                                                             | Page No. |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| 1  | Evolution of LPM Policy in the Past Thirty Five Years<br><i>R.K.S. Chan</i>                                                                                                        | 1        |
|    | <b>Invited Lecture</b>                                                                                                                                                             |          |
| 2  | Programme Management of Landslip Preventative Measures Projects<br><i>M.C. Tang</i>                                                                                                | 15       |
|    | <b>Papers</b>                                                                                                                                                                      |          |
| 3  | Geological Input to the LPM and LPMit Programmes 1972-2011<br><i>R.P. Martin &amp; K.C. Ng</i>                                                                                     | 29       |
| 4  | LPM project delivery, challenges from the design administration and construction perspectives<br><i>G.W.W. Ding, D.C. Chan &amp; F.S.T. Ling</i>                                   | 45       |
| 5  | Implementation of the Landslip Preventive Measures Project – Words from Some Contractors<br><i>T.K. Cheung, T. Lee &amp; R. Yu</i>                                                 | 53       |
| 6  | Safety-screening of Private Slopes under the Landslip Preventive Measures (LPM) Programme<br><i>S. H. Mak, Y.S. Au Yeung, K.C. Lam &amp; C.M. Wong</i>                             | 59       |
| 7  | Stakeholder Participation in the Implementation of Landslip Preventive Measures Projects<br><i>G.W.W. Ding, M. Tong &amp; K.T. Cheung</i>                                          | 65       |
| 8  | Construction of Slope Upgrading Works Along Busy Roads in Hong Kong<br><i>N.L. Ho &amp; M.J. Wright</i>                                                                            | 73       |
| 9  | Challenges of Landslip Preventive Measures Works with Complex Site Constraints: Case Study – Four Slope Features at Coombe Road<br><i>F.Y.K. Lee, B.S.W. Chu &amp; T.K.C. Wong</i> | 81       |
| 10 | Construction of Hand-dug Caissons for Slope Stabilization near the Peak Lookout<br><i>C.M. Wong, C.T.L. Lee &amp; R.C.M. Ting</i>                                                  | 91       |

|    |                                                                                                                                                                                                         |     |
|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 11 | Innovative Materials and Drilling Method adopted for Soil Nailing Works at Po Shan Road<br><i>C.M. Wong, C.T.L. Lee &amp; R.C.M. Ting</i>                                                               | 99  |
| 12 | Innovative Approach for Landslide Prevention – A Tunnel and Sub-vertical Drain System<br><i>S.F. Chau, J.C.Y. Cheuk &amp; J.Y.C. Lo</i>                                                                 | 105 |
| 13 | Challenges of Emergency Works and Landslide Risk Mitigation Works at Tai O, Lantau Island in the Aftermath of 7 June 2009 Rainstorm<br><i>F.S.T. Ling &amp; D.K.M. Heung</i>                            | 113 |
| 14 | Characteristics of Highways Department Roadside Slope Upgrading<br><i>V. Wong, T. Kok &amp; J. Chan</i>                                                                                                 | 121 |
| 15 | Upgrading Catchwater Slopes in Hong Kong<br><i>E.Y. F. Chan &amp; A.C.L. Cheung</i>                                                                                                                     | 129 |
| 16 | Science, Engineering Geology and the Landslip Preventive Measures Programme<br><i>S. Parry, J.R. Hart &amp; C.D. Jack</i>                                                                               | 135 |
| 17 | Some Recent Technical Advances in Slope Engineering Practice in Hong Kong<br><i>R.W.M. Cheung, T.H.H. Hui &amp; K. K.S. Ho</i>                                                                          | 145 |
| 18 | Evolution of Soil Nailing Construction Practice in the Past Decades<br><i>F.S.T. Ling, B.L.C. Cheung, C.L.H. Lam, T.K. Cheung &amp; J.M. Shen</i>                                                       | 153 |
| 19 | Application of Native Plant Species in the Landslip Preventive Measures Programme<br><i>I.O. L. Or, B.C.H. Hau &amp; R.W.M. Cheung</i>                                                                  | 163 |
| 20 | Application of Soil Bioengineering Measures to Man-made Slopes – A Pilot Study under the Landslip Preventive Measures (LPM) Programme<br><i>D.K.P. Cheung, R.P.M. Li, M.J. Lorimer &amp; L.H. Swann</i> | 171 |
| 21 | Landscape Design for Natural Terrain Hazard Mitigation Works at Tung Chung<br><i>J.C.Y. Tang &amp; C.W.M. Yeung</i>                                                                                     | 177 |
| 22 | Overview of Special Tasks in the Landslip Preventive Measures Programme<br><i>R.H.C. Law &amp; R.W.M. Cheung</i>                                                                                        | 183 |

|    |                                                                                                                                                             |     |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 23 | Technical Developments on Quality Assurance of Soil Nailing Works<br>under the Landslip Preventive Measures Programme<br><i>D.O.K. Lo &amp; W.M. Cheung</i> | 189 |
| 24 | Frequency Analysis of Extreme Rainfall Values<br><i>C.S.C. Tang &amp; S.P.Y. Cheung</i>                                                                     | 195 |
| 25 | Performance of Slopes Upgraded under the Landslip Preventive<br>Measures Programme<br><i>A.C.O. Li, J.W.C. Lau, C.L.H. Lam &amp; J. Cunningham</i>          | 201 |



# Evolution of LPM Policy in the Past Thirty Five Years

R.K.S. Chan

*Geotechnical Engineering Office, Civil Engineering and Development Department,  
The Government of the Hong Kong SAR*

## ABSTRACT

The combination of extremely hilly terrain, intense infrastructure and building developments and high seasonal rainfall renders Hong Kong to be susceptible to landsliding. Since its establishment in 1977, the Geotechnical Engineering Office has developed and implemented a comprehensive Slope Safety Management System to tackle the unique landslide problem in Hong Kong. One of the components of this System was the establishment of the Landslip Preventive Measures (LPM) Programme to systematically study and retrofit substandard slopes. Upon completion of the LPM Programme in 2010, some 4,500 government slopes were upgraded and 5,100 private slopes were safety-screened. The total expenditure of the Programme amounts to about HK\$ 14 billion. This keynote paper describes the background, rationale and evolution of the LPM Policy, key technical challenges, experience gained and achievement of the LPM Programme.

## 1 INTRODUCTION

Hong Kong has a small land area of about 1,100 km<sup>2</sup>. Only about 15% or 165 km<sup>2</sup> is developed land; the remaining 85% is woodland, country park areas or sparsely developed areas. The substantial economic expansion since the 1950's has been accompanied by extensive civil engineering and building works in both the public and the private sectors. The combination of extremely hilly terrain, deep weathered rock profiles and high seasonal rainfall has in the past resulted in some severe landslide problems in Hong Kong's dense urban environment.

In the 1960s, there was little statutory mechanism in controlling or government policy in regulating the slope formation works. Slope design and construction were based on rules of thumb, such as 10:6 cutting with 1 to 2 m wide berms at about 7.5 m vertical intervals giving an average slope angle of about 50° (Lumb 1975). Fill embankments were formed by end-tipping without any compaction, resulting in loose slopes at an angle of about 35°. Many of the man-made slopes were substandard and susceptible to landsliding during heavy rainfall.

## 2 LANDSLIP PREVENTIVE WORKS IN EARLY YEARS

In the late 1960s and 1970s, there were frequent landslides in Hong Kong claiming many lives. The rainstorm on 12 June 1966 caused widespread landsliding affecting densely populated housing estates and transport corridors. 64 people died and a further 48 went missing with more than 6,000 people directly affected.

On 18 June 1972 two disastrous landslides occurred rendering it the darkest day in the history of landslide disasters in Hong Kong. One of these landslides involved the collapse of a 40-m high road embankment in the Sau Mau Ping Resettlement Estate. The resulting flowslide engulfed a temporary housing area, killing 71 people and injuring 60 others (Figure 1). The other occurred in a steep hillside in a residential area at Po Shan Road. The debris demolished a 13-storey building, killing 67 people and injuring 20 others (Figure 2).

A commission of enquiry was set up amidst the ensuing censure to investigate into the causes of these landslides (Hong Kong Government 1972). These landslide disasters also prompted the Government to begin to put efforts on slope safety and allocate some resources to deal with the geotechnical problems arising from slopes. A Civil Engineering Unit was formed in the Buildings Ordinance Office (BOO) to carry out slope preventive works and geotechnical control of private building works.



Figure 1: Landslide at Sau Mau Ping in 1972



Figure 2: Landslide at Po Shan Road in 1972

Apart from engaging consultants to investigate and design remedial works for areas suffering from landslides, the BOO in 1973 also engaged consultants to initiate study on areas of potential instability. The study comprised two phases: the initial feasibility study was designated as Phase I and the detailed study to be followed up was designated as Phase II. The objective of Phase I Landslide Study was to locate and investigate areas of potential landslide hazard. It comprised conducting visual inspection of sizable cut slopes susceptible to landsliding in the urban areas of Hong Kong and Kowloon and categorization of these slopes for priority action. The study was completed in 1974.

The Phase II Landslide Study which comprised detailed investigation of areas identified in Phase I as requiring urgent study commenced in 1974. Implementation of Phase I and II recommendations for potentially dangerous slopes and walls on government land was carried out by government departments responsible for maintenance of the slopes concerned, e.g. the Civil Engineering Office, Highways Office and Water Works Office at the time.

Furthermore, the then Highway Office in 1974 completed a review of rock slope design problems in Hong Kong (Golder Associates 1974). The review summarized the main types of rock slope problems encountered and presented design methods to address them.

### 3 EARLY LPM WORKS BY GEOTECHNICAL CONTROL OFFICE (GCO)

In 1976, another disastrous landslide occurred at a 35-m high embankment in Sau Mau Ping, killing 18 people and injuring 24 others (Figure 3). The Government quickly appointed an Independent Review Panel comprising local and international geotechnical experts to investigate this landslide and make recommendations to deal with the slope safety problems in Hong Kong. The investigation revealed that the fill of the failed embankment was formed by end-tipping and was not adequately compacted. In view of the possibility that such conditions might be widespread, the Government extended the Phase II Landslide Study to include identification and inspection of sizable fill slopes in the territory. 2351 fill slopes were subsequently identified, 670 of which were considered as posing high or moderate risk to the public.

The increased awareness of landsliding problems associated with rising ground water levels and surface saturation and the failure of two retaining walls in the Mid-levels in 1976 prompted the Government to re-appraise the Phase I Landslide Study. The Phase I Re-appraisal Study of Natural and Cut Slopes and Retaining Walls was carried out in 1977 to identify and record sizeable slopes in Hong Kong. Over 8,000 sizable cut slopes, natural slopes and retaining walls were identified and registered. These 8,000 slopes together with the fill slopes identified in Phase II Landslide Study formed the first slope catalogue in Hong Kong and was commonly referred to as the 1977/78 Catalogue of Slopes.

In view of the probable widespread occurrence of potentially unstable slopes, the Independent Review Panel recommended to establish a government control body to provide continuity throughout the whole process of investigation, design, construction, monitoring and maintenance of slopes in Hong Kong (Hong Kong Government 1977). In 1977 the Geotechnical Control Office (GCO) in the Public Works Department (PWD) and the Geotechnical Control Branch (GCB) of the BOO were established. The GCO dealt with slopes on government land, while GCB was concerned with the stability of slopes on private land. This marked the



Figure 3: Landslide at Sau Mau Ping in 1976

turning point in the history of slope safety in Hong Kong. In 1983, the GCO and GCB were amalgamated and was later renamed as Geotechnical Engineering Office (GEO) in 1991.

Since its establishment, the GCO has developed and implemented a comprehensive Slope Safety Management System (Chan 2000) to tackle the unique landslide problems in Hong Kong. One of the key components of the System was the establishment of the Landslip Preventive Measures (LPM) Programme to retrofit substandard government slopes and safety-screen private slopes that were formed prior to the establishment of GCO. Ranking systems were devised to accord priority of slopes for action under the LPM Programme. The GCO undertook stability studies on both selected government and private slopes to determine which of them required stabilization works to bring to a satisfactory standard of safety. For private slopes with prima facie evidence indicating a potentially unstable situation, the GCO would make recommendations to the BOO to serve statutory Dangerous Hillside Orders (DHO) on the private owners requiring them to take necessary investigations and preventive actions. For government slopes found to be substandard, the GCO would initiate LPM actions.

Immediately after the Sau Mau Ping landslide in 1976, emphasis was given to find and retrofit more than 100 loose fill slopes amongst the extensive platform areas on which public housing had been constructed in the 1960s and 1970s. Substandard loose fill slopes were retrofitted by recompactifying the top 3 m of the fill bodies (Figure 4). Other novel techniques such as dynamic compaction (Figure 5) and the installation of sand compaction piles had also been experimented to identify means to expedite the treatment of loose fill slopes (Lam 1980). Substandard cut slopes were generally stabilized by cutting back the slope face to a flatter gradient. The design and supervision of engineering works were entrusted to the consultants until 1983, when it was taken over by GCO and handled by in-house staff.



Figure 4: Recompaction of Loose Fill Slope



Figure 5: Dynamic Compaction of Loose Fill Slope (Lam 1980)

In its early years, the GCO carried out preventive works on about 25 slopes each year under the LPM Programme with an annual expenditure of about HK\$30 to 70 million. Slopes and retaining walls affecting occupied buildings, particularly those at public housing estates, schools and hospitals, were given the highest priority.

#### 4 LPM WORKS IN THE 1980s

Following up on the Phase II Landslide Study, the GCO conducted area studies to examine the landslide hazards on an area basis. For example, an evaluation of the stability of 14 rock slopes which were located in close proximity to existing buildings in North Point was carried out and resulted in implementing stabilization works to these rock slopes (Golder Associates 1981).

In the aftermath of the Po Shan failure in the Mid-levels in 1970s, a major geotechnical study of the Mid-levels area of Hong Kong Island was carried out between 1979 and 1981 (GCO 1982). The Study involved an extensive technical appraisal on the geological, hydrogeological and soil properties of the northern side of Victoria Peak covering an area of about 150 hectares from the University of Hong Kong to Glenealy Valley (Figure 6) and generated a set of geotechnical controls for the development in the Mid-levels area (commonly known as Scheduled Area No.1). The Study also gave rise to the groundwater drainage works in the vicinity of the Po Shan hillside to improve its stability by lowering the groundwater. A total of 73 horizontal drains with lengths of up to 90 m were installed between 1984 and 1985.

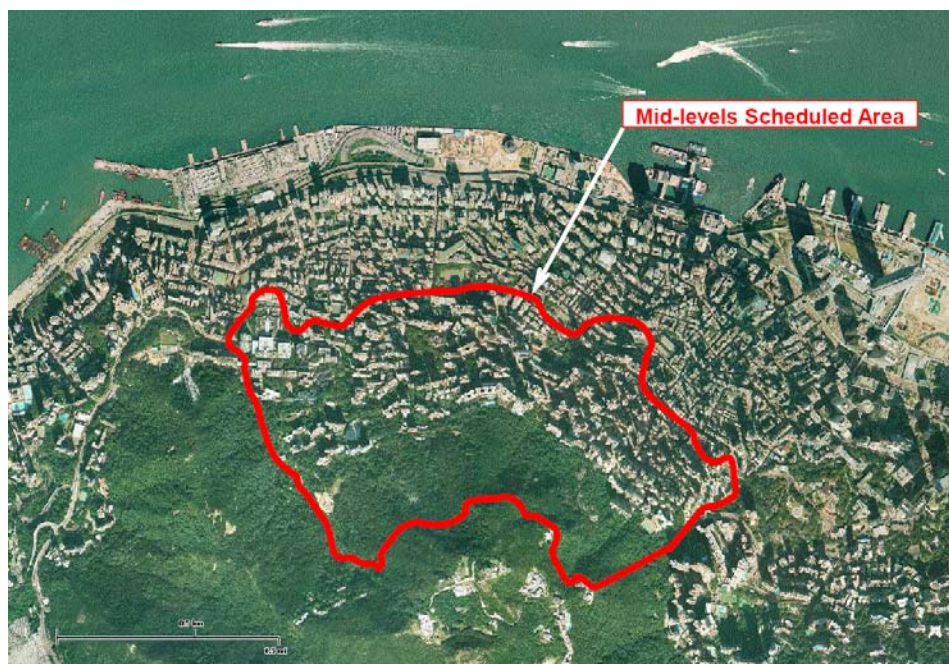


Figure 6: Mid-levels Scheduled Area

A boulder fall incident occurred in 1981 resulting in one casualty. It prompted the GCO to initiate the Mid-levels Boulder Field Preventive Works Pilot Scheme on the natural hillsides above Conduit Road which had a history of boulder falls. The study aimed at developing techniques for mapping the boulder field and identifying suitable strategy for boulder treatment. This study led to the insitu stabilization of boulders and the construction of a flexible boulder fence (Figure 7) in mitigating the boulder fall hazard in the area (Chan et al. 1986; Au & Chan 1991).

The GCO undertook a number of initiatives in the early 1980s to facilitate the screening of slopes and retaining walls for priority action and to expedite the delivery of LPM Programme.

- A masonry retaining wall study was conducted in 1981 (Chan 1982) to examine the construction practice and structure of masonry walls in Hong Kong. It reviewed past failure incidents (Figure 8) to gain better understanding of their structural behavior and put forward investigative techniques and remedial actions for masonry walls.
- A study designated as “CHASE” (Cut Slopes in Hong Kong – Assessment of Stability by Empiricism) was carried out to aim at establishing simple means to expedite stability assessments for existing slopes and design of cut slopes in weathered soils. Data on stable and failed slopes (Figure 9) were analyzed to develop some simple semi-empirical guidelines for initial stability assessment for cut slopes (Brand & Hudson 1982).

The efforts of the LPM Programme came under test in 1982 by two severe rainstorms resulting in 27 fatalities caused by landslides, mostly in squatter areas (Figure 10). Contrary to the 1972 and 1976 landslide disasters, the fatalities were resulted from relatively small and isolated incidents. No fatal failure occurred in any of the major slopes and this was cited as evidence that the slope safety efforts had been effective (Bowler & Phillipson 1982). The 1982 landslide incidents prompted the introduction of the systematic Non-development Clearance Programme in 1985 by the Government for squatters on vulnerable hillsides in the urban areas of Hong Kong, where squatters considered to be subject to undue landslide risk would be recommended for clearance on slope safety grounds.

In the late 1980s, the scope of the selection process for slopes to be included in the LPM Programme was extended to cover slopes posing a high indirect consequence to life, e.g. slopes affecting a sole access to a hospital and slopes adjoining catchwaters, etc. The focus of the LPM Programme remained on treating slopes affecting occupied buildings.



Figure 7: Boulder Fence at Mid-levels



Figure 8: Failure of a Typical Masonry Wall

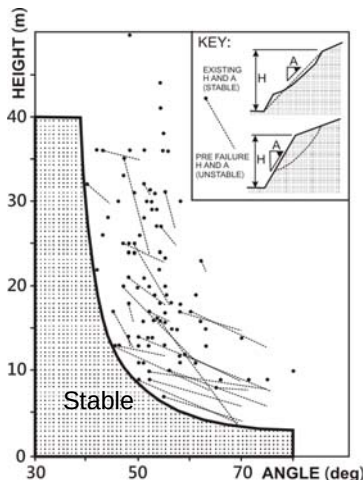


Figure 9: A Typical CHASE Plot for Slopes in Granitic Soils

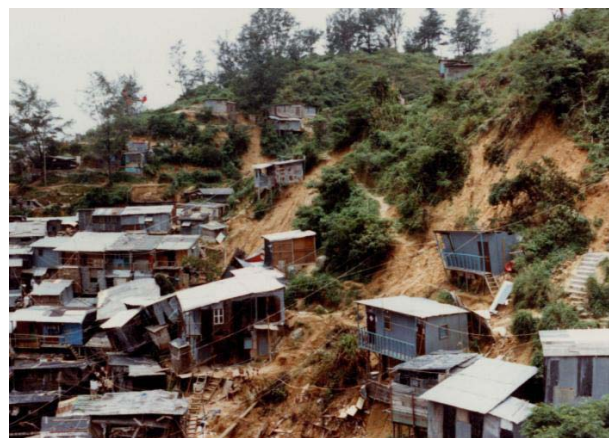


Figure 10: Landslides in Squatter Area in 1982

On average, the annual output of the LPM Programme in the 1980s was upgrading about 30 government slopes with an annual expenditure of about HK\$ 62 million (Figure 11).

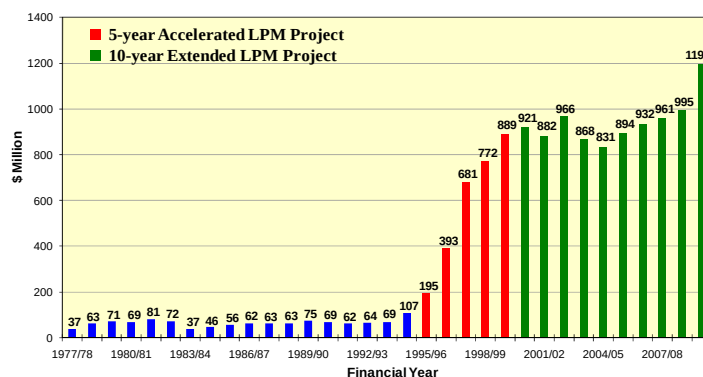


Figure 11: Annual LPM Expenditure

## 5 PROGRESSION OF LPM PROGRAMME IN 1990s – REACTION TO FAILURES

By early 1990s, there was significant reduction in fatalities caused by landslides (Figure 12) and the proportion of landslides affecting buildings had drastically reduced. It was considered by some people at the time that the LPM Programme had completed its historical role. At the same time, the expectation of the public continued to rise. With the resources the Government already invested in slope safety, the public was less tolerant of the occurrence of multi-fatality landslides. The previously secondary impact of landslides, viz. temporary closure of roads and building evacuation, also became key issues. A few fatal landslides in the early 1990s (Chan et al 1996) prompted the GEO to adjust the course of its LPM initiative.

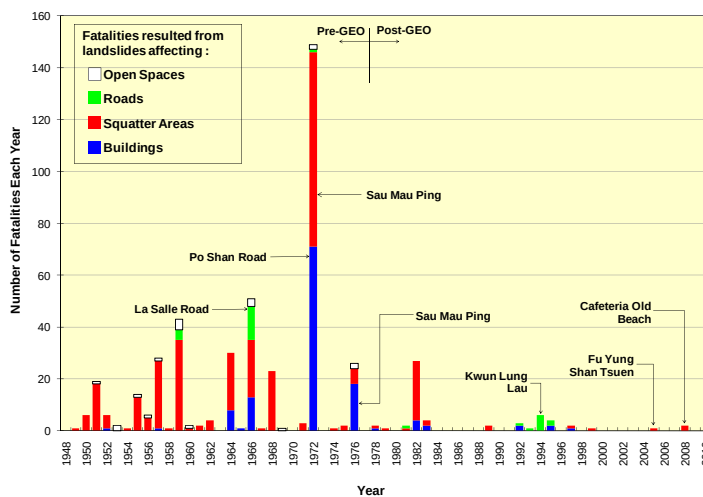


Figure 12: Landslide Fatalities in Hong Kong

A major landslide involving the failure of an unregistered masonry wall of 9 m high retaining a fill platform in a former dairy farm above Baguio Villas occurred in May 1992 (Figure 13). A large volume of loose fill materials was released and flowed down along a gully towards Baguio Villas causing two fatalities, five injuries and evacuation of 1,500 residents. This landslide brought to light that the 1977/78 Catalogue of Slopes was incomplete. It did not include all slopes formed before 1977 nor the many new slopes that have been formed since. Noting the need for a territory-wide slope re-cataloguing exercise, the GEO quickly launched the Systematic Inspection of Features in the Territory (SIFT) project to search for unregistered

slopes using aerial photograph interpretation in 1992. In 1994, the GEO commenced the 4-year Systematic Identification and Registration of Slopes in the Territory (SIRST) project to systematically identify, catalogue and register sizable man-made slopes in Hong Kong. When the project was completed in 1998, 54,000 slopes were catalogued.

On the morning of the Baguio Villas landslide, a fatal landslide also occurred at Kennedy Road killing one person and seriously disrupted the road traffic (Figure 14). In 1993, a landslide occurred on a cut slope adjacent to the Cheung Shan Estate bus terminus at Kwai Chung. The landslide debris inundated a bus shelter killing one person and injuring five others (Figure 15). The failures at these slopes affecting busy roads and pedestrian pavement were generally accorded a relatively low priority under the LPM Programme at the time. In consideration of the number of landslides at these slopes and the consequence of failures had been aggravated over the years due to increasing traffic density, more LPM resources were allocated to retrofit roadside slopes.

In 1994, the collapse of an old masonry wall below Block D of Kwun Lung Lau, which was previously assessed by a preliminary study under the LPM Programme as well as by geotechnical consultants engaged by the private owners, aroused considerable public outcry. The failure (Figure 16) resulted in five fatalities, three serious injuries and temporary evacuation of some 3,900 residents for fear of collapse of the building when its foundations were partly exposed after the failure. Public censure ensued when it was made known that only a small percentage of the slopes in the 1977/78 Slope Catalogue had been treated under the LPM Programme up to that time. Politicians called for a substantial injection of resources into slope safety.

The Government engaged Professor N.R. Morgenstern to carry out an independent review of the technical investigation of the Kwun Lung Lau Landslide undertaken by the GEO and to report on the adequacy of the



Figure 13: Landslide at Baguio Villas in 1992



Figure 14: Kennedy Road Landslide in 1992



Figure 15: Landslide at Cheung Shan Estate Bus Terminus in 1993



Figure 16: Kwun Lung Lau Landslide in 1994

Hong Kong Government's approach to slope safety. The Government took on board all of Professor Morgenstern's recommendations (GEO 1994). These included the launching of a systematic landslide investigation programme to provide a more integrated approach for slope stability studies and the setting up of a Slope Safety Technical Review Board to assist in enhancing technical quality improvement, keeping abreast of international standards of risk-taking and other aspects associated with the discharge of due diligence.

Landslide investigations not only advance the understanding of the causes and mechanisms of landslides, they also enhance slope engineering practice and the reliability of landslide preventive or remedial works. Through landslide investigations, the performance of the GEO's Slope Safety System is reviewed and areas for improvement are identified. The landslide investigation programme was launched in 1997 as a trial and was later integrated with the LPM Programme in 2000.

Subsequent to the Kwun Lung Lau landslide, a Slope Safety Review was conducted by the Works Branch (1995) which recommended that the LPM Programme should be accelerated to deal with the high-risk slopes. It also recommended that selected slopes of low consequence-to-life category affecting busy roads and footpaths should be included in the LPM Programme. The recommendations of the Slope Safety Review were implemented and in early 1995, a 5-year Accelerated LPM Project was launched to expedite by some 10 years the upgrading of the high-priority slopes in the 1977/78 Catalogue of Slopes. The pledged target was to upgrade about 800 government slopes and carry out safety-screening studies on about 1,000 private slopes. The Kwun Lung Lau landslide was a milestone event in that the GEO had introduced a number of measures to further improve its Slope Safety System.

## 6 5-YEAR ACCELERATED LPM PROJECT FROM 1995 TO 2000

The target of the 5-year Accelerated LPM Project pressed for a drastic increase in productivity by three times of that prior to 1995. To cope with the increase productivity, the GEO apart from boosting its staff resources by creating a new LPM Branch, also partnered with the geotechnical community to provide leverage on their resources by sourcing 80% of the bulk of LPM works to consultants. Programme management and project management concepts were adopted in the planning, initiation and monitoring of the 5-year Accelerated LPM Project to ensure delivery of the Project on time and within budget and to the satisfaction of the stakeholders.

In the mid to late 1990s, several slopes that had gone through a proper design process failed. These engineered slopes were designed by means of the limit equilibrium method to a slope gradient with an acceptable factor of safety and were constructed to the design profile. The slope failures highlighted the vulnerability of slope design (by cutting back) to uncertainties. Notable examples of slope failures were a landslide at a cut slope along a carriageway, Ching Cheung Road, in 1997 (Halcrow 1998) and a distressed cut slope affecting several public housing blocks at Shek Kip Mei in 1999 (Fugro Maunsell Scott Wilson Joint Venture 2000). The Ching Cheung Road and Shek Kip Mei landslides (Figures 17 and 18) highlighted the limitations of ground investigation and slope assessment practice and the vulnerability of cut slopes to adverse



Figure 17: Landslide at Ching Cheung Road in 1997



Figure 18: Landslide at Shek Kip Mei in 1999

geological features and hydrogeological conditions, which are hard to account for in the engineering geological model. The pragmatic approach of adopting more robust design solutions was called for. Examples of more robust design schemes are soil nailing, retaining structures, reinforced fill technology and toe support. Figure 19 shows that there has been increasing use of soil nailing in stabilizing slopes under the LPM Programme since the mid 1990s.

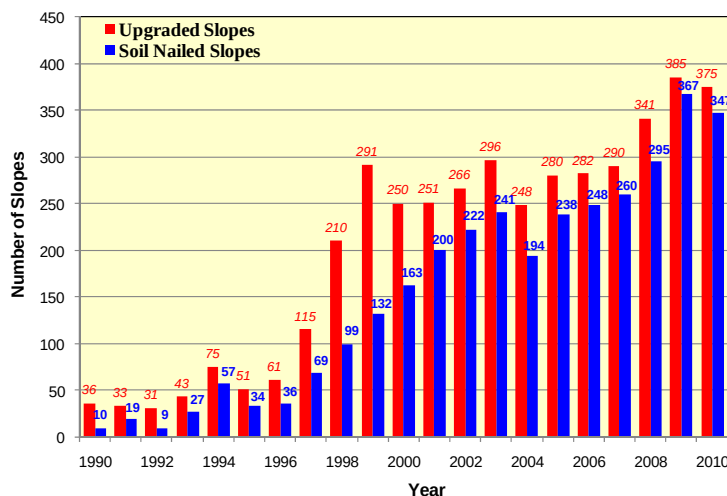


Figure 19: Number of Soil Nailed Slopes

The annual production of upgraded slopes between 1995 and 2000 was about 160 as compared with 50 in the preceding period. The annual expenditure for works was increased by more than seven-folds to about HK\$ 600 million and a total expenditure of HK\$ 2.93 billion was incurred in the whole of the Project. Upon completion of the LPM Project, 794 high-priority substandard government slopes affecting occupied buildings as well as busy roads and footpaths were upgraded; safety-screening studies were conducted on 1,461 private slopes with DHO served on 760 private slopes by the Buildings Department.

State-of-the-art quantitative risk assessment (QRA) conducted by the GEO indicated that upon the completion of the 5-year Accelerated LPM Project, the global landslide risk in Hong Kong posed by substandard man-made slopes was reduced to about 50% of that in 1977 (Cheung & Shiu 2000).

## 7 10-YEAR EXTENDED LPM PROJECT FROM 2000 TO 2010

When the New Slope Catalogue was completed in 1998, it contained records on some 54,000 sizable man-made slopes, about 65% of which were substandard. As part of Government's long-term strategy to improve slope safety in Hong Kong, the 10-year Extended LPM Project was launched in 2000 to dovetail with the 5-year Accelerated LPM Project. This 10-year Extended LPM Project dealt with the high-priority substandard man-made slopes in the New Slope Catalogue, including those slopes affecting developments and major roads/footpaths. The target annual output under the 10-year Extended LPM Project was to upgrade 250 substandard government slopes and to carry out safety-screening studies on 300 private man-made slopes. Similar to the Accelerated LPM Project, consultants were engaged in addition to deployment of in-house staff resources to implement the Project. The 10-year Extended LPM Project further expedited the annual LPM output in terms of the number of government slopes to be upgraded by another some 50% higher than that in the 5-year Accelerated LPM Project (Figure 20). The average annual expenditure on slope studies and upgrading works under the Project was about HK\$945 million - a historical high in the LPM Programme.

In addition to the 10-year Extended LPM Project, an Enhanced Maintenance Programme was also implemented by the Government to deal with the landslide risks from those high priority slopes not covered by the LPM Project. The responsible slope maintenance departments carried out preventive maintenance works, such as by means of prescriptive measures (Wong et al 1999), to achieve quick improvement to the stability of existing slopes. An integrated approach was adopted in government projects (e.g. road

improvement projects), in which the necessary investigation and upgrading works to existing substandard slopes were accommodated to minimize repeated geotechnical effort and disturbance to the local community.

The effectiveness and efficiency of the identification and selection of the most deserving government and private slopes for detailed studies and/or upgrading works under the LPM Programme were crucial to the productivity and outcome of the LPM Programme in terms of optimal risk reduction in the shortest time. To cope with the increased output of the LPM Programme, the public's high expectation of slope safety, together with traffic and environmental constraints imposed on LPM works, a Business Process Re-engineering (BPR) project on LPM slope selection was undertaken by the GEO in 1999 (GEO 2000). Key improvements made to the LPM slope selection process following the BPR Project included the development of an improved combined risk-based ranking system for selection of slopes (Wong 1998), fast-tracking of the letting of consultancies, enhancement of management and updating of slope data, integrated action through the 'lot-by-lot' approach for private slopes and 'local area' approach on a geographical basis for government slopes, etc.

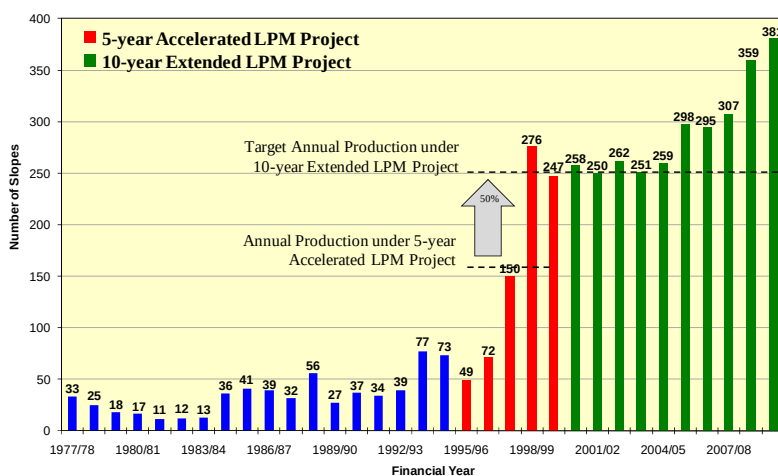


Figure 20: Number of Upgraded Slopes

The 10-year Extended LPM Project was successfully completed in 2010 with a total of about 3,100 government slopes upgraded and 3,300 private slopes safety-screened. It was estimated using QRA technique that the overall landslide risk posed to the community by the substandard man-made slopes in 2010 was reduced to less than 25% of that prevailing in 1977, reaching an as-low as-reasonably-practicable level that is commensurate with international best practice in risk management.

Apart from dealing with the high-priority substandard man-made slopes, the 10-year Extended LPM Project carried out special studies from time to time, for example:

- **Drainage Tunnels at Po Shan Hillside:** In the early 2000s, monitoring data showed that the groundwater levels in the vicinity of the Po Shan hillside were rather high locally during periods of heavy rainfall and that some of the horizontal drains, installed between 1984 and 1985, exhibited a decreasing trend of outflow. A study was commenced in 2005 and a more robust groundwater drainage system comprising drainage tunnels and sub-vertical drains, was designed and constructed between 2006 and 2009 to replace the horizontal drains.
- **Natural Terrain Hazard Studies:** Following the 'react-to-known-hazard' principle, studies and mitigation works to natural terrain landslide hazards were undertaken on an ad-hoc basis under the LPM Project. Most of these studies were conducted on sites affected by recent landslides, such as Sham Tseng San Tsuen (1999), Shek Lei Estate (2001), Tai O San Tsuen (2008) and Nam Chung Tsuen (2008). The expenditure incurred from these studies constituted less than 3% of that of the LPM Project (Wong 2009).

## 8 OVERALL OUTPUT AND ACHIEVEMENT OF LPM PROGRAMME

Since the late 1970s, about HK\$14 billion had been spent on studies and upgrading works on substandard slopes under the LPM Programme. The expenditure budget, commitment and spending under the LPM Programme for each financial year was strictly monitored and controlled. As a result, there had been no significant deviation (including both over-spending and under-spending) from the annual expenditure committed to Finance Committee of the Legislative Council.

By year 2010, the LPM Programme had completed detailed studies for about 4,800 government slopes, in which about 4,500 studied slopes were found substandard and subsequently upgraded by LPM works, and safety-screening studies for about 5,100 private slopes. The safety-screening studies resulted in the issue of DHO for about 2,500 private slopes under the Buildings Ordinance requiring the responsible private slope owners to undertake studies and necessary follow-up improvement works. In addition, about 5,000 government slopes had been dealt with under the Enhanced Maintenance Programme.

Through the implementation of LPM Programme, the landslide risk posed by substandard man-made slopes in 2010 was reduced to a reasonably low level of less than 25% of that in 1977. The success rate for slopes upgraded under the LPM Programme has been higher than 99.8%. The effectiveness of the LPM Programme is also reflected by the number of casualties caused by landslides, which has fallen sharply over the years.

Besides slope safety, special attentions were paid to construction site safety in the course of LPM works and the aesthetic aspects of slopes upgraded under the LPM Programme.

Construction site safety is particularly challenging in LPM works, which were carried out at height and on steeply-sloping ground. In 1998, the GEO started to implement a number of improvement initiatives and measures to promote and enhance site safety. Since then, the overall accident rate of LPM contracts had been significantly improved and maintained at a low level, being well below the threshold figure (a maximum accident rate of 0.6 accident per 100,000 man-hours worked) set by the Development Bureau (Figure 21).

With the increase on public expectations on slope appearance since 1990s, great effort was devoted to enhance the aesthetics of slopes upgraded under the LPM Programme. The Government has committed to make the appearance of engineered slopes as natural as possible, blending them with the surroundings and minimising their visual impact on the built environment. The commonly used methods are provision of vegetation covers with the use of erosion control mats as needed, masonry block facing, ribbed or other patterned finishes, toe planters, colouring and planter holes, coupled with suitable retention of existing vegetation. Since 2000, all man-made slopes upgraded under the LPM Programme have been landscaped, with specialist input from landscape architects (Chan 2005) and more than 50% of these landscaped slopes were “greened” (Figure 22).

Many innovations and significant technical advancements in slope engineering practice were also achieved under the LPM Programme through partnership between the Government and the geotechnical professions (Tang 2011).

By early 2000s, there was increasing difficulties in treating substandard loose fill slopes by excavating and recompacting/replacing the top 3 m of fill because of safety and environmental constraints such as instability of temporary cut slopes and removal of mature trees. In response, the GEO adopted the use of a “soil nails –

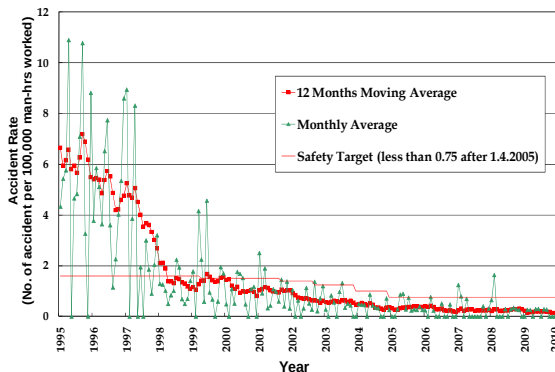


Figure 21: Accident Statistic in LPM Works Contracts

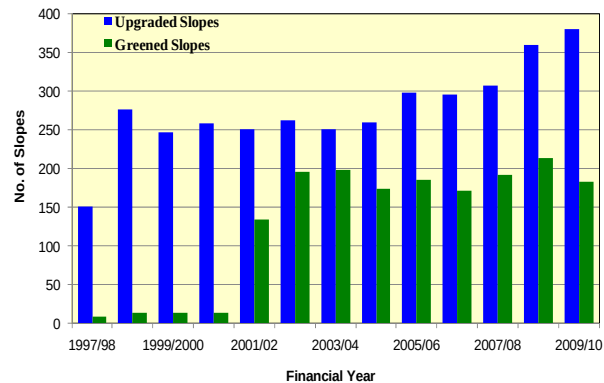


Figure 22: Number of Greened Slopes

grillage beams” system (HKIE 2003) in treating substandard loose fill slopes. This method has been proved to be robust, cost-effective and environmental friendly.

With the increasing use of soil nailing as slope stabilization measures under the LPM Programme, GEO conducted studies to further improve the soil nailing technology and rationalize the design approach. Some major advancements included improved detailing and approach for soil nail head design (Shiu & Chang 2004), enhanced knowledge on durability of steel soil nails and new practice on soil aggressiveness assessment and corrosion protection measures (Shiu & Cheung 2003). A guidance document on soil nail design and construction was published in 2008 (GEO 2008).

Incidents of “short piles” and “short nails” in the late 1990s and early 2000s aroused concern of the industry over the quality assurance of buried engineering works. To enhance the quality control of soil nailing works under the LPM Programme, the GEO strengthened site supervision and introduced independent site audits on soil nailing works, and in 2001 began to identify and try out potential non-destructive testing (NDT) methods that could be used to assess the quality of installed soil nails. The NDT methods are not to replace good supervision at the time of construction; they are to provide additional quality assurance and serve as a deterrent against mal-practices. Among the potential NDT methods examined, time domain reflectometry (TDR) was found to be the simplest, relatively quick and least expensive (Cheung 2003). In 2004, the GEO pioneered the use of TDR to audit its soil nailing works under the LPM Programme.

Maintaining slope safety is a long-term challenging project and its success would depend on the joint efforts and supports of the stakeholders, the general public in particular. The achievement of the LPM Programme has been astounding and is well appreciated by the community. The key factor to win the trust of the public is a clear and meaningful objective: Safe Slopes Save Lives.

## 9 WAY FORWARD

The Government’s concerted effort in the past some 30 years has brought about substantial improvement in slope safety and a significant reduction in the number of landslide fatalities in Hong Kong.

However, there are still remaining landslide risks to the community. The majority of the remaining landslide risk comes from about 15,000 moderate-risk man-made slopes affecting development and about 2,700 natural hillside catchments with known hazards and close to existing buildings and important transport corridors. If investment in slope safety were not maintained, landslide risk would progressively increase with time due to slope degradation and encroachment of more urban development or redevelopment on steep hillsides (Figure 23). This will cause, in addition to risk to life, significant economic losses and social disruption as a result of road blockages and building evacuation due to landslides, thereby compromising public safety, sustainable development and Hong Kong’s reputation as a modern metropolitan city and tourist hub.

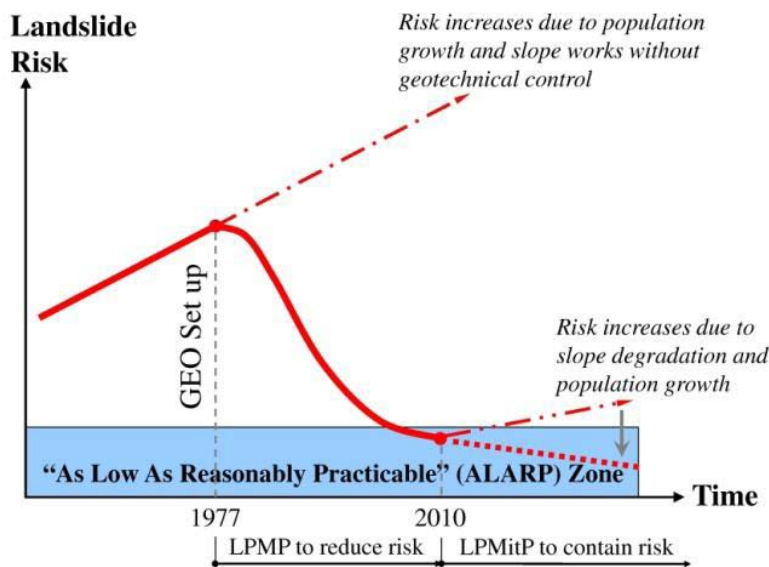


Figure 23: Landslide Risk in Hong Kong

In 2010, the GEO, with the support from the Legislative Council, launched the Landslip Prevention and Mitigation Programme (LPMitP) to dovetail with the LPM Programme, as a long-term rolling programme to deal with the remaining landslide risks arising from both man-made slopes and natural hillside catchments. The GEO and the geotechnical practitioners will continue to work together in a concerted effort to contain the landslide risks in Hong Kong to within an as low as reasonably practicable level.

## ACKNOWLEDGEMENTS

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# Landslip Preventive Measures Programme – Project Management from Client’s Perspective

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## ABSTRACT

Following the injection of additional resources into the Landslip Preventive Measures (LPM) Programme by the Government in 1995, the level of LPM output was boosted from upgrading about 30 slopes a year to about 160 slopes a year under the 5-year Accelerated LPM Project, and to about 250 slopes a year under the 10-year Extended LPM Project. At the peak production, there were about 40 active consultancy agreements, 40 active works contracts and 200 active construction sites close to existing development or busy roads at any time. Up to end 2010, about HK\$14 billion were spent under the LPM Programme. The planning, management, monitoring, communication and development of the different tasks under the LPM Programme is rather complicated. This paper summaries the key aspects relating to the project management from GEO’s perspective, including resources deployment, financial management, programme management, quality assurance and construction management. Some salient aspects of continuous improvement are also highlighted.

## 1 INTRODUCTION

Given the dense development in a mountainous terrain coupled with seasonal torrential rainfall in Hong Kong, slope safety used to be one of the key areas receiving the attention of the HKSAR Government. A Landslip Preventive Measures (LPM) Programme was launched by the Geotechnical Engineering Office (GEO) (known as Geotechnical Control Office (GCO) before 1991) in 1977 to retrofit substandard Government slopes and safety-screen private slopes that were formed prior to the establishment of GCO. At the start, the effort was focused on sizeable slopes threatening residential buildings and important facilities such as hospitals and schools; the number of slopes upgraded each year was about 30. Following the endorsement of the recommendations of a slope safety review, which was conducted by the then Works Branch (1995) in response to a fatal landslide in 1994, additional resources were injected into the LPM Programme in 1995 to boost the level of LPM output from upgrading about 30 slopes a year to about 160 slopes a year under the 5-year Accelerated LPM Project in 1995-2000. The level of LPM output was further increased progressively in the 10-year Extended LPM Project in 2001-2010. In 2009 and 2010, the annual output of the LPM Programme in respect of upgrading of substandard Government slopes reached a peak level of 380, i.e. 2.4 times of the output in 1995-2000 and 13 times of the output in early years (Figure 1).

More than 90% of the registered man-made slopes in Hong Kong have a height less than 20 m. The typical LPM works to a registered man-made slope costs less than HK\$3 million. LPM works

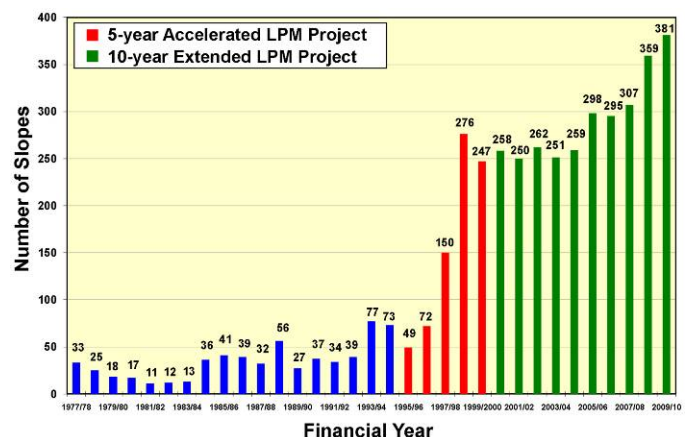


Figure 1: Number of Government slopes upgraded under the LPM Programme

for individual slopes are relatively minor comparing with the large capital works project under the Public Works Programme (PWP) of the HKSAR Government. However, at peak production, more than 300 slopes are upgraded in a year, and there are about 40 active consultancy agreements, 40 active works contracts and 200 active construction sites close to existing development or busy roads involved in the LPM Programme at any time. Up to end 2010, about HK\$14 billion were spent under the LPM Programme (Figure 2). The planning, management, monitoring, communication and development of the different tasks under the LPM Programme is rather complicated (Tang et al. 2007).

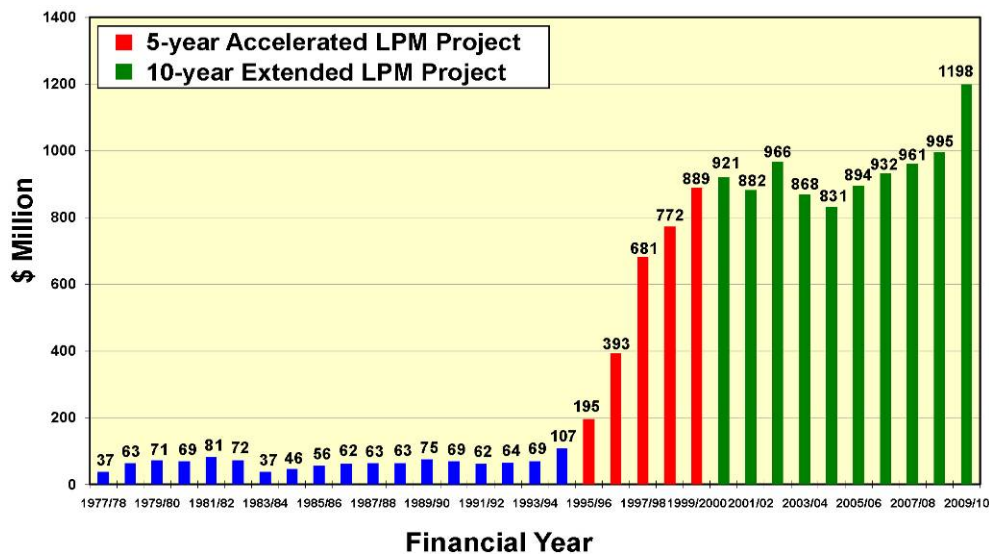


Figure 2: Annual expenditure under the LPM Programme

The concept of project management has been strengthened in the LPM Programme since 1995. Centralised supporting units, guidelines, and management and communication forums at different levels were set up to ensure timely delivery of quality output within the approved budget. This paper summaries the key aspects relating to the management of the LPM Programme.

## 2 RESOURCES DEPLOYMENT

### 2.1 Organisation within GEO

Before 1995, LPM output was delivered mainly by one division (the Design Division) in the GEO (Figure 3). After the injection of additional resources in 1995, a new LPM Branch, comprising two divisions (the Design Division and Works Division) and a Project Management Unit, was set up in 1995. In 1996, the Project Management Unit was subsumed under the newly established Landslip Investigation Division (Figure 4), which was responsible for overseeing the implementation of the systematic landslide investigation initiative and management of projects under the LPM Programme. The then Landslip Investigation Division, Design Division and Works Division were renamed as LPM Division 1, 2 and 3 respectively in 2004.

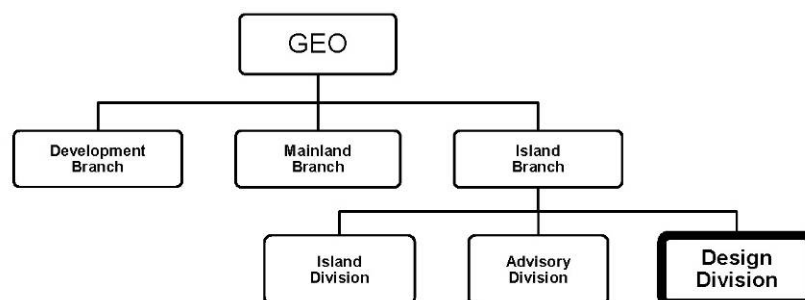


Figure 3: Organisation of the GEO before 1995

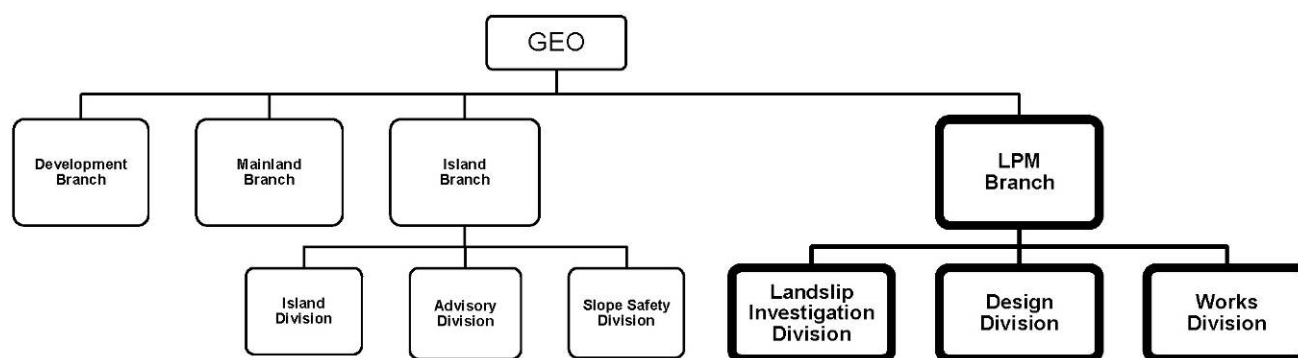


Figure 4: Organisation of the GEO in 1996

Apart from these key players, many other Divisions in the GEO including the Slope Safety Division, Geotechnical Projects Division, Standards and Testing Division, Planning Division and the three District Divisions are involved with the LPM Programme by providing support on safety-screening of private slopes, slope information system, ground investigation (GI), laboratory testing, setting standards and quality control. These supporting divisions also undertake some consultants management duties.

## 2.2 Engagement of LPM consultants

In the early years of the LPM Programme, consultants were engaged for the study and upgrading of fill slopes, while in-house staff were gradually established to deal with the fill slope problem as well as other types of slope features (e.g. cut slopes, rock slopes and retaining walls). From 1983 onward, the design and supervision of LPM works were handled by GEO in-house staff. Since 1995, in order to cope with the acceleration of the LPM Programme, the GEO had engaged private geotechnical practitioners again and in a large scale. Geotechnical consultants were engaged for studies, design and administration of works contracts for the LPM Programme. In recent years, about 10 LPM consultancy agreements were let every year. To facilitate the selection of consultants, a long list of LPM consultants was established. Currently, there are about 30 consultants in the list. To maintain corporate competence in LPM design and construction, the GEO continues to undertake in-house design and administer works contracts for the delivery of about 20% of the LPM output.

## 2.3 Establishment of the LPM specialist contractors list

When the LPM Programme commenced in 1977, contractors from List I and List II under the category of Site Formation and Roads & Drainage were invited to tender for the LPM works. With the experience gained in dealing with the LPM works in the 1980's and early 1990's, the GEO recognised that the nature of LPM works was different from normal site formation or roads & drainage works. LPM works comprise construction of various kinds of slope stabilisation measures (e.g. cutting back, soil nailing, rock slope treatment, surface protection, etc.) close to occupied buildings or adjacent to busy roads. Access to sites was generally difficult, and the working space was often severely restricted. It is envisaged that only contractors who are experienced in the LPM works and have a suitably skilled labour force and appropriate equipment and plant are capable of carrying out the job in a timely, cost effective and safe manner. Time consuming pre-qualifications exercise was required to avoid engagement of inexperienced contractors under the category of Site Formation and Roads & Drainage. With the rising public awareness on slope safety in the early 1990's, GEO also observed a demand from the private slopes owners/agents for a list of specialist contractors for LPM works. In light of these, the LPM specialist contractors list (i.e. List of Approved Suppliers of Materials and Specialist Contractors for Public Works under the Category of "Landslip Preventive/Remedial Works to Slopes/Retaining Walls") was established by the then Secretary for Works in November 1994. So far, a total of 169 contractors had made requests for inclusion into the LPM specialist contractors list. 59 of these contractors got through the assessment and were included in the list. Regular vetting of the contractors on the list was conducted. 21 contractors were subsequently found no longer meeting the criteria and were removed from the list, and there are currently 38 contractors in the LPM List.

### 3 FINANCIAL MANAGEMENT

#### 3.1 Establishment of the LPM Block Vote

LPM projects were initially funded as individual projects under the Government's PWP. Under this arrangement, a programme on the individual LPM works projects was submitted to the Finance Committee of the Legislative Council for upgrading to Category A projects for funding allocation each year. This process of annual programme submission and funding allocation was not very effective in coping with the ongoing and changing nature of the LPM works and in meeting the public demand on quick handling of the large amount of potentially substandard slopes. It lacks flexibility in allowing changes of scope and priority after the slope upgrading works design and in reflecting the realistic cost and programme of the individual works items which might vary at different stages of a LPM project. Furthermore, due to its unpredictable nature, no exact allowance could be made in the annual programme for major remedial works to slopes following landslides.

In December 1983, the Finance Committee approved the creation of a new block allocation – Subhead 5001BX under Head 705 Engineering for LPM (i.e. the LPM Block Vote). Under the block allocation, funding is allocated to the LPM Block Vote based on the programme and estimates of the funding required for all the LPM work items on an annual basis. The vote controller, Director of Engineering Development (now the Director of Civil Engineering and Development) is authorized to control the distribution of the block allocation to individual LPM work items provided that the overall annual allocation is not exceeded. A Landslip Preventive Measures Committee (LPMC) chaired by the GEO with members from all the departments involving in expenditure under the LPM Block Vote was set up to advise on matters relating to the administration of the block vote.

Before the creation of the LPM Block Vote in 1983, there were only 31 LPM projects in Category A of the PWP. In 2010, there were more than 400 active LPM work items, each covering studies, GI, upgrading works, urgent repair works or a combination of the above. Creation of the LPM Block Vote has proven to be a major breakthrough in financial management, without which the vast LPM output would not be possible.

#### 3.2 Control on expenditure

Realistic estimates and expenditure within and close to the budget are always the basic requirements for Government projects. Although the LPM Block Vote allows changes of distribution of fund amongst different LPM work items, stringent internal monitoring and control mechanisms had been imposed to ensure proper control on expenditure of all individual projects. All individual projects need to go through the internal procedure of defining the scope, preparing an estimate and seeking approval for fund allocation. Approval has to be sought for any changes in the scope and allocation. Dedicated programme management teams have been established in the LPM Branch to coordinate the funding application and monitor the expenditure situation of all the LPM items. Data on progress and expenditure from all LPM projects are collected centrally and the LPM Programme Managers' (the Chief Geotechnical Engineers of GEO concerned) attention is drawn to any potential problems that might result in the actual expenditure of the LPM Block Vote being seriously deviated from the allocation so as to trigger the timely remedial measures such as changes of programme in other LPM projects and application of supplementary provisions from the Finance Committee.

Apart from the monitoring by the programme management teams, there are management meetings at different levels from Development Bureau to senior professionals, to manage and monitor expenditure under the LPM Block Vote. The management meetings include the CEDD House Keeping Meeting chaired by the Permanent Secretary for Development (Works), the Public Works Programme Management Meeting chaired by the Director of Civil Engineering and Development, the LPM Programme Manager Meeting and the LPM Expenditure Meeting chaired by the Deputy Head of the GEO (LPM), and the progress meetings with consultants and contractors chaired by the project teams. Furthermore, ad-hoc meetings are organised with the top management of the consultants and contractors to settle individual problems on a need basis. With the extensive network on control and monitoring, GEO had managed to achieve an expenditure of 98% to 99% of the annual allocation under the LPM Block Vote in the recent years (Figure 5).

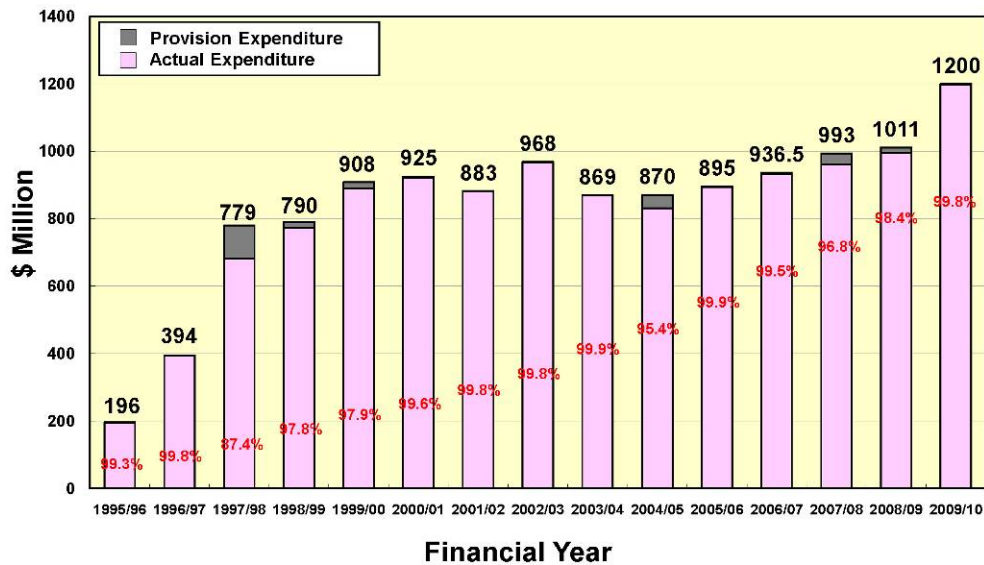


Figure 5: Annual expenditure under the LPM Programme against the annual allocation (1995/96-2009/10)

## 4 PROGRAMME MANAGEMENT

### 4.1 Slope prioritization and selection

The LPM Programme targets to reduce the overall landslide risk by the greatest degree within the shortest possible time by dealing with the sizeable substandard man-made slopes posing the highest risk to the community. Figure 6 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 occupied buildings and major roads (facility group 1).

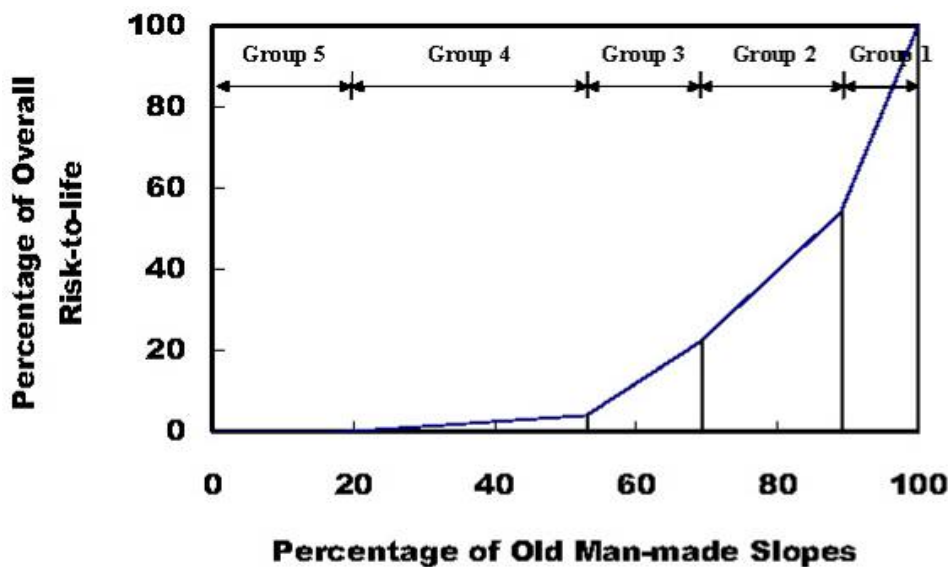


Figure 6: Risk profile of old man-made slopes

Given the large stock of registered man-made features, a risk-based prioritization system is required to enable that the most deserving slopes would receive priority attention. At the initial stage of the LPM Programme when the knowledge and key data on slopes and landslides were rather limited, a qualitative risk

ranking system was developed for prioritization. This initial ranking system relied heavily on the engineering judgment of professional geotechnical engineers on the likelihood of landslides assessed through site inspections. The factors that could affect instability potential were not explicitly taken into account. Experience indicated that the system was satisfactory in differentiating the top 10% to 20% of the slopes posing the highest risk for LPM action in the initial stage of the LPM Programme. These slopes were mainly those affecting occupied buildings and major roads.

With the improved knowledge of landslides especially in respect of failure mechanisms and debris mobility, and the availability of more landslide data and key slope attributes, a new priority classification system (NPCS) with enhanced resolution to more effectively prioritize all the high risk slopes was developed in the mid 1990's (Wong 1998). The NPCS is an expert formulation system which requires basic data on likelihood of landslides (instability scores, IS) and consequence of landslides (consequence scores, CS). The engineering judgment element on likelihood of landslide is relatively light for the NPCS. Extensive calibration work was done to assist in formulating the scoring formulae and establish the numerical weightings.

As the factors that govern the likelihood and consequence of landslides on soil cuts, rock cuts, fill slopes and retaining walls can differ significantly, different data and formulae were devised for the different types of slopes. The ranking scores for the different types of slopes (i.e. soil cuts, rock cuts, fill slopes and retaining walls) were merged based on the relative risk of each of the slope types.

The data pertinent to the ranking score of a slope feature may become outdated due to change in land use, environmental change, recent signs of distress, etc. Hence, the key data pertinent to a slope needs to be reviewed before the selection of the slope for LPM action. In recent years, a typical LPM consultancy agreement (for upgrading about 30 slopes) will review and update the data of about 100 slopes, which was about 1% of all the high risk slopes built with limited geotechnical input before the setting up of GCO in 1977. After the data updating process, the most deserving slopes are selected. These are generally high-ranking slopes with scores above the 'cut-off' level. High risk Government slopes in clusters will be included under the same LPM project following the "local area approach" to enhance efficiency of construction, and private slopes in the same building lot will be selected for safety-screening studies at the same time so as to ensure that all Dangerous Hillside Orders for the same private lot can be issued in one go. A dedicated team (the Slope Selection Team) has been established in the LPM Branch to package slopes into consultancy agreements for data updating, oversee the data updating exercise to ensure consistency, work in partnership with the project teams to select the most deserving slopes and facilitate the endorsement of the recommended slope selection by the LPMC. The Slope Selection Team also maintains an overall picture of the status of slopes pending upgrading.

Other than the GEO, other Government departments may improve the stability of existing slopes through development projects or preventive maintenance programmes. Slopes that will be dealt with under development projects will not be selected for LPM action. The coordination between the LPM Programme and the ongoing preventive maintenance programmes of the slope maintenance departments is exercised under the LPMC. The LPMC provides guidance to the slope maintenance departments on the priority setting for the preventive maintenance programmes so that the preventive maintenance programmes would focus on the slopes that do not receive priority attention under the LPM Programme. To avoid duplication of effort, all slopes to be included in the LPM Programme and the preventive maintenance programmes are subject to the endorsement by the LPMC. The GEO's Slope Selection Team provides the secretariat support to the LPMC and coordinates slope selection for the LPM Programme and the preventive maintenance programmes.

#### *4.2 Monitoring of LPM output*

A target output in terms of the number of Government slopes upgraded and the number of safety-screening study conducted for private slopes is set each year. Under the 10-Year Extended LPM Project, about 250 Government slopes are upgraded (Figure 1) and 300 safety-screening studies are conducted each year (Figure 7). In order to ensure that the annual target output is met, the programme management teams plan ahead taking into account the lead time required for consultants selection, site investigation, slope design and construction. The estimated output from each LPM project is monitored closely and timely contingency measures will be taken to address any potential delay. The programme management tool of "stagger chart" (Groves 1983) is used to keep track of the estimated and actual monthly output (Figure 8). The output is also monitored by the various management meetings at different levels along with expenditure.

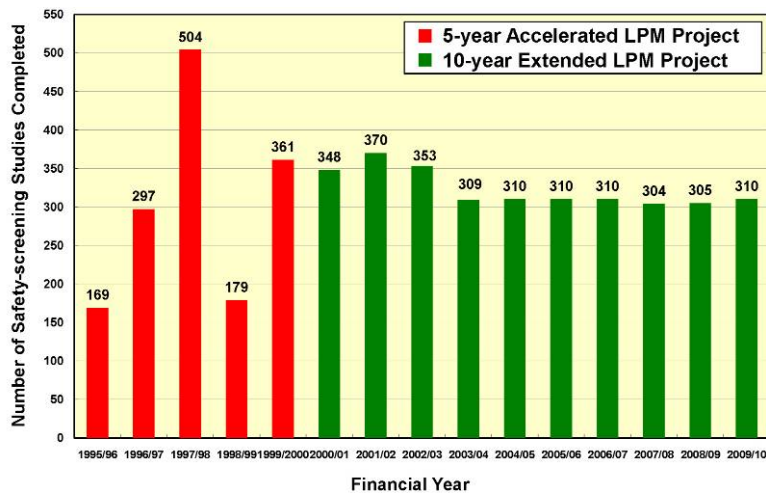


Figure 7: Number of safety-screening studies completed from 1995/96 to 2009/10

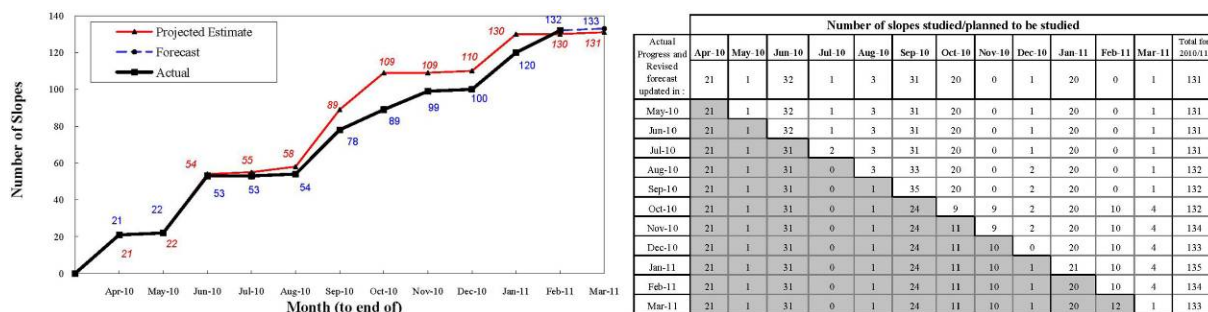


Figure 8: An example of a stagger chart for monitoring the output of safety-screening studies

### 4.3 LPM Information System

In the old days, slope information related to LPM works is kept by individual teams in various databases. Information sharing and retrieval was ineffective and inefficient. In the late 1990's, a centralised computerised system on LPM information was established (Figure 9). This allows the programme management teams and the project teams to update and obtain information about the status, nature and progress of the LPM works for each slope readily. This is an essential tool for the LPM Programme management.

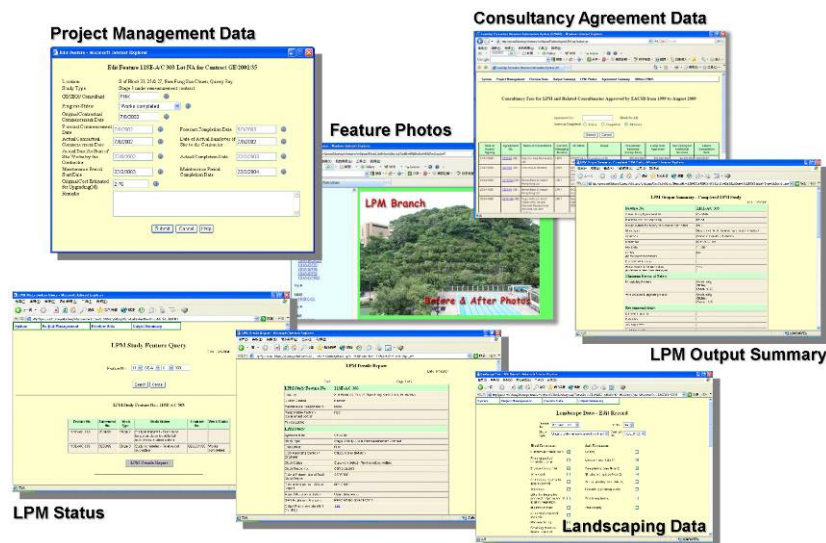


Figure 9: LPM Information System

## 5 QUALITY ASSURANCE

### 5.1 Quality management

A Quality Management System (QMS) covering unified procedures, best practices, feedback and improvement mechanism on LPM processes was established in the early 1990's. The LPM QMS was certified under ISO 9001 in 1996 (Figure 10). This was among the first batch of ISO 9001 certificates obtained by the works departments.



Figure 10: The LPM QMS

To assure the quality of work, many audits are carried out on different aspects of work under the LPM Programme, including:

- Third Party Audit of QMS by Certification Body
- Internal Audit under ISO 9001
- Technical Audit on contract administration
- Construction Site Safety Audit
- Consultancy Audit on consultant management system
- Auditing for Prevention of Substandard Works
- Second Party Audit on Checking of LPM designs
- Second Party Audit on Installation of Soil Nails

Corrective and preventive actions arising from the audits are taken promptly to address the non-compliances and observations identified.

### 5.2 Quality of soil nailing

Soil nailing has been extensively used for stabilisation of man-made slopes in Hong Kong since the 1990's (Watkins 1992). Similar to other buried works, it is difficult to check the quality of soil nails after installation. Much effort was made in ensuring the quality of soil nailing works under the LPM Programme. First, full-time supervision of the critical activities of soil nailing, such as steel bar installation and grouting, had been exercised for years. Second-party audits on soil nailing works at randomly selected LPM sites were conducted since 2002. Non-compliances and observations identified in the audit inspections were referred to the project teams for follow-up actions. Common observations and non-compliances were presented in the periodic liaison meetings with the LPM consultants and contractors to avoid recurrence of non-compliances and to further improve the quality of site works and site supervision.

To further enhance the quality of LPM works, GEO has prepared guidance notes on supervision of soil nail works for site supervisory staff. These guidance notes provide advice to the site supervisory staff on the standard of supervision, preparation of site records, and checking of workmanship and materials as per the contract requirements. Since 2003, GEO has been jointly organising a regular training course on "Quality Supervision of Soil Nail Construction" with the Hong Kong Polytechnic University. The training course

covers the duties and procedures in site supervision at various stages of soil nail construction, the latest development and requirements, and the common non-conformities identified in soil nailing works. The course has been well received by the site supervisory staff, contractors' site management staff and graduate engineers.

Since 2003, the GEO has been using the Time Domain Reflectometry (TDR) technique (Figure 11) to check the integrity of soil nails after grouting. It is found to be a useful tool in identifying possible defects and triggering follow up quality check of soil nails with suspected defects (Cheung 2006).

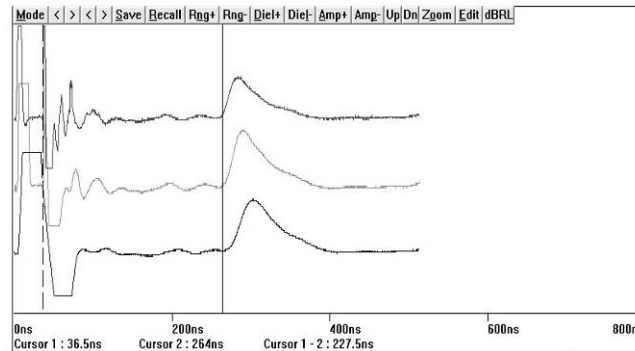


Figure 11: Use of time domain reflectometry to check the integrity of soil nails

### 5.3 Landslide investigation

Systematic landslide investigation (LI) is an integral part of the LPM Programme. All landslides reported to the GEO are examined and screened in order to identify cases that warrant follow-up study. Worthy cases, such as the Ching Cheung Road landslide in 1997 (Figure 12), are studied in detail to document the failure and relevant background information, establish the probable causes, and identify the necessary follow-up actions. Amongst the numerous benefits, systematic LI is found to be very useful in identification of slope types in need of early attention under the LPM Programme and to improve the knowledge on the causes and mechanisms of landslides in Hong Kong so as to formulate new ideas for reducing landslide risk and enhancing the reliability of slope upgrading works (Chan & Ho 2001).



Figure 12: The 1997 Ching Cheung Road landslide

## 6 CONSTRUCTION MANAGEMENT

### 6.1 Sample tender documents for LPM works

LPM contracts are managed and construction works are supervised by different LPM consultants as well as the GEO in-house teams. Many different LPM contractors are also involved in implementing the works. It is important to ensure consistency in the standard of construction works in respect of workmanship, materials and construction method, as well as construction supervision. To achieve this goal, GEO has compiled and maintained a set of sample tender documents for LPM contracts for the reference of project engineers and LPM consultants. The documents are updated from time to time when new policies/directives are promulgated or issued. It is recognised that the compilation and regular updating of the sample tender documents by GEO is a highly effective means to ensure the quality, consistency and sufficiency of tender documents for LPM works and the quality of site works during construction. The sample tender document also significantly reduces the time required for preparation of tender documents by individual LPM consultants, and thereby assists in smooth delivery of the LPM works.

## 6.2 Construction site safety

It is the Government's policy to deliver public works projects safely, efficiently and with due regard to the environment. LPM is intrinsically a dangerous activity due to the need to work at height which is exacerbated by the steepness of the slopes, difficult access and lack of working space. The overall accident rate of LPM contracts before 1997 was significantly higher than the then Works Bureau safety target of 1.6 accidents per 100,000 man-hours worked (Figure 13). Since the mid-1990's, GEO has implemented many site safety measures including:

- The 'Pay for Safety Scheme' has been adopted in all LPM works contracts and related ground investigation contracts irrespective of the contract sum since 1996.
- The contractor is required to provide at least one full-time Safety Officer under a LPM contract, and to appoint a foreman or ganger as the Safety Representative for each works site and at least one full-time Safety Supervisor for each works site where the number of workers exceeds 20.
- Routine Site Safety Management Committee meetings, weekly site safety walk and periodic inspections and meetings with the CEDD Departmental Safety and Environmental Advisory Unit are undertaken to monitor and review the safety performance of the contract or contractor. Site safety is also a standing item in the agenda of high level regular meetings including the GEO Senior Staff Conference, the LPM Programme Manager Meeting and the Liaison Meeting with the LPM contractors.
- LPM contractors are encouraged to participate in safety promotion campaigns. Some LPM contractors have obtained various awards under the "Considerate Contractors Site Award Scheme" organised by the Development Bureau (DEVB). In addition, the "GEO Best LPM Contractor Award Scheme" was introduced in 2007 and the "CEDD Construction Site Safety Award Scheme" was launched in 2009 aiming to give recognition to contractors with good site safety performance, promote site safety in LPM works and motivate contractors to raise their level of site safety awareness.

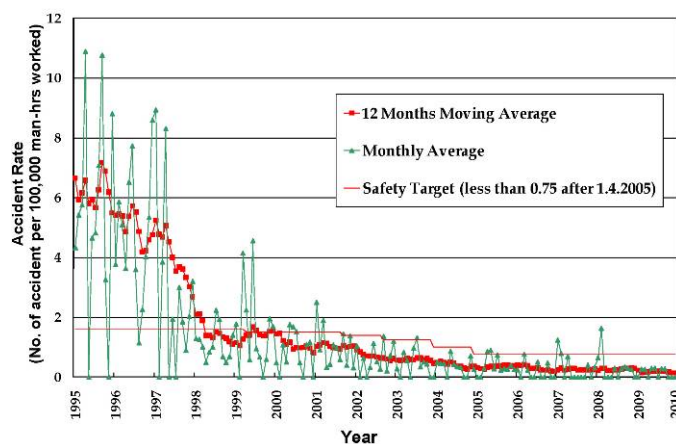


Figure 13: Accident statistics for LPM works contracts

In 1995, the accident rate of LPM contracts was approximately 6.5 accidents per 100,000 man-hours. After implementation of various site safety measures since 1997, the accident rate per 100,000 man-hours over a

rolling 12-month period has been reduced by more than 95% to about 0.11 in December 2010 (Figure 13), well below the current DEVB's safety target of 0.75. Moreover, no fatal site accident has occurred in LPM works contracts since 2000.

## 7 CONTINUOUS IMPROVEMENT

### 7.1 Studies relating to LPM

Continuous improvement is an integrated element of the LPM Programme. Over the years, different studies, some carried out by GEO supporting Divisions and others by LPM consultants, have been undertaken to facilitate and enhance the delivery and performance of the LPM Programme. These studies cover various aspects including data collection, process improvement, quality assurance and technical development. Examples of studies having significant impact on the LPM Programme are the Business Process Re-engineering on selection of slopes for LPM action (Figure 14), studies of slopes affecting a particular type of facility (such as squatters, catchwaters, railways, bus shelters and schools), review of causes of delay and cost variations, review of queries and complaints, review of results of site safety audits, enhancement of procedures for safety-screening studies, and improvement of the technical issues relating to design and construction (such as fill slope stabilisation, soil nail materials, soil nail heads, facing and pullout tests, slope drainage systems and erosion control measures).

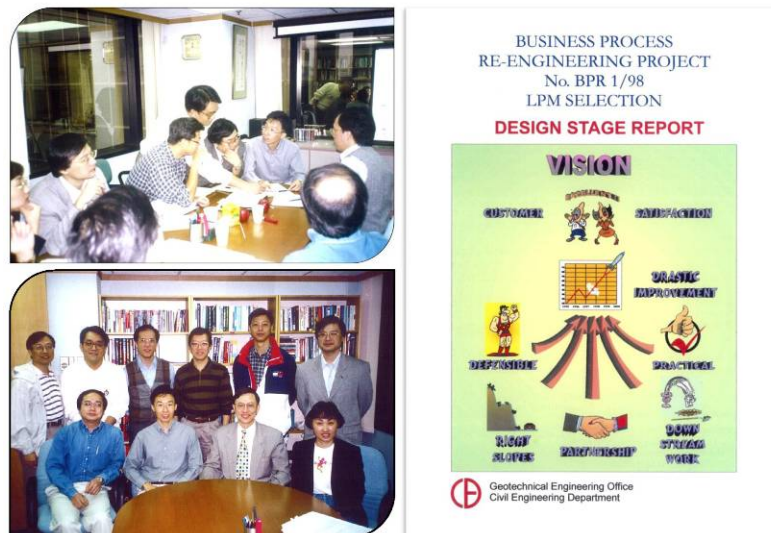


Figure 14: Business Process Re-engineering on slope selection under the LPM Programme

### 7.2 Landscaping

Apart from maintaining the highest standards of slope safety, it is the Government's policy to make man-made slopes look as natural as possible. GEO paid particular attention to the appearance of slopes since the 1980's. Considerations for vegetation on slopes had been stated in the Geotechnical Manual for Slopes since 1984 and were specified in various technical guidance documents since then.

In the early days, professional landscape design input in LPM works was limited, and shotcrete cover was frequently used. With higher public expectation and the much increased number of slope upgrading works in late 1990's, the number of complaints on slope appearance escalated in early 2000's. The GEO received a spate of complaints from academics, individual members of the public and organisations including the Swedish Chamber of Commerce in Hong Kong and the Hong Kong Conservation Photography Foundation. Public concerns were also expressed through the newspapers. In response, the GEO initiated new greening initiatives and improve the practice of landscape design.

Provision of professional landscape design advice was incorporated in LPM consultancies on voluntary basis in 1995. This has become a mandatory requirement since 1997. Landscape consultants were also

engaged to provide support to LPM projects since 1999. In the 2000's, GEO conducted various studies and trials to improve the technology of landscape treatment on slopes, including the slope greening technology, application of different vegetation species, soil bioengineering application and the method of preserving the masonry blocks and trees on masonry walls. Reports on landscaping studies and technical guidelines on landscape treatments (GEO 2000) issued by the GEO are major references by consultants and professionals for slope works.

Landscape treatment is now a basic requirement in the design and construction of LPM works. All slopes upgraded under the LPM Programme are greened as far as practicable (Figure 15). If greening is not practicable, e.g. due to steep slope gradient, site restriction or objection from nearby occupants, the slope will be beautified by other landscape measures such as decorative panels and stone pitching. More than half of the slopes upgraded under LPM Programme in 2000-2010 were greened (Figure 16). Training on landscape aspects is provided to professional and site staff to ensure that the greening initiatives are properly implemented. Through the concerted effort, the appearance of LPM slopes has been much enhanced. The achievement in slope appearance is often praised by the media, individual members of the public and landscape professionals (Figure 17).

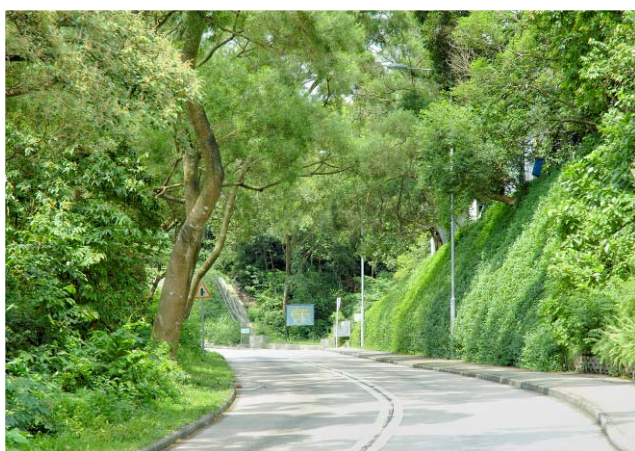


Figure 15: Landscaping treatment for upgraded slopes

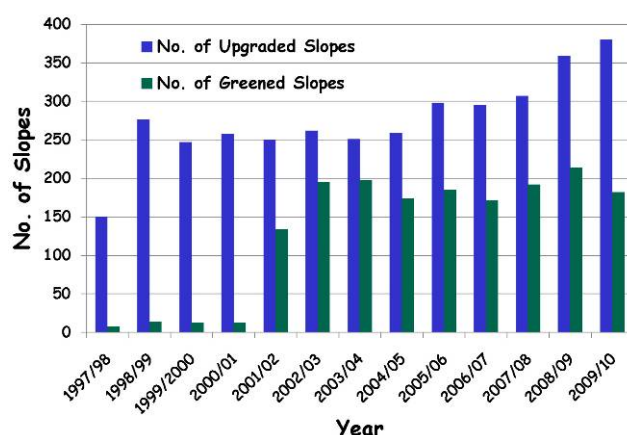


Figure 16: Greened slopes under the LPM Programme



Figure 17: GEO's achievement in slope appearance appreciated by landscape professionals

### 7.3 Experience sharing

The GEO promulgates the latest development in design and construction practice relating to LPM through different technical and guidance documents including GEO Publications, Geoguides, Geospecs, Manuals, Technical Guidance Notes (TGN), GEO Circulars, GEO Reports and Design Technical Guidelines. Liaison

Meetings are organized with LPM consultants (Figure 18) and LPM contractors regularly to discuss and share experience on findings of LI and LPM studies, innovative ideas on design and construction practice and problems encountered during the delivery of the LPM Programme. Many ideas and practices evolved and developed under the LPM Programme, such as the use of heat-shrinkable sleeve for soil nail connections, concrete strip footings for hoarding, mobile rig for soil nailing, noise reduction measures and grout pipe details, have become the common practices in the industry.

GEOTECHNICAL ENGINEERING OFFICE, CIVIL ENGINEERING DEPARTMENT  
LANDSLIP PREVENTIVE MEASURES PROGRAMME  
LPM CONSULTANTS LIAISON MEETING, 14TH JUNE 1996



Figure 18: LPM Consultants Liaison Meeting on 14 June 1996

## 8 CONCLUSIONS

With over 30 years' concerted effort by the GEO, the LPM consultants, the LPM contractors and the geotechnical profession, a comprehensive LPM project management system has been developed. Processes on planning, management, control and development of the LPM services had been developed and enhanced continually to facilitate the upgrading of 4,500 Government man-made slopes and completion of safety-screening studies for 5,100 private slopes in 1977-2010. The framework and achievements of the LPM Programme are world recognized and the Programme is the role model for some countries.

## ACKNOWLEDGEMENTS

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# Geological Input to the LPM and LPMit Programmes 1972 to 2011

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## ABSTRACT

The evolution of geological input to the LPM and LPMit Programmes is described in five sections corresponding to the main phases of the work: pre-LPMP proper 1972-1978, LPMP first phase 1978-1995, accelerated LPMP 1995-2000, extended LPMP 2000-2010, and LPMitP 2010 onwards. A brief programme overview sets the scene in each section, followed by an account of notable geological aspects and technical findings. Along with gradual improvements in ground investigation practice, most of the significant developments have come about through detailed landslide investigations and follow-up research and development studies. Rapid growth of engineering geological and geomorphological input to natural terrain hazard assessment has been the most significant change in the transition from the LPMP to LPMitP over the last decade, and this trend will continue for some time. The final section discusses some current key issues related to investigation and design approach, programme management, and uncertainty in assessing natural terrain hazards.

## 1 INTRODUCTION

This paper aims to summarise geological input to the Landslip Preventive Measures (LPM) and Landslip Prevention and Mitigation (LPMit) Programmes since the government commenced LPM work in 1972. Based on Tang (2010), the work described below is sub-divided into five phases: (i) an early Landslide Study phase, pre-LPMP proper 1972-1978, (ii) LPMP first phase 1978-1995, (iii) LPMP accelerated phase 1995-2000, (iv) LPMP extended phase 2000-2010, and (v) LPMitP phase (2010 onwards).

Natural and cut slopes formed in colluvial and saprolitic soils, and weathered igneous rock, are inherently variable and potentially geotechnically complex. Fill slopes and retaining walls created from the same soils and rocks often contain materials with radically different properties over short distances. Appreciating this variability and helping to quantify it in a realistic way for engineering design has been at the heart of geological input to the LPM effort for four decades.

Hong Kong is fortunate that programme managers down the years have consistently stressed the importance of investigating failures, and carrying out research and development (R&D) studies. Landslide investigations and follow-up R&D studies have been the main sources of improved technical awareness. Many of the lessons learned and key developments in geological understanding have become embedded in mainstream geotechnical practice.

This review touches on some key developments but cannot cover all relevant aspects. Further information is given in numerous publications and conference proceedings, e.g. IMM HK (2000, 2002), Martin & Li (2004), GEO (2007a, 2007b), GSLHKRG (2007), HKIEGD (2007, 2009).

## 2 EARLY DAYS : LANDSLIDE STUDY PHASE 1972-1978

### 2.1 Programme Overview

The two catastrophic landslides on 18 June 1972 at Sau Mau Ping (a fill slope failure) and Po Shan Road (cut slope and natural hillside) were the first trigger in establishing the LPMP. The landslides resulted in 138 fatalities and 80 injuries. Government commissions of enquiry into the incidents led to setting up a civil engineering section with geotechnical advisory duties in the then Public Works Department (PWD) and a series of landslide studies by geotechnical consultants.

The landslide studies comprised Phase I visual inspections of some 7,000 cut slopes in urban Hong Kong and Kowloon in 1973/74 and Phase II area-based detailed investigations from 1975 onwards. The Phase II investigations initially targeted cut slopes, natural slopes and retaining walls, but were expanded to include a special investigation of old fill slopes, following the recommendations of a government-appointed independent review panel into the Sau Mau Ping fill slope failure of 25 August 1976 which caused 18 deaths and 24 injuries. The same consultants also produced the first local catalogue of slopes in 1977/78, containing some 10,000 features.

### 2.2 Geological Aspects and Technical Findings

By the mid 1970s most present-day aspects of conventional site investigation (SI) for man-made slopes were already in place (Brand & Phillipson 1984; Pyle et al. 2007). These included thorough desk study based on detailed aerial photograph interpretation (API), site mapping, trial pitting, rotary coring with water flush and Mazier triple-tube sampling, standard penetration testing, GCO probing, discontinuity survey and piezometric monitoring. The use of geological and ground models based on plans and cross-sections through critical areas was already commonplace in the Phase II studies, supported by detailed core logging and laboratory testing of Class 1 (i.e. undisturbed) samples. Figure 1 shows a typical example, drawn from a 1975 Landslide Study Phase IIB area study report.

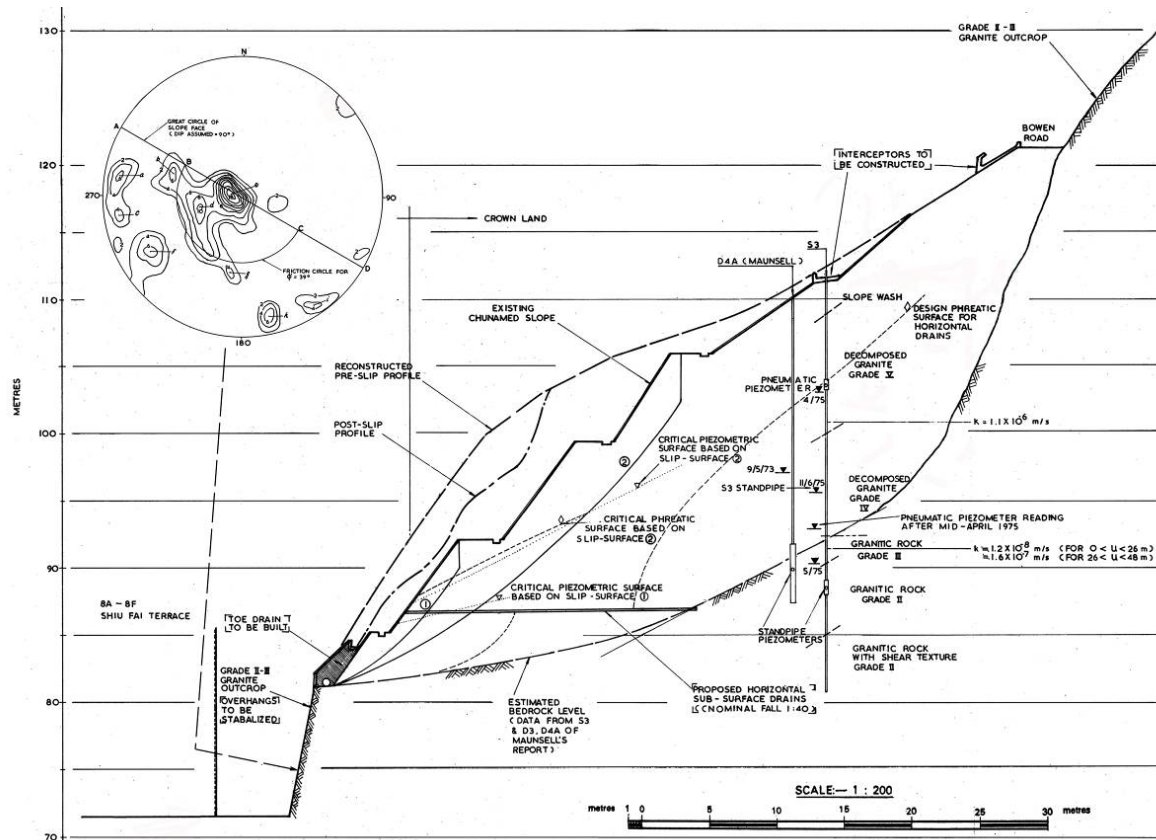


Figure 1: Example of ground modelling based on field mapping, discontinuity survey, ground investigation and field testing, drawn from a Landslide Study Phase II area report (Binnie & Partners 1975)

Recognition of the liquefaction mechanism as the root cause of the disastrous fill slope failures was a key technical finding of the independent review panel, prompting attention to be given to investigations and recompaction works on loosely-placed fill embankments in the first few years of the next phase.

### 3 LPMP FIRST PHASE 1978-1995

#### 3.1 Programme Overview

Further recommendations from the independent review panel in 1977 led to creation of a separate Geotechnical Control Office (GCO) in the PWD and a Geotechnical Control Branch in the Buildings Ordinance Office. By mid 1978 the GCO had set up the rolling LPMP, with priority given to upgrading man-made slopes affecting public housing, hospitals and schools. As noted, the early focus was on fill slopes, with studies and works managed by consultants. In-house GCO LPM studies of rock and soil cut slopes and retaining walls commenced in 1981 and the first in-house LPM contract was let in 1982.

From 1978 to 1983 funds were provided by individual Public Works Project (PWP) items. These covered a number of area studies, as well as preventive works to man-made slopes and some hillside drainage works. A more flexible Block Allocation system was set up in 1983, allowing annual funding of studies and works. LPM works were carried out on about 630 slopes in total during this phase. Annual numbers of slopes dealt with varied from about 10 to 80, with annual expenditure in the range of HK\$40M to 110M.

#### 3.2 Geological Aspects and Technical Findings

Tropical weathering, which changes a rock into soil, has been affecting Hong Kong for millions of years since pre-Quaternary time, resulting in thick weathering profiles. Based initially on Ruxton & Berry (1957), the GCO developed a 4-fold rock mass weathering scheme for the classification of weathering profiles (GCO 1984). In parallel a 6-fold materials decomposition grade classification scheme for small samples was developed, facilitating the systematic description of saprolitic soils and weathered rock and enabling typical engineering properties to be assigned on a reliable basis. During the 1980s the mass classification scheme was expanded to six classes and the materials classification refined based on field index testing (GCO 1988). Development of these weathering schemes provided a key component of the framework for systematic technical assessment of slopes in Hong Kong.

Local development and use of air-foam as a drill flush fluid was an important advance in SI practice in the early 1980s, greatly improving the recovery of undisturbed samples of colluvial and saprolitic soils. Other ground investigation (GI) improvements in this phase included the first use of slope surface stripping and mapping, Casagrande piezometer tips and 'Halcrow' bucket strings for groundwater monitoring, tensiometers for measuring soil suction, clear plastic liners for Mazier samples, impression packer and borehole televiewer devices for downhole rock joint survey, and introduction of gINT database management and report production software in the early 1990s (Brand & Phillipson 1984; Pyle et al. 2007).

The consultant-led Mid-levels Area Study (MLAS) and a series of GCO in-house Geotechnical Area Studies (GAS) were important area studies funded by PWP items in the early LPMP. The MLAS involved detailed ground investigation and groundwater monitoring over a sizeable part of the Mid-levels residential area and surrounding natural terrain. The work led to improved understanding of near-surface hydrogeology and provided the rationale for subsequent installation of long raking drains as preventive works in the hillside adjacent to the 1972 Po Shan Road Landslide (Figure 2). The GAS Programme involved systematic regional terrain classification by API and broad appraisal of geotechnical constraints on development at 1:20,000 scale and selected larger-scale area studies at 1:2,500 scale (Styles & Hansen 1989). Earlier terrain classification of the Mid-levels area in 1978/79 had provided the basis for an initial moratorium on building development in the area, later replaced by a set of special controls on development, including requirements for prior approval of GI plans and a restriction on the depth of excavations.

Although not funded as an LPM item, GCO's decision in 1982 to establish the Hong Kong Geological Survey (HKGS) and commence systematic geological re-mapping of Hong Kong at 1:20,000 scale was significant for the LPMP. Maps and memoirs published by the HKGS from 1984 onwards contained a vast amount of new data, enabling improved geological modelling for geotechnical work across the board.

Another key GCO initiative was commencement of ad-hoc landslide investigation (LI) in 1982. The first batch of ten LIs highlighted deficiencies in basic ground investigation practice (Hencher 1983). Some of these

findings were incorporated in revised technical guidance in Geoguides 2 and 3 on Site Investigation (GEO 1993) and Rock and Soil Descriptions (GCO 1988) respectively. A key technical finding of these and subsequent LIs in the late 1980s was appreciation of the importance of structural control of failure surfaces in saprolites. Another significant finding from LIs and other detailed slope studies was recognition of soil piping as a common near-surface process in colluvial and saprolitic soils (Brand et al. 1986).

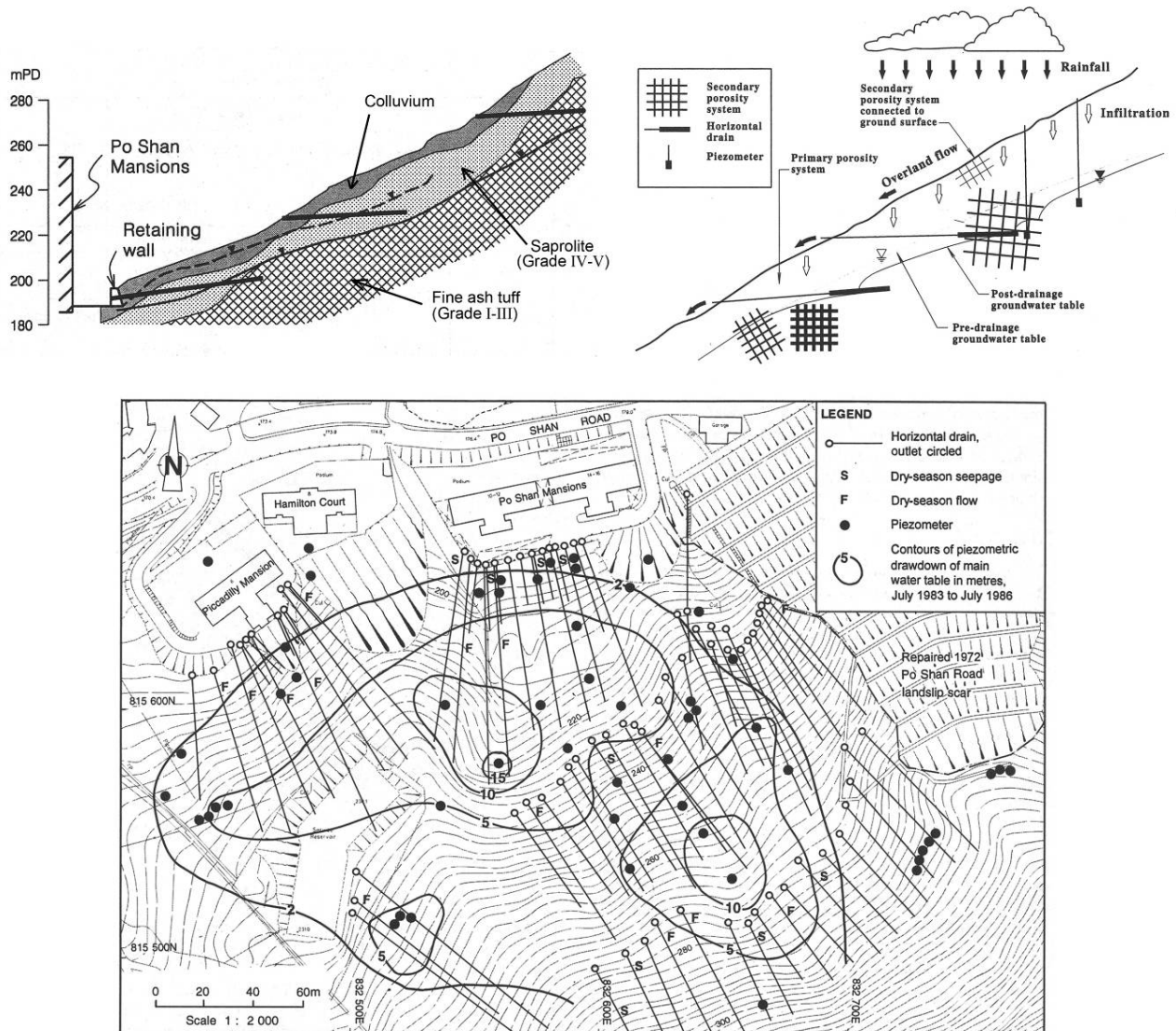


Figure 2: Hydrogeology of part of the Mid-Levels area, showing conceptual modelling of porosity systems (Au 1990) and groundwater drawdown by raking drains at Po Shan (Martin & Siu 1996)

The GCO began R&D studies on laboratory testing in the late 1970s, expanded the scope by 1981 to include field studies, and established a Special Projects R&D Division in 1983. The earliest field study, CHASE (Cut Slopes in Hong Kong Assessment of Stability by Empiricism), involved detailed logging and description of nearly 200 slope surface strips, extensive index testing, and collation of existing GI, topographical and hydrological data. About half the slopes examined had failed previously, as indicated by existing failure scars. The data were analysed in various ways to assess the extent to which empirically-based rules could be drawn up to aid cut slope design. Two outcomes of the project were significant for the LPMP: (i) an enhanced semi-quantitative material decomposition classification of granitic and volcanic rocks was developed based on field description and index testing, subsequently incorporated in Geoguide 3, and (ii) guidance on the first stage (Stage 1) of the cut slope investigation, design and construction (IDC) process was modified for the remainder of the 1980s to include discriminant analysis graphical plots for preliminary assessment of failure potential and prioritisation of features for detailed investigations at the next stage.

## 4 ACCELERATED LPMP 1995-2000

### 4.1 Programme Overview

The 5-year Accelerated LPM Project was launched in the aftermath of several fatal landslides in the early 1990s, notably the 1992 Baguio Villas Landslide at Pokfulam, involving two fatalities from collapse of a hitherto unregistered retaining wall and fill body, and the 1994 Kwun Lung Lau Landslide, when five pedestrians were killed by sudden collapse of a steep stone-pitched cut slope in a volcanic saprolite. Recommendations in the report on the latter failure by Morgenstern (1994) identified a need for a more integrated approach to slope stability studies and the setting up of a technical review board to monitor slope safety practice in Hong Kong.

The accelerated project involved a dramatic increase in scope and scale of the LPMP. About 130 new posts were created in the Geotechnical Engineering Office (GEO, renamed from GCO in 1991). LPMP scope was expanded to include slopes affecting busy roads, footpaths and public waiting areas. Project management changes included establishing dedicated lists of LPM consultants (currently 27 members) and LPM contractors (38 members) for bidding, tendering and employment on LPM assignments. A new catalogue of slopes was set up, containing some 57,000 features identified by territory-wide systematic API, field checking and data collection. From 1996 onwards the government's slope safety work was subject to annual review by the Slope Safety Technical Review Board (SSTRB), which included international representation.

About 800 public slopes were upgraded in this phase, and nearly 1,500 private slopes were screened by Stage 2 stability studies. Annual numbers of slopes treated by LPM varied from about 50 to 280, with annual expenditure ranging from about HK\$200M to 800M.

### 4.2 Geological Aspects and Technical Findings

A significant advance in SI practice in this phase was development and testing of a light-weight portable drill rig capable of taking triple-tube samples up to 15m deep on relatively inaccessible sites. The sampler can be mobilised without the need for extensive access scaffolding. It was included as a standard item in GEO term GI contracts from 2000 onwards.

Investigation of two fatal landslides at Fei Tsui Road, Chai Wan and Shum Wan Road, Aberdeen in 1995 yielded important new findings on the nature, distribution and role played by kaolin-rich zones in weathered rock profiles (Figure 3; Kirk et. al. 1997, Parry et al. 2004). Laterally extensive kaolin-infilled discontinuities were identified towards the base of the saprolite and upper few metres of underlying less weathered rock. The infills were bounded by a well-defined weathering front and appeared to act as a barrier to further kaolin transportation with depth. Prior to these LIs it was commonly assumed that occurrences of near-surface kaolin were restricted to zones of hydrothermal alteration. Appreciation of its potential widespread occurrence as part of a weathering profile was a very significant finding. A series of area-based R&D studies was undertaken to assess the prevalence of such features and possible correlation with sites of previous landsliding and perennial seepage (Figure 3). GEO subsequently published technical guidelines on the recognition of geological features hosting silt- and clay-rich layers affecting cut slope stability (GEO 2004a). Stage 1 data collection checklists in the LPMP were modified to include items related to these layers.

Following the 1994 and 1995 fatal landslides GEO carried out R&D studies to assess the effectiveness of geophysical techniques for improved site characterisation. Both surface and downhole techniques were extensively tested and compared at a number of test sites. Positive findings were that a combination of resistivity and ground penetrating radar was useful for identifying the geometry of existing masonry walls, and a combination of downhole gamma density, spectral gamma and neutron porosity logging for identifying relatively weak clay-rich layers >30mm thick in weathered rock profiles. The results were incorporated into GEO technical guidance notes on SI practice (GEO 2004b).

A major GEO initiative with wide implications for geological input and SI practice in the LPMP was the development of prescriptive measures for general use in upgrading man-made slopes and walls (GEO 2009). This was in contrast to previous restricted use of prescriptive measures for rock cut stabilisation measures and recompaction of loose fill slopes. Experience with numerous failures of unsupported cut slopes in a major rainstorm in November 1993 was used as the basis for drawing up prescriptive design guidelines for preventive maintenance and slope upgrading works. The guidelines covered three types of prescriptive works (surface protection and drainage, subsurface drainage, and reinforcement by soil nailing) and were made

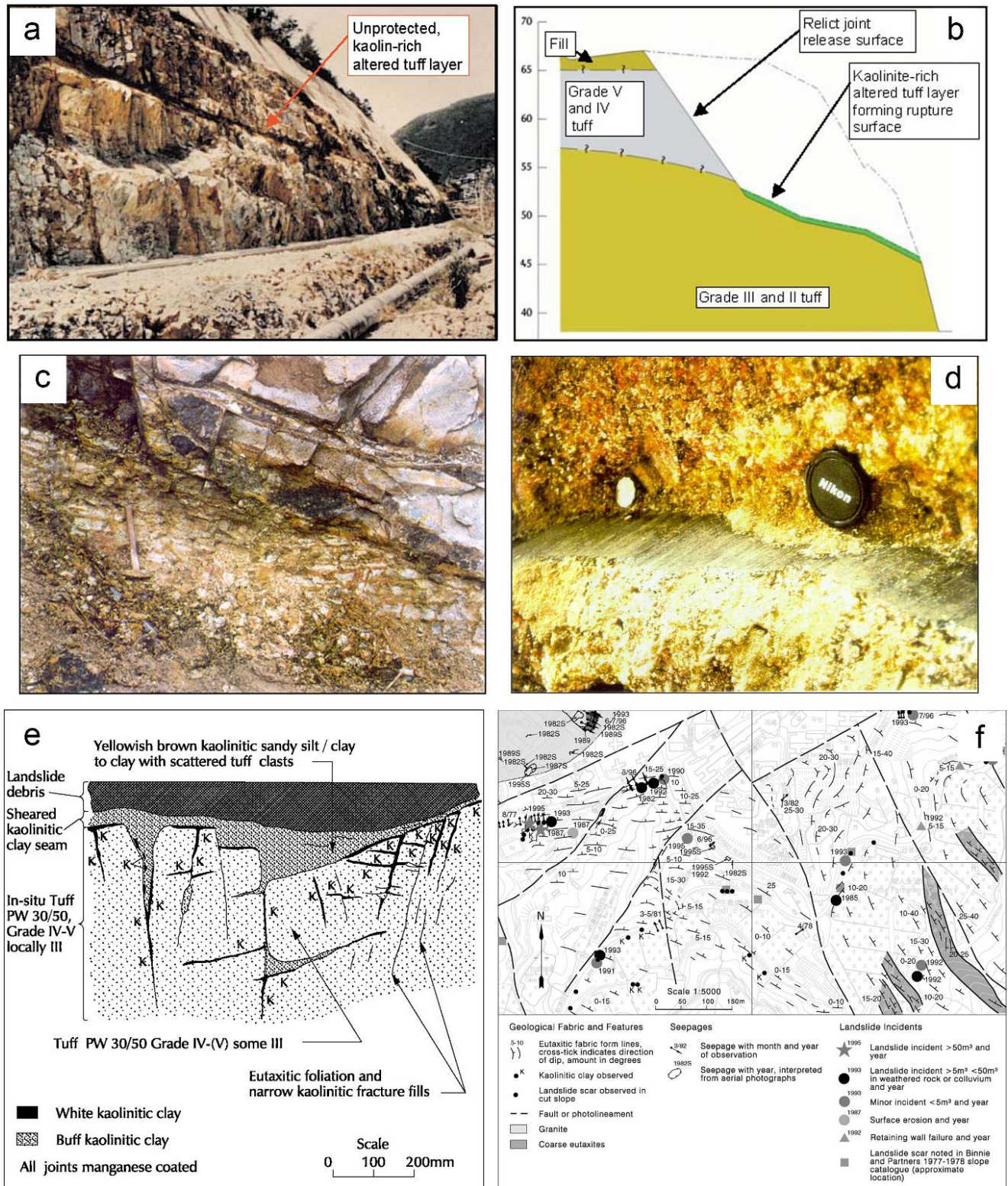


Figure 3: Kaolin-rich zones in weathered rock: (a) kaolinite-rich altered layer at the 1995 Fei Tsui Road Landslide site, before failure, (b) forming the rupture surface and (c) close-up view; (d) slickensided kaolin-infilled discontinuity at the 1999 Shek Kip Mei Landslide site (FMSWJV 2000); (e) concentration of kaolin seams and infills close to the weathering front at the 1995 Shum Wan Road Landslide site (Kirk et al. 1997); (f) composite map from the Chai Wan Engineering Geology Area Study (based on Campbell & Koor 1998)

applicable to slopes of modest geometry and with no observable or recorded adverse geological material or groundwater.

The first edition of the prescriptive guidelines was published in 1996 and had an immediate impact on the LPMP. The availability of a 'design without GI' methodology facilitated rapid increase in the scale of LPM work planned in the accelerated project. At the same time widespread use of prescriptive measures led to concerns about cursory site inspections to validate the design process, downgrading of the value of GI, overly-simplistic classification of adverse ground conditions, and possible over-reliance on soil nailing alone as a 'silver bullet' upgrading measure (Martin 2003).

Another important technical development in this phase was creation of the first natural terrain landslide inventory (NTLI) within the GEO (King 1999). Together with other territory-wide datasets on topography and geology, this set the scene for development of regional landslide susceptibility mapping, and, in the next phase, for rapid development in Geographic Information System (GIS)-based analysis of natural terrain.

## 5 EXTENDED LPMP 2000-2010

### 5.1 Programme Overview

In the extended phase of the LPMP the targets were further increased as the government pledged to deal with all remaining old (pre-1977) high consequence man-made slopes by 2010, at minimum rate of 250 slopes/year and in so doing reduce overall landslide risk to 25% of the 1977 level. The work involved many programme- and project-management initiatives, including development of a new priority classification scheme and ranking method for prioritising deserving slopes, the advent of an area approach to LPM packaging on efficiency grounds, and similarly a 'lot-by-lot' approach for efficient screening of private slopes in Stage 2 studies.

Over the 10 years of this phase the work was arranged under 71 IDC consultancies, 103 consultant-supervised LPM contracts, 17 GEO in-house works packages, 20 Stage 2 consultancies and 40 dedicated GI contracts. Annual expenditure varied within a range of about HK\$830M to 1200M.

### 5.2 Geological Aspects and Technical Findings

Increasing use of schedule-of-rates (SOR) 'design-as-you-go'-type LPM works contracts towards the end of the 1990s and into this extended phase of the LPMP had significant implications for geological input. The SOR approach, involving a few common items of preventive works (typically soil nailing, drainage and surface protection), often applied with minimal GI and groundwater monitoring, was expanded to cover bigger and potentially more geologically complex slopes.

In 2004 GEO commenced trial geological auditing of slopes upgraded under the LPMP, in response to a recommendation from the SSTRB to verify if adequate geological competency was being used in the LPM design and checking process. The work covered geological process auditing (i.e. a checklist approach) and geological model auditing of 12 cut slopes with LPM designs completed and works construction underway (Parry et al. 2004). The auditing revealed six aspects with room for improvement, including lack of pertinent geological observations in API records and clearly stated GI strategies, and overly-simplistic geological models. Recommendations were made to introduce geological review/audit into the LPMP from 2005 onwards, with special focus on slopes with anticipated adverse or complex geological conditions and/or past major failures. Another review conducted in 2007-2008 found that whilst the documentation of geological information had improved, there was still room for improvement in developing appropriate engineering geological models.

After nearly two decades of ad-hoc LIs, dedicated LI resources were provided to GEO in the accelerated LPMP phase. Following trials in the period 1997-1999, the LI effort was upgraded as a systematic annual programme from 2000 onwards, with resources to undertake investigations of all significant landslides provided by consultancies under GEO management. Annual reviews of significant landslides have been produced by GEO since 1997. A key early finding was that over 70% of reported failures in engineered cut slopes were due to more adverse groundwater conditions than were assumed in design, mostly because of a failure to detect transient perched water tables (Wong & Ho 2000). Another was a realisation that large progressive failures with evidence of ground distress over periods of many years were more common than had been traditionally assumed. Together with the influence of pre-existing discontinuities and kaolin seams,

appreciation of these various geological factors was a major part of the rationale that led GEO to publish new guidelines on enhancing robustness and reliability in slope design (GEO 2004c). Ho & Lau (2010) presented the key lessons learnt from LIs with emphasis on the role of engineering geology in assessing inherent uncertainties in slope stability.

With most of Hong Kong's developed areas extending from the limited level ground onto sloping ground, the need to address natural terrain hazard was bound to increase as the pressure on land resulted in building and infrastructure projects being located nearer to natural hillsides. Geological input to natural terrain hazard studies (NTHS) and risk management was the most significant aspect of change in the extended LPMP. The first natural terrain hazard assessment guidelines (Ng et al. 2003) were published to recommend appropriate practice and procedures, in particular for application of the Design Event approach. The momentum for further developments was boosted from 2002 onwards by incorporating discrete packages of NTHS and mitigation measures into LPMP consultancies, following the react-to-known-hazard principle for sites affected by very recent (i.e. last few years) natural terrain failures.

Along with site-specific NTHS, various technical development studies such as age-dating of landslides (Sewell & Campbell 2005) and terrain susceptibility mapping (MFJV 2003) were undertaken. During a rainstorm on 14 April 2000, a swarm of some 100 natural terrain landslides occurred in the Tsing Shan foothills. A regional study covering about 6.5km<sup>2</sup> was initiated to examine landslide problems in this area in the context of their geomorphological setting. In addition to slope gradient, key landslide initiation factors were found to include proximity to lithological boundaries, rock outcrops and heads of drainage lines (Figure 4). Guidance on regolith classification was developed from this study and led to consolidation of guidelines on geomorphological mapping for NTHS (GEO 2004d).

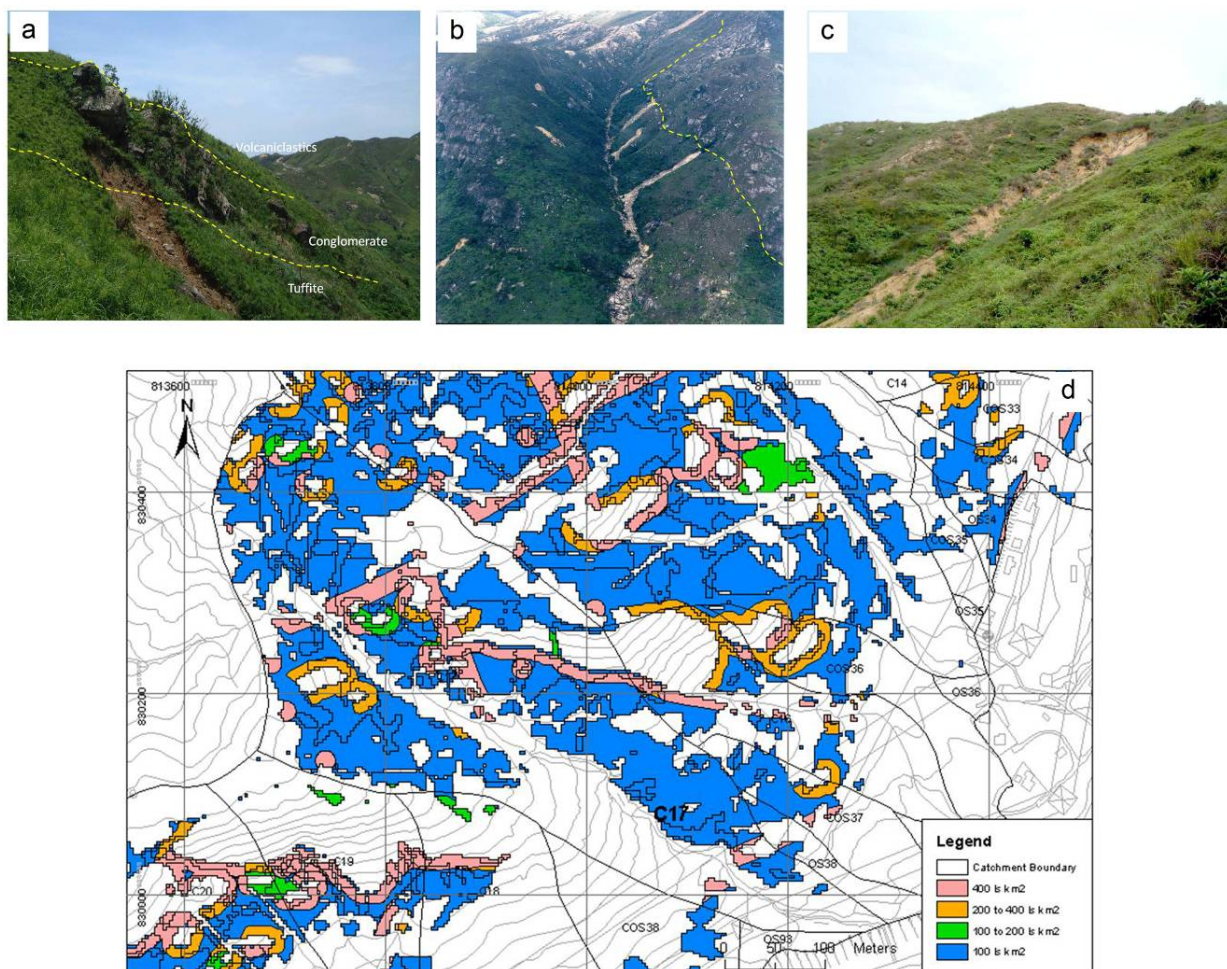


Figure 4: Key landslide initiation factors in the Tsing Shan foothills, including proximity to (a) lithological boundaries, (b) rock outcrops, and (c) heads of drainage lines; (d) terrain susceptibility map of part of the Tsing Shan foothills, integrating the relevant controlling factors (based on MFJV 2003)

Around the mid-2000s, GEO began technical development work to support the formulation and implementation of a natural terrain risk mitigation strategy for the post-2010 programme. The Enhanced Natural Terrain Landslide Inventory (ENTLI), comprising about 105,000 landslide records based on systematic API, was prepared by 2007 (Dias et al. 2009). In parallel, a systematic hazard identification exercise was also undertaken, involving compilation of an inventory of hillside catchments with historical natural terrain landslides (primarily based on ENTLI) that had occurred close to existing buildings and important transport corridors (denoted as Historical Landslide Catchments, HLCs; MFJV 2007). Based on pilot HLC data prepared in 2004, a risk-based HLC priority ranking system had been developed by Wong et al. (2006).

As with other natural geological hazards, given the current state of knowledge and available geotechnology, prediction of where and when hillside failure will occur remains a distant goal; nonetheless there remains much scope for improving current practice. A regional natural terrain hazard review of the northeast Hong Kong Island (c. 9km<sup>2</sup>), based primarily on detailed API, commenced in 2007 and was aimed at enhancing current practice in identifying hillsides susceptible to landslides (MFJV 2009). The approach to engineering geomorphological and hazard mapping was further improved and is now routinely applied to site-specific NTHS (e.g. ARUP 2010; Figure 5), with appropriate modifications to suit individual site conditions.

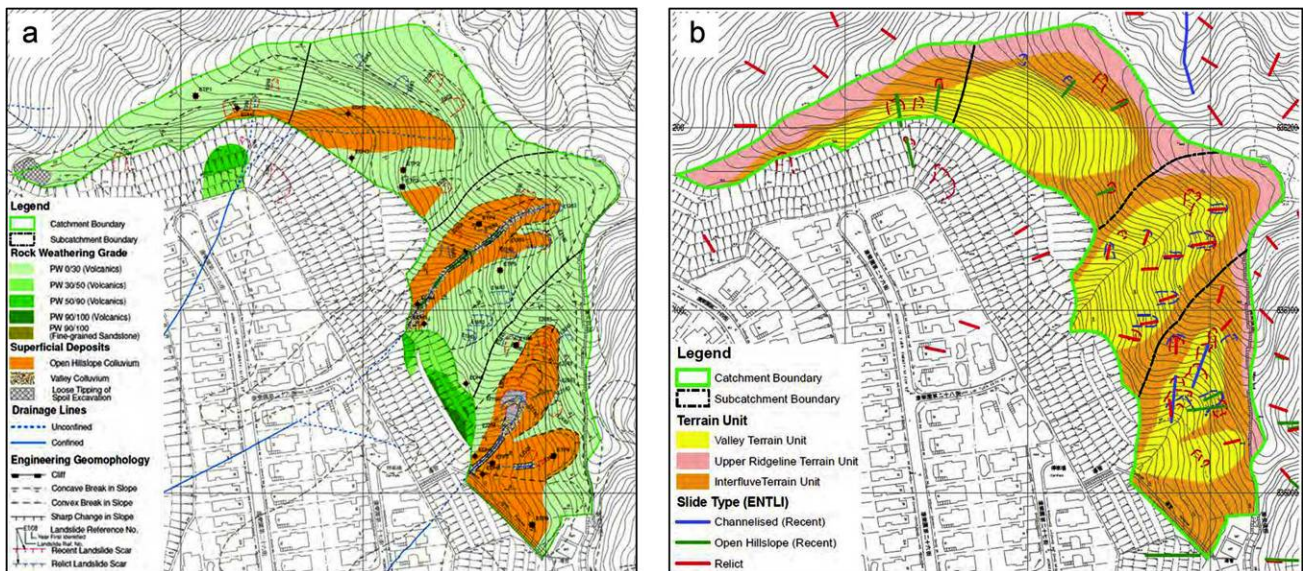


Figure 5: Hazard models of the hillside above Hong Lok Yuen based on (a) detailed engineering geomorphological mapping, and (b) classification of terrain units with similar landform and landslide susceptibility conditions (based on ARUP 2010)

In view of the need under the LPMitP to study sizeable natural hillside areas and handle large volumes of spatial data, GEO has utilised advances in information and digital technologies to enhance geotechnical practice (Wong 2004). Geospatial datasets (e.g. ENTLI, HLC inventory and digital terrain models) are compiled in formats that can be accessed and managed by GIS, to the point where GIS has now become a standard tool for natural terrain related studies. Digital photogrammetry is another technique introduced in the early 2000s for stereo visualisation and photogrammetric analysis, particularly for geotechnical work covering a large area. A pilot airborne LiDAR (Light Detection and Ranging) survey of Hong Kong Island in 2006 demonstrated that LiDAR data would be beneficial in deciphering ground features under a thick vegetation cover (Ng & Chiu 2008). Besides facilitating preparation of engineering geomorphological and subsequent hazard maps, LiDAR data also allow generation of high-resolution terrain models which are crucial for accurate prediction of debris flowpaths from mobility modelling.

## 6 LPMitP 2010 ONWARDS

### 6.1 Programme Overview

The LPMP was formally concluded in March 2010. Concerted planning from 2007 onwards for the LPMitP phase meant that the natural terrain element of the overall effort on landslide risk reduction gradually evolved from a minor part to its present dominant role, although traditional LPM work on man-made slopes is likely to continue. Ongoing work in the LPMitP includes annual targets to implement risk mitigation works for 30 natural hillside catchments. The most deserving catchments with known hazards are selected by risk-based priority ranking. Under the rolling LPMitP, the current annual expenditure on natural terrain related studies and mitigation works is over HK\$300M, i.e. about 50% of the total resources, as compared to less than 5% on average under the LPMP.

### 6.2 Geological Aspects and Technical Findings

An important issue in selecting man-made slopes for action under the LPMitP is to identify those at an advanced stage of degradation with signs of distress or past instabilities. This approach requires appropriate engineering geological input through detailed API and field inspection, taking account of possible inter-relationships with adjoining natural hillsides.

Noting the significant increased output of natural terrain work under the LPMitP, Chan (2007) and Wong (2009) highlighted a number of issues in tackling natural terrain landslide risk management. Those specifically relevant to geological aspects include possible underestimation of the design event, inadequate prediction of the nature of landslide debris, mis-interpretation of debris flowpaths, and occurrence of landslides in low-ranked HLCs or non-HLCs. Whilst the nature of landslide debris can be better appreciated through careful field mapping and characterisation, and prediction of debris flowpaths can be improved with the help of terrain models generated from LiDAR data, other aspects cannot be readily defined or codified because of their wide scope and partially implicit nature. A pragmatic approach is therefore adopted.

To overcome the limitations of the HLC framework, which is based on known failures, an area-based approach to natural terrain hazard studies has been adopted, whereby HLCs are combined in study packages with adjoining hillside catchments that have similar topographical, geological, geomorphological and environmental settings. This is necessary to take account of some lower-ranked and/or non-HLC hillsides flanking developed areas that may also be susceptible to failure. In addition, studying larger hillside areas is more amenable to systematic application of engineering geomorphology for hazard assessment.

Following a severe rainstorm on 7 June 2008 which triggered about 2,600 landslides on Lantau Island, GEO commissioned a regional natural terrain hazard study of West Lantau (c. 18.5km<sup>2</sup>), the area most affected by the storm. Hazard identification, based primarily on API and supplemented by field reconnaissance, coupled with an appropriate level of consequence assessment, was carried out to identify and qualitatively rank the most problematic hillside catchments in the study area for detailed investigation and implementation of mitigation works (Figure 6; Millis 2010).

Some of the technical development work carried out during the extended phase of the LPMP has borne fruit in the LPMitP. With the experience gained from the pilot airborne LiDAR survey in 2006, a territory-wide survey was conducted in December 2010. The processed data is expected to be available in the second half of 2011 and will be an important dataset to aid in geomorphological studies, complementing conventional API. Building on the pilot study in 2005 on dating of relict natural terrain landslides, the HKGS of GEO has been nominated as a centralised party responsible for managing the acquisition of landslide age data through procurement of service contracts with specialist laboratories. The scope of age-dating work covers carbon 14, optically-stimulated luminescence and cosmogenic radioisotope techniques.

## 7 DISCUSSION

Notwithstanding some notable technical advances over nearly four decades, application of best engineering geological practice in the LPMitP presently faces a number of significant challenges. Ho & Lau (2010) have made some suggestions for enhancing geotechnical and engineering geological input in landslide risk management, while some of the challenges associated with natural terrain hazard assessment have been addressed by Parry & Ng (2010). The authors consider that areas of concern are mainly related to

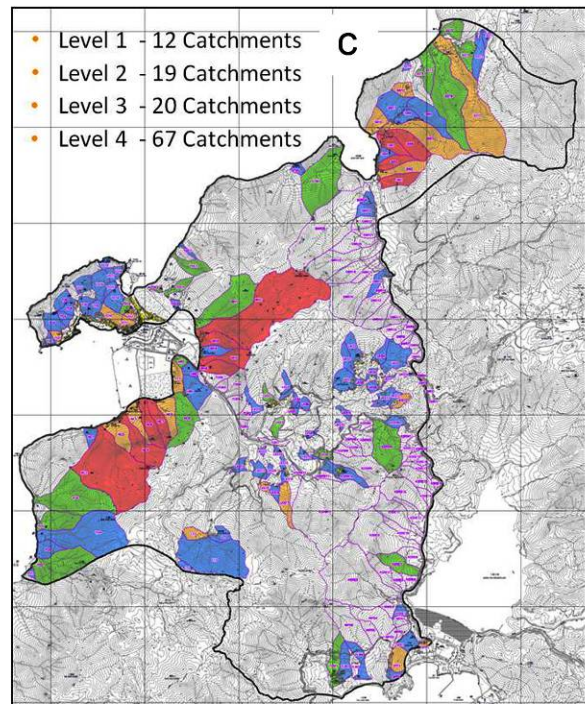
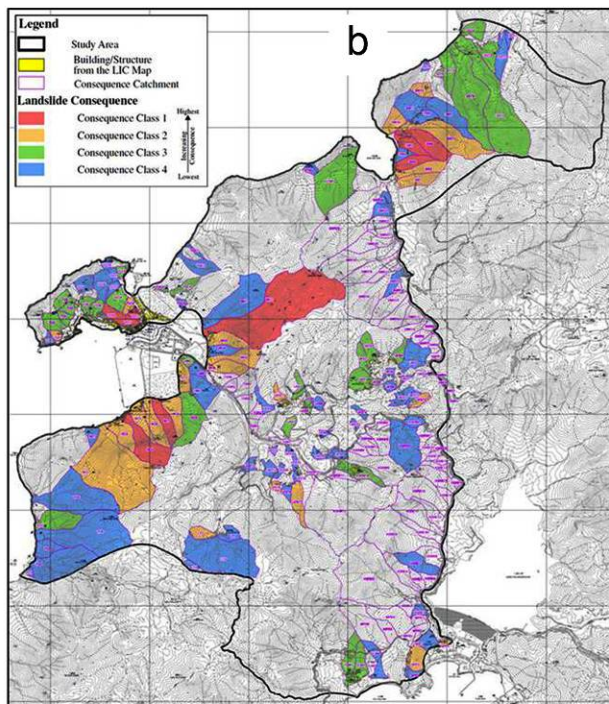
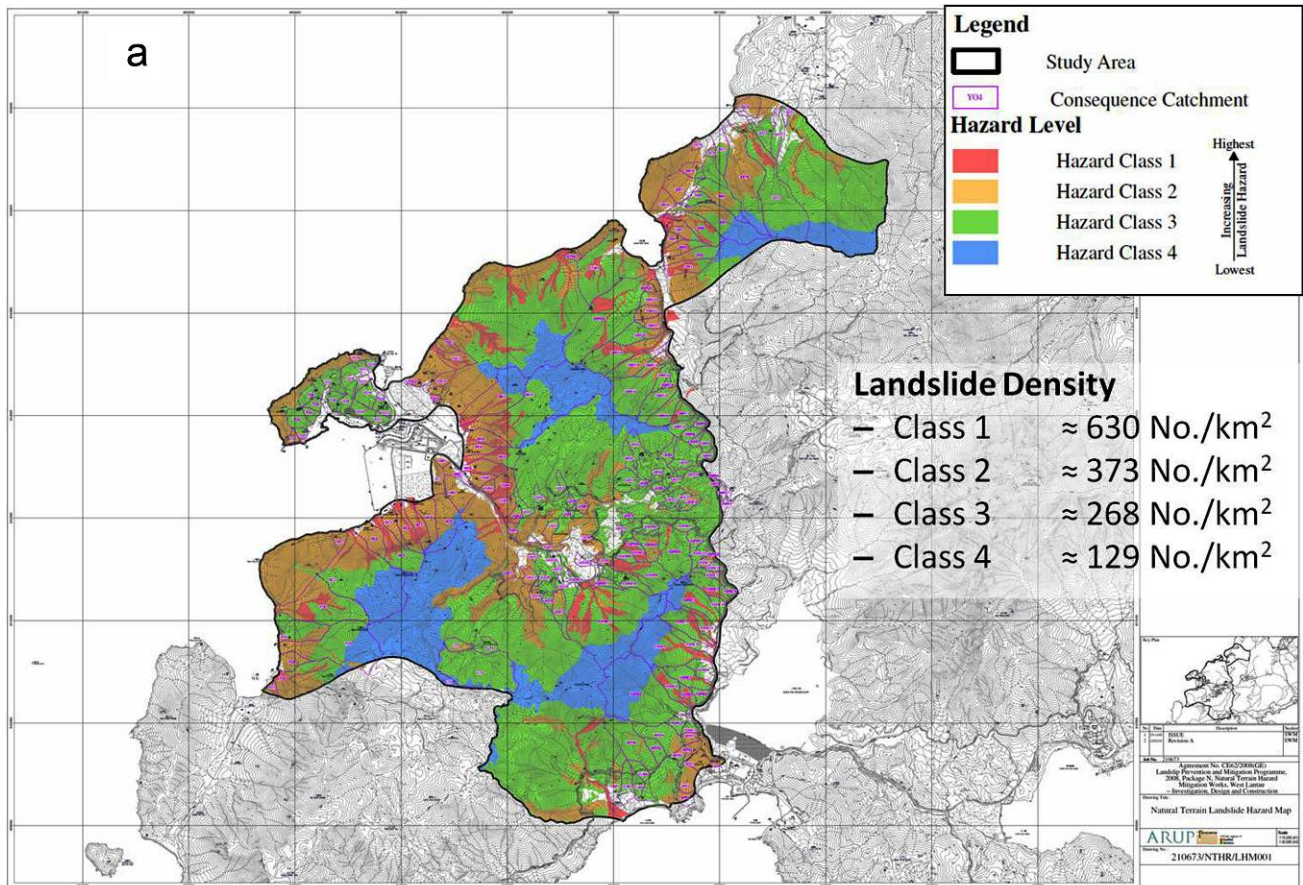


Figure 6: Regional hazard and risk mapping of the natural terrain at West Lantau: (a) landslide hazard map of hillside catchments in the study area and correlation with landslide density, (b) consequence map of catchments affecting villages only, and (c) landslide risk map of catchments affecting villages only (based on Millis et al. 2010).

investigation and design philosophy, programme management, and uncertainty in estimating the likely type and scale of future hazardous events.

### 7.1 Investigation/Design Approach

A number of issues deserve improvements in practice, or at least a considered discussion on currently perceived deficiencies, including:

Incomplete/Inadequate desk studies Despite extensive published guidance on good practice, key elements of basic SI are still done too often in a cursory manner, or findings overlooked. The comprehensive data collected from desk studies, including API reports, are commonly not adequately evaluated, thus leading to poor planning of GI. As a result, safety-critical ground conditions may not be identified and taken into account in the geotechnical design and works variation orders may be needed to address ‘additional’ hazards revealed during the construction stage, which should have been foreseeable from diligently-executed desk studies and GI. It is also of concern that the ENTLI, which was compiled without ground checking, may be used by practitioners for hazard assessment without due consideration of this limitation. Specifically, without an appropriate level of detailed site-specific API and ground checking, the c. 90,000 relict features identified with different degrees of uncertainty in the ENTLI may lead to significant under- or over-estimation of design events.

Over-conservatism Arguably the prevailing design philosophy in local slope engineering has tended to become unbalanced over time, such that considerations of risk reduction at more or less any cost have outweighed those of optimum risk reduction based on due consideration of hazard probabilities and preventive/mitigation costs. Possible scenarios that could develop include man-made slopes where improbably deep failure surfaces in thick weathered profiles are judged to pose risk and lead to selection of very costly unconventional LPM design options over conventional options (e.g. long soil nails), and where unusually high groundwater levels based on scant direct evidence are employed, leading to very conservative and costly designed drainage options. It also seems quite possible that current trends in the application of the Design Event approach to NTHS could lead to over-conservative assessments of natural terrain hazards, resulting in extensive preventive works (e.g. soil nailing) over large hillside source areas, or extensive and potentially unnecessary mitigation works at their lower margins (e.g. debris barriers and fences). Such works could also cause unnecessary visual and environmental impacts.

### 7.2 Programme Management

Bureaucratic desire for greater efficiency and effectiveness invariably arises as long-term public works programmes evolve. Programme managers are generally cognisant of the trends but face difficulty in resisting pressures from resource controllers who may lack appreciation of professional geotechnical issues. From an engineering geological perspective two particular areas of concern are:

#### ‘Formulaic’ and compressed programming – is technical rigour maintained?

Long-running works programmes are inevitably streamlined and refined over time. Programme steps and data collection methods become increasingly codified and routine. While contributing to improved productivity and efficiency, such trends carry the risk that technical rigour may be compromised and items of potential significance overlooked within a ‘tickbox’ mentality to data collection, especially during desk studies and GI. Furthermore, suitably rigorous or insightful engineering geological appraisal, which commonly requires additional time for data collection including field work and data analyses, may be diluted in the face of tighter programming schedules and reporting milestones. This effect is likely to be more acute in dealing with natural terrain related work where most studies generally cover a large area. Another possible scenario would be where some geological or geomorphological observations, which due to their bulk or complexity are omitted from study reports so as to be more readily understood by non-geotechnical practitioners, end up being left in boxfiles and overlooked. Potentially valuable information would thus become forgotten with time.

#### IDC as default LPMitP packaging

The use of combined IDC consultancies as the main type of work packaging in the LPMitP, coupled with the

annual pledge to deal with 30 HLC catchments and to meet an expenditure target, has knock-on implications for geotechnical practice. In the face of much uncertainty in interpretation of natural terrain, programme managers are likely to favour conservative estimates of design events. As HLCs are primarily defined as hillside catchments with known failures that occurred close to existing important facilities, it may be argued there is a *prima facie* hazard, particularly for high-ranking HLCs, hence IDC packaging is justifiable and efficient because design and construction of preventive or mitigation works is bound to be required. However, with this approach the likelihood of NTHSs producing a 'no significant hazard' conclusion is negligible in most cases. With time, as the LPMitP begins to deal with lower-ranking HLCs, it will be of interest to see if this trend continues. If it does there may well be a case for introducing standalone investigation assignments in the LPMitP (i.e. to separate the I stage from the DC stages).

### 7.3 Natural Terrain Issues

As compared to man-made slopes, natural hillsides cover large areas of generally variable ground conditions resulting from surficial processes acting on geological timescales and a lesser degree of modification by human activities. The conventional API approach used for man-made features to establish development history and help plan detailed ground investigation is generally not applicable. Engineering geological and geomorphological approaches are required for studying landscape evolution of natural terrain. While high quality engineering geological input, including field mapping, is considered essential in NTHS, Parry & Ng (2010) noted the difficulty in developing realistic hazard models and determination of design events. Therefore, more insightful engineering geological development work is needed to reduce potentially large uncertainties in making hazard predictions, especially in assessing possible large-magnitude, low frequency landslide events with potentially serious consequences. For example, better understanding of the relevance of relict landslides in the assessment of realistic design events is an area deserving further work.

The ongoing programme of systematic dating of relict landslides has potential to establish a landslide age database that should provide a better framework for determining design events, in particular to help assess the crucial question of whether existing large debris lobes represent single failures or multiple events at different times. Furthermore, high-quality LiDAR data should be able to complement conventional API in assessing the relevance of morphological features, such as topographical depressions, whose detailed characteristics are largely obscured by thick vegetation. Despite NTHS apparently becoming routine work under the LPMitP, there is no room for complacency. Much effort is still needed to enhance the current state of knowledge and geotechnology for assessing natural terrain hazards, and hence to implement more cost-effective and appropriate mitigation strategies.

## 8 CONCLUSIONS

Geological input to landslip preventive and mitigation measures in Hong Kong has evolved episodically over the last 40 years. Technical advances in engineering geological knowledge and practice have been the key driver of change, but non-technical factors, such as changes in programme management, have also been influential. Until recently the works programmes were focused on man-made slopes and retaining walls. Many aspects of site investigation and design practice for man-made features have remained essentially similar since the late 1970s but with incremental improvements in a number of GI techniques. Changes in geological aspects of the work have come about mainly through landslide investigations or follow-up research and development studies. Notable developments have included recognition of soil piping as a common near-surface process, the occurrence of kaolinitic clay seams in normal weathering profiles, and the importance of structural control in large landslides.

The most significant change has been rapid recent growth of geological and geomorphological input to natural terrain studies and mitigation works. Based on preparatory work in the 1990s, this has accelerated dramatically since 2002 as discrete packages of natural terrain hazard assessment and mitigation works design were introduced into the programmes. Key developments have been made in the areas of regolith mapping, terrain classification based on engineering geomorphological mapping as a key component of hazard assessment, and common use of digital technology in data gathering and GIS-based analyses. Engineering geological input to natural terrain work will play a central role in the slope safety effort for the foreseeable future, but application of best practice faces a number of challenges related to uncertainty in assessing the scale of hazardous events, design philosophy and programme management.

## ACKNOWLEDGEMENTS

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# LPM project delivery, challenges from the design administration and construction perspectives

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## ABSTRACT

In the quest to progressively reduce the landslide risk from slopes that affect the Hong Kong community, sub-standard government slopes are systematically upgraded under the Landslip Preventive Measures (LPM) programme of the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department. Over the years since the establishment of the GEO in 1977, a large number of slopes had been upgraded under the LPM programmes and so were the wealth of experience that had been accumulated embracing the design techniques, planning and construction aspects. Much had been presented previously on the geotechnical design topics and on advancements in the slope upgrading techniques. In this paper, the experience and challenges from the design administration and construction perspectives, which are equally important in the smooth delivery of slope upgrading works, will be presented. For some of the situations if not well administered and planned in advance, delay affecting the programme output would arise and result in cost implications on construction contracts. Even if all the administrative issues have been cleared, disruptions during construction could also happen requiring the proactive management of the site supervisory team to alleviate the impact on the contract.

## 1 INTRODUCTION

Over the past 30 years in reducing landslide risk, the government has been undertaking systematic slope upgrading programmes with increasing levels of outputs. These programmes were the Landslip Preventive Measures (LPM) Programme since 1977, the 5-year Accelerated LPM Project between 1995 and 2000, and the 10-year Extended LPM Project between 2000 and 2010. To dovetail the preceding LPM programme completed in 2010, the GEO has launched the Landslip Prevention and Mitigation Programme (LPMitP). Over the years, a notable number of slopes have been upgraded and as a result, the overall landslide risk from man-made slopes has been substantially reduced.

In implementing these intense slope upgrading programmes, a pool of experience covering the geotechnical design, design administration and site construction have been accumulated. In the following, experience on the latter two aspects is presented. It aims to share with practitioners some of the considerations and situations which may have significant impact on progress, programme and smooth delivery of projects, and to inspire practitioners to carefully review and plan ahead for scenarios, which may give rise to costly delay and expensive contract implications. At times, situations not originally expected may arise during construction and this demands great effort from site administration to address promptly in order to alleviate the impact.

## 2 DESIGN ADMINISTRATION PERSPECTIVE

### *2.1 Identify government department responsible for maintenance of the slope*

Regular maintenance of slopes and natural terrain hazard mitigation measures is essential to avoid deterioration and to upkeep their functions. Lack of maintenance had been found a major contributory factor to many landslides in Hong Kong. It is therefore important to identify the parties responsible for the maintenance of the slopes at the early stage so that their requirements on future maintenance can be incorporated in the design and avoid last minute changes. The identification of maintenance party for a slope

can be done by checking the Slope Maintenance Responsibility Information System of the Lands Department. In case of doubt, the designer should write to the Lands Department for clarification. For natural terrain catchments, agreement has to be sought from the relevant department to take up the maintenance of the mitigation measures when completed. Usually the beneficiary-maintains principle would apply, i.e. owner of the facility that the measures protect would maintain the mitigation measures. This ensures that the completed works will have a department or departments responsible for the maintenance.

## *2.2 Excavation permit (XP) application and related issues*

For upgrading roadside slopes maintained by the Highways Department (HyD) or the construction involves excavation on roads or footpaths, an excavation permit (XP) has to be obtained from HyD through the Excavation Permit Management System (XPMS) prior to commencement of the works. The Traffic Department (TD) and the Road Management Office (RMO) of the Hong Kong Police Force provide traffic advice on the Temporary Traffic Management Schemes (TTMS) that accompany the XP applications. Knowledge of the requirements from these two offices can greatly assist designers in arriving at the most suitable design option and make due allowance in the construction programme. Experience from past submissions reveals some common restrictions normally imposed and these are highlighted below. It must be emphasized that the following scenarios are for general reference only and situations may vary from case to case.

- (a) For busy route or road in the vicinity of schools, lane closure is normally restricted to off peak hours from 10 am to 3pm, or sometimes only to the morning session of 10am to 1pm. For more severe situations on high speed road such as Lion Rock Tunnel Road, lane closure hours will be more stringent and likely to be between midnight and 6am the next morning. The contractor may need a construction noise permit in performing night works. On roads leading to beaches, any proposed TTMS involving lane closure within the swimming season should be avoided because of the anticipated heavy beach traffic. XP applications should be made with sufficient lead time particularly in areas where large numbers of construction activities or utility laying are anticipated. This ensures that the construction work can be carried out within the desired timeframe. In some areas, there may be a need to consult the views of the local community and other stakeholders on the proposed TTMS.
- (b) Avoid closing footpaths particularly in busy areas. It will be most welcomed by the general public if disruption to the normal pedestrian route can be avoided where at all possible.
- (c) Sites which need TTMS be implemented along the same road, should be separated by some minimum distance which varies depending on details of the TTMS and road conditions. If the sites are close, endeavour can be made between the parties to combine the TTMS if the combined length is not greater than 100 m. Otherwise, it will be necessary to adjust the construction programme of the projects concerned.
- (d) Depending on the result of a trial run, imposed conditions may be varied by TD or RMO to alleviate the impact on traffic flow. For example, the lane or carriageway width to be maintained may have to be increased.

An example of such instance is a case on May Road where TTMS had to be implemented to provide working space for loading/unloading and for drilling soldier piles along the slope toe, while maintaining the dual traffic flow. Because of the presence of another project in close proximity, no lane closure was allowed. The width of the carriageway proposed to be maintained was 6 m. TD requested a trial run be performed prior to the commencement of construction works. Following the trial run, TD requested the carriageway width be increased to 7 m to improve the maneuverability for the passing traffic. This posed a serious problem as it would mean squeezing space from the already tight works area much needed for loading/unloading and drilling the soldier piles. Discussions were made with TD and the contractor. A scheme was finally worked out where the requested 7m width was provided along the bend and 6m width along the straight section of the road. Although it trimmed

some working space away from the original scheme, there was still sufficient space for works to proceed. Figure 1 shows the final arrangement of the adopted scheme.

The impact on the contract was minimized in this instance. Had the requested changes not been accommodated due to site constraints, this would have necessitated a revision of the TTMS, the construction method and would have caused significant time and cost implications to the contract.

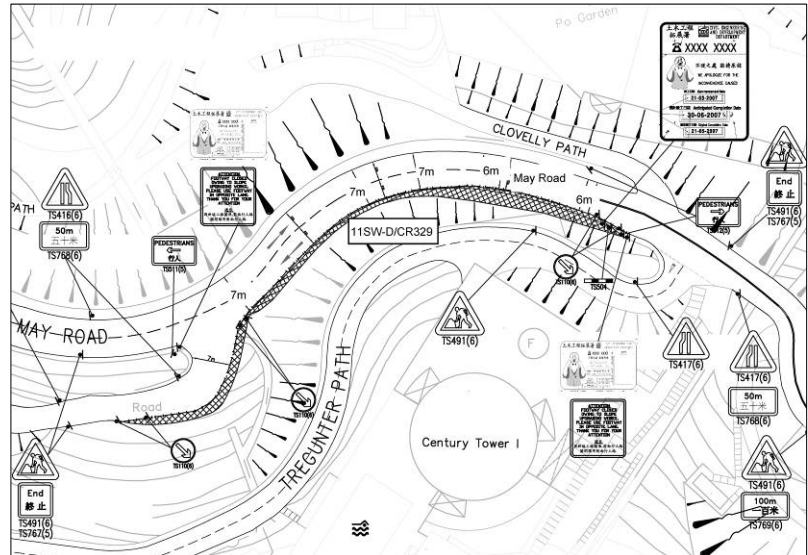


Figure 1: Final TTMS scheme for 11SW-D/CR329

- (e) There may be situations that the subsidiary works critical to a major project, not originally known to the project engineer, is found in conflict with the proposed TTMS of a LPM project prior to construction. At times, this may create a major impact on the construction programme involving modification of the TTMS, increase in construction time, or modification of the construction scheme. The situation of repeated road opening within a 3 month period at the same location should be avoided or addressed.
- (f) According to the XPMS manual, the XPMS system will withhold the accepting function until the time between the acceptance by TD/RMO and the intended start date of the works is less than 120 days. Traffic advice has to be reaffirmed in case the advice was given outside the above period.

For works considered minor under the Roads (Works, Use and Compensation) Ordinance and the TTMS only occupies an unallocated government land on a small road not under the jurisdiction of HyD and closure of the part will not interfere unreasonably the normal flow of traffic, application can be made to the District Land Office (DLO) to occupy the land under temporary allocation. For major road closure, a consultative process involving the public and District Council will have to be followed.

It is obvious from the preceding that XP can critically affect the smooth delivery of LPM projects particularly for roadside features. This necessitates a detailed and comprehensive planning.

### 2.3 Consultation

In finalising the project plan for the proposed works, the project engineer circulates a plan showing the proposed works area and works site to relevant departments including District Office (DO) to collect their comments on aspects, amongst others, landscaping, traffic measures, occupation of the works site/works area. In turn, DO will consult the District Councillors, the local residents/community of their views, or recommend the project engineer to conduct his/her consultation with the residents living in the vicinity. In the latter case, the consultations are normally conducted through the building managements of the nearby buildings. Usually, the collected feedbacks cover landscape, traffic, noise and environment which are areas most pertinent to the daily lives of the residents. In response, the project engineer may have to explain more of the project through a direct reply or distribution of information notes, or make necessary arrangement in the project to address concerns of the public.

The process should be considered beneficial to the project as it allows views of the public be collected well in advance and in time to address public's concerns by the project team. LPM works are commonly welcomed by the public as it aims to improve slope safety. At times, project engineer may have to explain to the local village residents or nearby building residents details of the project to clear their doubts and to secure their supports. In conducting these dialogues, the project engineer should be sincere in the communication to establish trust among the parties.

## 2.4 Designated Project

LPM or LPMit project that falls within a country park, a conservation area or a site of special scientific interest is considered a designated project under the Environmental Impact Assessment (EIA) Ordinance unless exempted under the provisions, and would require an environmental permit for the construction. Designated projects are projects or proposals that may have an adverse impact on the environment. The statutory EIA process entails the submission of an environmental impact assessment report and the involvement of the Advisory Council on the Environment (Council) and the public during the process. If the EIA report with proposed mitigation measures is approved by the Environmental Protection Department (EPD), permit would be granted.

As a case example, LPM slope No. 15NW-C/C3 (Figure 2) located in Lamma Island falls within a conservation area and in an area of scientific interest where Romer's tree frogs were found. These frogs took habitat on the moist vegetated area along the slope toe. EIA report was submitted and the process took about 1 year for obtaining the environmental permit (EP). The EP contained conditions requiring measures to be taken to preserve the environment, the habitat and the tree frogs. The experience was that sufficient time had to be allowed in the programme for satisfying the EIA process and complying with the conditions imposed under the EP. For instance, ecological study was required under the EP. It took about two years, i.e. two breeding periods of the Romer's tree frogs, to collect sufficient information for the ecologist to prepare the required translocation manual for the translocation of frogs to a holding facility for breeding and returning the captive frogs to the native ground following completion of the LPM works. In this case with the agreement of the authority, time was saved by taking a head start before the actual EP was granted in collecting the requisite information and preparing the manual.

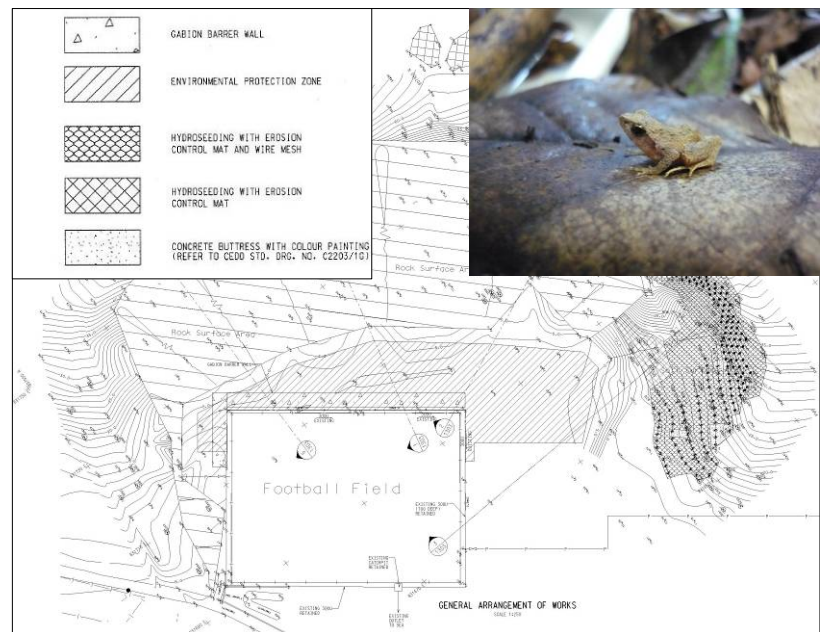


Figure 2: Construction plan showing the environmental protection zone of slope No. 15NW-C/C3

## 2.5 Careful site reconnaissance and field inspections at the design and construction review stage

In carrying out a comprehensive geotechnical study of a slope, there are generally numerous considerations that a designer has to carefully consider/address, amongst others, the facilities that the slope affect, the geology, environmental and tree preservation, requirements from the stakeholders etc. For the practitioners, thorough field inspection at the initial design stage is always considered to be a crucial and indispensable step to verify the presence of previous landslide scars and to confirm if there exists distressed ground, seepage, steep local terrain or features otherwise not easily identifiable on the topographic plan.

The importance of field inspection during the construction review stage cannot be understated particularly immediately at the site commencement stage. Very often, some areas of the slope are not accessible during the design stage. It would be an opportune time as soon as the area concerned become accessible for the designer to verify the design assumptions against the actual site conditions. Often it reveals situations which necessitate modification(s) to the design measures as enhancement to the slope upgrading works. A few typical scenarios worthy of attention both at the design stage and during construction review are listed below and are not meant to be exhaustive.

- (a) *Identify suitable works area for storage of construction materials and equipments:* Area suitable for the usage should have convenient access for loading and unloading, and away from houses to avoid causing noise and dust nuisance. It is important to verify the land status before a decision is made.

Sometimes, what appears to be government land could in fact be a private lot. In case of doubt, clarification from the District Land Office must be sought.

- (b) *Slope drainage alignment:* Particularly for the crest channel alignment, site verification has to be made to confirm the feasibility of the alignment in terms of avoiding existing trees, adequacy of fall, interception of flow from existing streams or seepage, routing of channels away or at sufficient clearance from village houses to avoid overcharging or flooding the area, checking adequacy of the discharge collection points etc.
- (c) *Topography near the slope crest:* Look for steep or locally steep terrain, presence of boulders or other structures. As an example, following site clearance, a distressed masonry wall was found near the crest not identified at the design stage because of thick overgrowth (Figure 3). Additional soil nails with skin wall were ordered. Such has to be instructed as soon as possible during the construction phase to alleviate costs and site programme implication.
- (d) *Setting out of nails and grid beams to accommodate existing trees:* The setting out has to be checked carefully and necessary adjustment be made to avoid conflict with existing trees accordingly.
- (e) *Limited working space and change of terrain:* More often than not, there are situations where limited working space not originally envisaged at the design stage or the actual terrain was found posing difficulty to construction. Changes to the construction methods have to be made such as from percussive drilling to coring method because of the lack of working space in the case of soil nailing, or requiring additional drilling platform in the case of soldier pile construction. It would be desirable to involve the contractor and the site supervisory personnel in devising any change in the working methods.



Figure 3: Distressed masonry wall

### 3 CONSTRUCTION PERSPECTIVE

Despite numerous efforts having been devoted in the planning and design of LPM works for a sub-standard slope, it is not uncommon that the design has to be modified during the construction phase for a number of reasons. For instance, the presence of unforeseen ground condition would inevitably lead to review of the original design and the need for variation orders. XP plays a critical part in the implementation of LPM works, especially for roadside features. Under extreme cases, the Police might order immediate removal of the TTMS and refuse any further road closure. The knock-on effects to the works could be very significant. In recent years, the participation of the public during construction of LPM works has increased substantially. That came in the form of public enquiries and/or complaints. In some occasions, the normal operation of the works could be seriously affected. The views of the public have to be addressed as soon as possible through communication to understand the cause, identifying measures that can mitigate, and making adjustments as necessary. To share with practitioners the experience of the construction team, some of the situations/scenarios normally of concerns to the neighbourhoods are reviewed below.

#### 3.1 Clearance of overgrowth on slope and tree preservation for LPM works

For slopes covered by dense vegetation, clearance of overgrowth could sometimes attract complaints whereby the local residents could misunderstand it as felling of trees. This requires effective communication and patience of the team to explain to the public the difference of overgrowth and trees, and that the existing trees will be retained and protected. A schematic drawing showing the landscaped slope would surely help to ease

their concern. What is more important in the communication is the message that we share the same vision as the community in environmental preservation.

### 3.2 Noise and dust

Soil nails are now commonly used in upgrading slopes. The noise from percussive drilling could sometimes attract complaints. To mitigate the impact, measures taken include postponing the drilling operation to after 9:30am, erecting barriers to attenuate the noise, no drilling operation during special event days of neighbouring institution(s), or switching from drilling to coring.

Similarly for dust issues associated with sprayed concrete and soil nailing operation, barrier has to be erected to attenuate the complaint.

### 3.3 Additional landscape measures

The visual perspective on appearance invariably varies across individuals. Works that had been done as a norm might be perceived by an individual with a different perspective. As a case example, a drainage pipe was laid on a slope for drainage diversion. Concern was received on the visual appearance of the pipe along a section of the alignment visible from a resident's flat. The drainage pipe was a ductile iron pipe with an external zinc coating and bituminous paint; a conventional material that had been used for many years. The pipe was black in colour and did not reflect light. After some discussions, it was agreed to cover the relevant portion of pipe with wire mesh and additional planters and creepers. The complainant was satisfied with the improvement measures. In other occasions, residents may request planting of more trees.

### 3.4 Implementation of TTMS for roadside feature

For the site implementation of TTMS schemes which although have the initial blessing of the TD/RMO, the outcome could be quite eventful. The experience could best be shared by an actual case. A cut slope No. 11SW-B/C605 is located east of the junction of Magazine Gap Road and May Road in Hong Kong Island (Figure 4). The slope is about 45 m long, up to 15 m high and dips at 70° to the horizontal. The lower 5 m of the slope comprises jointed rock, with the upper 10 m formed in soil derived from weathered rock. The slope is situated directly at the roadside, abutting a 180° bend on Magazine Gap Road with no footpath. At the location, the road is a single carriageway supporting one lane of traffic in each direction. The road is narrow with heavy daytime traffic.

Works Order for the LPM works was issued to the contractor on 7 April 2008. The scheduled completion date was 30 September 2008, with a construction period of 177 days. The proposed slope upgrading works mainly comprise the installation of soil nails in the upper slope portion. The existing sprayed concrete on the lower rock slope portion was to be removed for inspection and design of the rock slope remedial works. In view of the absence of working space adjacent to the slope and to minimize the need for road closure, a temporary steel working platform within the slope footprint had to be erected for the installation of soil nails. However, closure of one lane of the road was required for the erection of the platform and its subsequent dismantling. As conditions of approval by TD and RMO, the proposed lane closure and related TTMS could only be carried out within restricted working hours on the site, from 10am to 3pm, Monday to Friday.

The construction of LPM works had not been smooth since commencement. Whenever the contractor attempted to close one lane of the road for mobilization of plant and equipment, complaints from road users were received every time. The contractor was obliged to re-open the road and carry out the works intermittently. It became obvious that the design of remedial works for the lower rock slope portion had to cope with this site constraint.

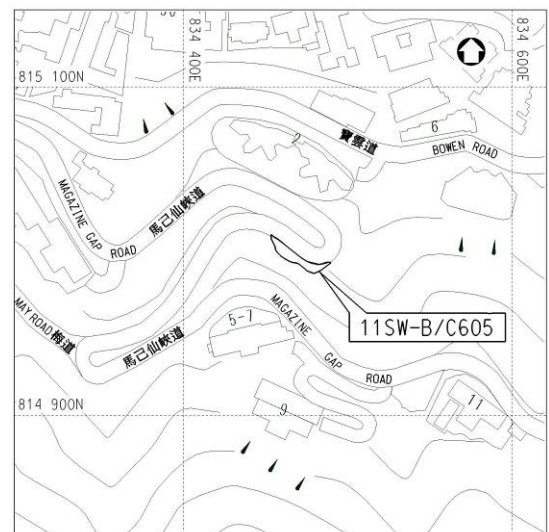


Figure 4: Location plan of feature

Regular complaints on the road closure had caused serious delay to the LPM works. Some significant events are summarized below:

- (a) On 11 September 2008, when the contractor closed one lane of the road for the erection of the steel platform, RMO received numerous complaints and immediately rescinded the approval of the TTMS. The TTMS was revised and further trial runs were carried out in January 2009. However, repeated public complaints were received once the contractor implemented the TTMS for the erection of the temporary steel platform. To minimize the complaints from the public, the Contractor had to carry out the works in a piece-meal manner intermittently (i.e. not to implement the TTMS everyday).
- (b) After completion of the soil nailing works for the upper slope, the contractor started to install the rock dowels for the lower rock slope which required the implementation of the TTMS and lane closure. Just a few days later (on 28 September 2009), complaint on the TTMS was received. The works were again suspended.
- (c) The contractor was then instructed to provide additional manpower to monitor the traffic flows during the implementation of the TTMS. Labourers equipped with walkie-talkies were deployed to the uphill and downhill sides of the TTMS, identifying the ends of the traffic queues and reporting the traffic situation to the foreman. Additional site staff was stationed at the site to record the time of delay to the drivers at the queuing ends and to regulate the operation of the stop/go signs to suit the traffic condition the best they could.
- (d) The dowels installation and the buttressing works for the lower rock slope were then carried out with the implementation of the enhanced TTMS. However, complaints on traffic congestion due to the TTMS never stop. On 23 December 2009, when the Contractor was concreting the buttress, RMO received strong complaints and ordered the immediate removal of the TTMS and did not permit any further road closure. Without the TTMS, the concreting of the buttress could not be carried out. Attempts were made to apply for a night permit from EPD for carrying out the remaining works at nights to minimize the impacts on traffic due to the TTMS, but failed. Without other alternatives, the contractor was instructed to complete the remaining buttress by cement grouting to avoid any lane closure though it would take much longer time to complete. A photograph showing the traffic jam during concreting of the buttress is illustrated in Figure 5.
- (e) Upon completion of the buttress wall, it was necessary to dismantle and remove the remaining temporary steel platform though a large part of it had been incorporated in the buttress. After repeated negotiations between the Consultants, the Contractor, RMO and GEO, RMO finally permitted further implementation of the TTMS only for 8 days immediately after the long public holidays of Chinese New Year and Easter (i.e. 17-20 February and 7-10 April 2010). The temporary steel platform was successfully removed under the tight schedule.
- (f) The Works were finally completed on 9 April 2010 suffering a delay of 556 days.



Figure 5: Serious traffic jam during implementation of TTMS

### 3.5 Discussion

The situations and events described above are scenarios commonly faced by site management, and most of which are environmental related and of concerns to the public. For issues of visual perspective, the residents and local community would be facing the finished LPM works for a considerable length of time, much longer

than the limited time involvement by the project team during planning, design and construction of the works. It seems fair for them to express their view of our works and preference which could be different from our perspective. With the benefit of hindsight, most of the requests improve the aesthetic appearance of the slope and a greener slope, which is a mutual common goal.

In recent years, the increasing participation of the public in the LPM works, especially during the construction phase in the vicinity of densely populated urban areas, has a profound effect on the construction programme and the slope work design. The role of the engineer has been changing and evolving over the years. Administration of LPM projects has evolved from the conventional process of project delivery, i.e. focusing on the technical part of the planning and design of works, to a broader perspective that includes the views and needs of the public and community at large.

#### **4 CONCLUSION**

For smooth delivery of LPM projects, experience indicates that proactive design and site administration are critical and quite often requires more effort, patience and time for complicated cases. An early understanding of the requirements, in particular, the determination of maintenance responsibility, permission of access to site, approval of excavation permit with associated TTMS, EIA process, etc are essential to the overall planning of LPM projects. Even so, disruption could happen during construction and this requires the proactive and professional effort of the site construction team to deal with the situation as it occurs.

Public consultation is an essential component of good planning, especially for those slope works in sensitive areas that would take considerable time to complete. It is imperative to incorporate the views and opinions of the affected residents and community into the design of LPM works the best we could. Public engagement is an on-going process and the grievances and dissatisfaction of the affected individuals or groups would be heard through queries and/or complaints during construction of the LPM works.

A complaint is an opportunity to improve and a lesson for reference. It is unrealistic to think that we can avoid complaints. Rather, we should welcome and listen to complaints, rectify what can be rectified, and learn how to explain to the public our scheme, policies and objectives. Only through continuous improvement that we can successfully deliver the LPMitP on slope works and service better.

#### **ACKNOWLEDGEMENTS**

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# Implementation of the Landslip Preventive Measures Project – Words from Some Contractors

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## ABSTRACT

Over the past 10 years, there were quite steady outputs and expenditures under the Landslip Preventive Measures (LPM) Programme managed by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). Each year, about 300 government man-made slopes were upgraded at the total annual expenditures of about HK\$ 1 billion. The LPM contractors have been working in close partnership with the GEO in achieving the LPM targets for reducing the landslide risk in Hong Kong. However, the LPM contractors have faced very fierce and keen competition among themselves in the construction industry as reflected by the very competitive tendered prices for LPM works. On the other hand, the ever-increasing public expectations for the safety and environmental aspects have imposed more and more severe constraints and difficulties on contractors in the delivery of the committed services and targets. In this paper, the major challenges and difficulties encountered by contractors in the execution of LPM works in last ten years will be presented. The paper also describes the key strategies and methods adopted by LPM contractors to overcome those difficulties in order to maintain their competitiveness in the construction market. Some suggestions are also made for the LPM contractors and the Government to work in close partnership for ensuring that the construction industry delivers better value and develops a culture of continuous improvement, eventually achieving the GEO's mission to meet the Hong Kong's need for the highest standard of slope safety.

## 1 INTRODUCTION

Over the past ten years, there were quite steady outputs and expenditures under the Landslip Preventive Measures (LPM) Programme managed by the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD). Each year, about 300 government man-made slopes were upgraded at the total annual expenditures of about HK\$ 1 billion. The LPM contractors have been working in close partnership with the GEO in achieving the LPM targets for reducing the landslide risk in Hong Kong. However, the LPM contractors have faced very fierce and keen competition among themselves in the construction industry as reflected by the very competitive tendered prices for LPM works. On the other hand, the ever-increasing public expectations for the safety and environmental aspects have imposed severe constraints and difficulties on contractors in the delivery of the committed services and targets.

## 2 CHALLENGES AND DIFFICULTIES FACED BY LPM WORKS

In the last ten years, there have been increasing contractual requirements and obligations imposed on LPM works, together with new legislations and regulations related to construction activities and practices. Among these, the followings are most relevant to LPM works:

- (i) Site safety (e.g. new legislation and regulations, safety plan, risk assessment, etc.);

- (ii) Temporary traffic arrangements and control;
- (iii) Conditions and special requirements under Excavation Permits;
- (iv) Tree protection and preservation;
- (v) Site cleanliness and tidiness (including prevention of mosquito breeding);
- (vi) Improvement of public image of construction sites (e.g. attractive hoarding designs & site uniforms);
- (vii) Management and handling of Construction and Demolition (C&D) materials;
- (viii) Monitoring of payment of wages to workers; and
- (ix) Handling of public complaints

Significant costs have been incurred due to those additional requirements and constraints mentioned above. Although there are some provisions (e.g. site safety, temporary traffic arrangement and site cleanliness) under LPM contracts to pay for these requirements, the payments allowed are far less than the actual costs borne by contractors to meet these stringent requirements. As a result, LPM contractors have to continuously implement effective means to improve their efficiency and productivity in order to maintain reasonable profit margins. The improvement measures adopted by some LPM contractors to maintain their competitiveness in the construction industry are discussed in the following paragraphs.

### *2.1 Streamlining of Operations to Cut Costs*

To reduce operational costs, LPM contractors have to identify effective means to improve the efficiency of the management and operation of their organizations. They need to streamline operations and workflow, reduce the size of their organization and cut running costs. As sub-contracting is a common practice in the construction industry, it is important for LPM contractors to maintain a close partnership with their sub-contractors. The main-contractors may need to negotiate with their sub-contractors and suppliers for better terms under the very difficult market conditions.

### *2.2 Improvement of Technical Competence and Quality of Services*

To ensure their competitiveness, LPM contractors have to improve their technical competence and quality of services continually in order to ensure that all LPM works will be carried out in compliance with contract specifications and requirements, in addition to the relevant ordinances and regulations. The top management of main-contractors should demonstrate their concern and commitment to the quality of the works. They should carry out periodic site inspections and maintain close dialogues with their frontline site managers, foremen and workers. Proactive and direct involvement of the top management could help to identify the major problems at the earliest opportunity, and thus devise the best possible solutions to minimize the adverse effects upon the works.

### *2.3 Maintaining Good Relationship with Sub-contractors*

Sub-contracting is a common practice in the construction industry in Hong Kong and there is no exception for the construction of LPM works. Proper management of sub-contracting is essential and necessary to ensure that the execution of a project is commercially viable. To ensure the quality of the works executed by sub-contractors up to the required standards, the main-contractor needs to provide strong technical support and resources back-up to them, particularly for those complicated geotechnical works in difficult ground conditions because LPM sub-contractors normally have inadequate technical resources in their organizations. As the main-contractor is ultimately responsible for the quality of all constructed works, supervision of the works, including those carried out by sub-contractors, should be done by the supervisory staff from the main-contractor. Meetings between the main contractor and its sub-contractors, attended by the top management of the main-contractor, should be held regularly. Such meetings could provide good opportunities for both parties to detect the major problems at the early stage and work together to implement control measures and minimize disruption to the works. To ensure smooth implementation of a LPM project, the main-contractor should take initiative in preparing major submissions (e.g. design of temporary works) to the Engineer for approval in good time and also liaising with the relevant authorities, including the Police, Highways Departments and Lands Department. As sub-contractors for LPM works are normally small companies

vulnerable to cash-flow problems, timely payment by the main-contractor to its sub-contractors is most critical in maintaining their momentum and diligence in carrying out the works.

### **3 PARTNERING RELATIONSHIP BETWEEN GEO AND LPM CONTRACTORS**

After discussion about the crucial issues and measures for a LPM contractor to maintain competitiveness and produce quality outputs under the fierce competition in the construction industry, we would like to make some suggestions to strengthen the partnering relationship with the GEO, as our Client.

#### *3.1 Steady Workload for Schedule of Rates (SoR) Contracts*

Schedule of Rates (SoR) Contracts are commonly adopted by the GEO for delivery of the LPM projects. SoR contracts provide the GEO with the flexibility of engaging contractors earlier before completion of the design of upgrading works for slopes to be included in the contracts. Once a SoR contract has started, the LPM contractor needs to set up an adequate site organization and team up with sufficient competent sub-contractors to cope with the estimated amount of LPM works based on the contract sum. Overhead costs to fulfill some contractual requirements (e.g. insurance & site safety) are more or less fixed by the contract sum. Normally, an even distribution of workloads over the contract period, discounting the first few months for establishment and preparation, is assumed by the contractor for planning of his resources. The contractor may suffer massive financial burden if there is significant fluctuation of workloads or large reduction of the total expenditure compared with the original contract sum. Therefore, it is very important and helpful to the contractor if there is a steady workload with the total expenditure close to the original contract sum.

#### *3.2 Early Involvement of Contractors in Design of the Works*

Owing to the uniqueness of each LPM site, it is a good practice to get the contractor involved in finalizing the design of the LPM works. The detailed design of the works can be optimized with useful inputs from the LPM contractor based on its specialized knowledge and experience in local construction practice. This practice has been promoted and encouraged by the GEO in the past ten years under the LPM Programme and has proved to be very useful and effective. In particular, this has helped to save a lot of abortive works and minimize unnecessary disputes on the programme of the works, methods of construction, arrangement for access, etc. Such collaboration between LPM contractors and designers should be further enhanced in the new Landslip Prevention and Mitigation (LPMit) Programme with a view to continuously improving the cost-effectiveness of executing LPM works.

#### *3.3 Performance Assessment of Contractors*

It is understood that the GEO has adopted the formula approach in accordance with ETWB Technical Circular (Works) No. 8/2004 (ETWB, 2004), which takes into account of both the tender price and the tenderer's past performance, in the evaluation of tenders for LPM contracts. Under that evaluation methodology, the past performance of a LPM contractor is a critical factor to determine its overall competitiveness in a tendering exercise. Therefore, it is important to establish a reliable performance assessment system which can fairly and effectively differentiate the good from bad performers. The Government has made the following major improvements to the assessment system in last few years:-

- (i) adoption of a 5-grade marking scheme instead of the previous 3-grade marking scheme since the 1<sup>st</sup> quarter of 2007;
- (ii) promulgation of clear guidelines for completion of contractors' performance reports using; and
- (iii) independent audit of contractors' performance reports since the 3<sup>rd</sup> quarter of 2007.

To maintain the consistent standard and objectivity of the LPM contractors' performance reports, all reports will be reviewed by a special committee, namely the Report Review Committee (RRC), which is composed of

GEO directorate staff. In addition, appeal mechanism has been in place for LPM contractors to raise queries and questions about their performance scores. Realizing the importance of the performance assessment system, the GEO and LPM contractors should continue to work together in future to improve the system, which would recognize and reward good performers and penalize the poor for the ultimate target of achieving high standards of LPM works. We should look forward to an equitable and effective system as an impetus to drive contractors to enhance their capability and performance through better training of their staff, more investment in human resources and plant, and setting a more healthy business planning.

### *3.4 More Cooperative Attitude by the GEO and Its Consultants*

We understand the Government has been promoting a partnering spirit between the public works contractors and the client departments. We appreciate the GEO has paid special efforts to cultivate a cooperative relationship with LPM contractors with a view to achieving a win-win situation for implementing the LPM Programme. Liaison meetings between LPM contractors and the GEO at three-month intervals were started long time ago. These liaison meetings have provided an effective forum for discussion and exchange of views on major issues of special concern to LPM contractors. The GEO also makes use of this venue to promulgate major new initiatives, legislations, regulations and special contractual requirements in the construction industry and seeks feedbacks from contractors. In addition, regular meetings between the Chief Geotechnical Engineers and the top management of LPM contractors are also held on an individual project basis.

The regular communications between the GEO and LPM contractors at high level have proved to be useful to promote the partnering spirit, it is suggested that such contacts should be further enhanced in the new LPMit Programme.

In addition to the high level communications, we believe there are still rooms for improvement of the relationship between LPM contractors and site supervisory staff. It is important that the site supervisory staff maintains a helpful and partnering attitude towards the contractors. Site supervisors should be sympathetic with the difficulties and constraints faced by the contractors and exercise judgment and flexibility in checking the works. For examples, it would be helpful to the contractor if the site supervisor can arrange early inspection of the works upon receipt of notice of inspection from the contractor. For the benefit of programming of the works, the resident engineer can help to review the contractor's method statement quickly and provide useful comments and pragmatic suggestions. Site supervisors should also adopt a collaborative attitude with the contractor to work out a flexible programme to inspect major items of the works (e.g. large scaffolding system) in phases to suit the progress of construction.

A sincere partnering relationship between LPM contractors and the GEO and its consultants is important for achieving the key slope safety targets (e.g. annual target of upgrading substandard government slopes), with LPM works constructed to the highest standards of workmanship.

## **4 CONCLUSIONS**

As a group of conscientious and committed LPM contractors, we wish to wrap up our experience sharing and look forward to further improving the partnering relationship with the GEO and other stakeholders of the new LPMit Programme by quoting Mr Henry Tang's foreword in his report "Construct for Excellence" (Tang, 2001):

*"As a major client of local construction, the Government has an overriding interest in ensuring that the construction industry delivers better value. We urge the Government to commit itself to becoming a best practice client and a facilitating regulator in order to drive the change programme forward. At the same time, we urge industry participants to develop a culture of continuous improvement and always to seek to surpass clients' expectations."*

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# Safety-screening of Private Slopes under the Landslip Preventive Measures (LPM) Programme

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## ABSTRACT

Of the 60,000 sizeable man-made slopes in Hong Kong registered in the Government Slope Catalogue, about a third are of private responsibility. To reduce the landslide risk to as low as reasonably practicable, slope owners, i.e. government and private slope owners, should maintain the safety of their own slopes. In addition to assisting private owners to maintain their slopes through public education, publicity and information services and community advisory services, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department carries out safety-screening of private slopes under the LPM Programme. The main objective is to establish prima facie evidence for serving Dangerous Hillside (DH) Orders, under Section 27A of the Buildings Ordinance, on the responsible private owners requiring them to rectify their slopes which are dangerous or liable to become dangerous. For compliance with the DH Order, owners will have to investigate and upgrade, if necessary, the slopes stipulated in the Order, thereby enhancing the safety of private slopes through works. The safety-screening exercise is one-off and owners are expected to continue to maintain their slopes through regular inspection and maintenance. This Paper describes the role and importance of safety-screening of private slopes under the Hong Kong Slope Safety System. The scope of safety-screening studies and its methodology and procedures will be presented. Some interesting cases will be discussed to elaborate the major difficulties encountered and how the problems were resolved with concerted efforts amongst key stakeholders.

## 1 INTRODUCTION

Hong Kong's hilly terrain, intense developments and heavy rainfall in the summer make us prone to landslides. There are currently about 60,000 sizeable man-made slopes registered in the Government Slope Catalogue. About one third (i.e. about 20,000) are of private responsibility and the remaining (i.e. about 40,000) are government slopes. In the holistic approach to reduce landslide risk in Hong Kong (GEO, 2005), community involvement is a key to meet Hong Kong's needs for the highest standards of slope safety.

## 2 PUBLIC EDUCATION & ADVISORY SERVICE

Concerted efforts from Government, private slope owners and the public are needed to reduce landslide risk in Hong Kong. The GEO has an on-going public education programme on slope safety to reduce (i) the probability of landslides through regular maintenance by slope owners in accordance with Geoguide 5 (GEO, 2003), and (ii) the consequence of landslides through personal precautionary measures during heavy rain.

Free and easy access to slope information is crucial in helping the public to take timely actions on their slopes. The GEO has developed a computerized Slope Information System (SIS) to contain pertinent information on the 60,000 registered man-made slopes in the Catalogue. The public can freely retrieve slope information at the Hong Kong Slope Safety Website (<http://hkss.cedd.gov.hk>) from their homes and offices.

Advisory service to the lay public will help them to deal with slope issues. The Government 24 hour one-stop hotline – 1823 Citizen's Easy Link answers queries and provides guidance to common slope safety problems. The Community Advisory Unit (CAU) in the GEO provides proactive outreach advisory services to

the public, including owners and their agents, on slope safety matters through talks and seminars, meet-the-public and free advice to owners on how to deal with slope maintenance and Dangerous Hillside (DH) Orders.

Financial assistance could help private owners to fund their slope works. The Building Safety Loan Scheme, administered by the Buildings Department (BD), provides loans to private owners for their slope maintenance and upgrading works, including the investigation and works needed to comply with DH Orders.

### **3 GOVERNMENT REGULATORY ACTION ON PRIVATE SLOPES**

#### *3.1 Need for government regulatory action*

Notwithstanding the public education and advisory service described in Section 2 above, Government needs to take timely action to deal with slopes which could have serious public safety concerns. Where a slope of private responsibility is found to be dangerous or liable to become dangerous, the Building Authority, under the statutory powers of Section 27A of the Buildings Ordinance (Hong Kong Government, 2005) may carry out emergency works and/or serve a DH Order on the responsible owners. The Order will require them to investigate the stability condition and, if found necessary, to carry out upgrading works. As part of its efforts to enhance the safety of private slopes, the GEO has been carrying out safety screening of selected private slopes. The main objective of the safety-screening study (Stage 2 Study) is to confirm whether prima facie evidence on a private slope can be established for serving a DH Order.

Under the LPM Programme completed in 2010, about 5,200 private slopes have been safety-screened resulting in the service of DH Orders on some 2,500 slopes. However, in the interest of public safety, the safety-screening exercise on private slopes will continue under the ongoing Landslip Prevention and Mitigation (LPMit) Programme which commenced in 2010.

#### *3.2 Follow-up actions after service of DH orders*

After service of a DH Order, the BD would install a landslip warning sign at a conspicuous location to alert nearby residents and members of the public to the potential landslide danger. The Authorized Person engaged by the owners to deal with the DH Order is also required to monitor the conditions of the slope and advise on any signs of impending danger.

If the owners do not complete the tasks by the dates specified in the DH Order, the BD may prosecute the owners pursuant to Section 40(1B) of the Buildings Ordinance. In the interest of public safety, the BD may also carry out the investigation and any subsequent works in default and recover the costs plus supervision charges from the owners pursuant to Sections 32A & 33 of the Buildings Ordinance.

### **4 METHODOLOGY OF SAFETY-SCREENING**

#### *4.1 General Approach*

Private slopes are selected from the Catalogue for Stage 2 Study on a risk-based priority order (GEO, 1998). A lot-by-lot approach has been adopted to include all eligible slopes within a single private lot to be studied in one go as far as possible. Stage 2 Study on private slopes generally includes desk study, review of maintenance responsibility, aerial photograph interpretation, site reconnaissance, stability calculations and, if necessary, land survey. As it is the owners' responsibility to carry out detailed investigation to confirm the stability of a private slope, ground investigation is normally not carried out under Stage 2 Study.

It can be seen that safety-screening is a multi-disciplinary task involving professional input from geotechnical engineers, structural engineers, land surveyors, estate surveyors, building surveyors and lawyers. The task also requires concerted efforts from different departments, including GEO, BD and Lands Department (Lands D). The GEO is responsible for the slope selection and safety-screening. The estate surveyors in Lands D advise on the maintenance responsibility (MR) of slopes with support from lawyers on the interpretation of relevant lease conditions. Being the authority for enforcing the Buildings Ordinance, BD is responsible for all administrative matters on the service of DH Orders. If needed, the structural engineers of BD will give expert advice on structural aspects of the study. Authorized land surveyors (ALS) are often engaged to carry out boundary survey of the slopes and nearby private lots.

## 4.2 Technical criteria for the service of DH orders

The GEO uses at least one of the seven technical criteria laid down in GEO Circular 24 (GEO, 2010) to determine if prima facie evidence exists that a situation is dangerous or liable to become dangerous. The most common criterion used is Criterion F as shown below :

*"Criterion F - For a slope, a mechanism exists by which failure can occur, and the factor of safety, calculated from a stability assessment based on generalized or typical parameters without site-specific ground investigation (e.g. Stage 2 Studies), is less than 1.2. However, judgment should be exercised in each case and due consideration must be given to the results of sensitivity analyses which cover factors of safety ranging from 1.1 to 1.2."*

## 4.3 Review of slope maintenance responsibility

The Slope Maintenance Responsibility Information System (SMRIS) of Lands D is the initial source of information on the slope MR. However, the MR information in the SMRIS may not be up-to-date and accurate due to the limitations and constraints in preparing the SMRIS. As the slope MR is crucial to the downstream actions, it has to be carefully reviewed during the Stage 2 Study. An estate surveyor is normally engaged under Stage 2 consultancy agreements to assist Lands D to carry out the MR review.

Owners served with DH Orders may question or disagree with the MR determination. In fact, MR issues are always the main reason of appeal to the BD Appeal Tribunal for DH Orders. For some complicated cases, (e.g. old or missing lease documents and ambiguous lot boundaries), the MR issue could take years to resolve. Such difficulties will be illustrated in Section 5 of this paper.

## 4.4 Survey of boundaries of slopes and private lots

The boundaries of the registered slopes are only indicative as land survey of the slope boundaries and surroundings were not carried out when compiling the Catalogue. Generally, land survey for Stage 2 Study is only limited to that required for stability analysis and MR review. The exact slope boundaries and private lot boundaries are sometimes critical to the slope MR determination and ALS is usually employed. For example, if a retaining wall is very close to and encompasses a number of private lots or sub-divided lots belonging to different owners, a very precise survey by the ALS of the boundaries lots and the retaining wall will be carried out to determine the owners of the different parts of the wall for the purpose of service of DH Orders. The ALS may have to answer queries from the affected owners or even to testify in the BD Appeal Tribunal.

# 5 CASES TO ILLUSTRATE DIFFICULTIES WITH MR DETERMINATION

## 5.1 Case 1: Lot Boundary Survey

As shown in Figure 1, Slope A is located in Demarcation District (DD) Lot 1 and DD Lot 2 in the New Territories. Based on the Lot Index Plan, Slope A is located close to the lot boundary and a slight deviation in the lot boundary will change the MR. Lot boundary survey by ALS 1 employed by GEO indicated that Slope A was located wholly within DD Lot 1 and Lot 2 and the lot owners of DD Lot 1 and Lot 2 were responsible for maintenance. As the slope was liable to become dangerous, a DH Order was served on these lot owners.

Upon receiving the DH Order, the lot owner lodged an appeal and employed his own ALS to carry out another lot boundary survey. The re-established boundaries by ALS 2 were significantly different from the earlier results as Slope A was established as almost wholly outside both lots.

Both ALS's followed the Code of Practice issued under the Land Survey Ordinance but adopted different approaches in their lot boundary re-establishment, thus producing two different results. ALS 1 re-established lot boundaries by scaling off from the Lot Index Plan. Although the shapes and areas of DD Lot 1 and Lot 2 were maintained, the re-established boundaries were significantly in conflict with the existing occupations. On the other hand, ALS 2 carried out the works by adopting the original occupation taking into account the existing buildings. To give the benefit of doubt to the owners, BD withdrew the DH Order.

This discrepancy in lot boundary was mainly due to the quality of the DD Sheets. Soon after the British assumed complete control of the New Territories in 1898, DD Survey was carried out for the allocation and registration of all private lots in the rural New Territories originally held by the indigenous villagers. The Cadastral Maps (DD Survey Sheets in scales of 1:3960 or 1:1980) were expressed in multiples of 0.01 acre (around 40m<sup>2</sup>). The cadastral survey covered the whole of the New Territories and divided the New Territories into 477 Demarcation Districts.

For land granted subsequent to the preparation of the DD Sheets and before 1960's (i.e. old new grant lots in the New Territories), the location, areas and dimensions of these lots as shown on the land grant documents are normally subject to the survey by Government under the terms and conditions of the leases with varying degrees of accuracy. As such, the lot boundary re-established by ALS may have discrepancies with the lease plan. The allowable discrepancies will be different case by case, according to the reliability of the documentary evidence and the availability of the physical evidence on the ground. In all cases, discrepancies shall be within the tolerance set out in the Code of Practice issued under the Land Survey Ordinance.

This case study illustrates that the determination of lot boundaries for DD lots is difficult and even with expert input from ALS, discrepancies in lot boundaries survey is not uncommon.

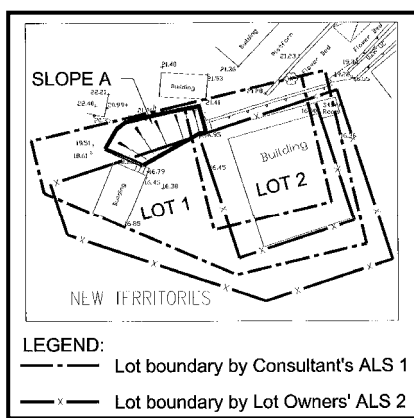


Figure 1: Case 1, Site Layout Plan

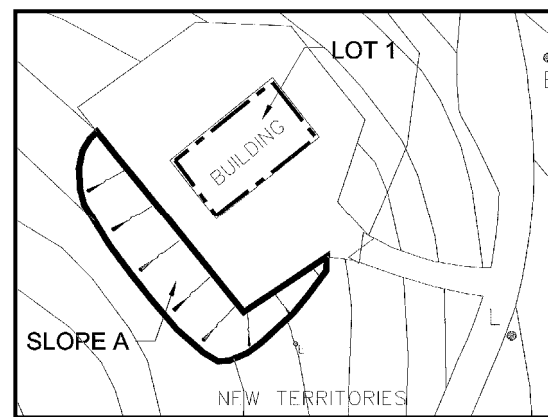


Figure 2: Case 2, Site Layout Plan

## 5.2 Case 2: Slope Wholly Outside the Lot but under the MR of the Lot Owners

As shown in Figure 2, Slope A is located wholly outside Lot 1. The Lease of Lot 1 contains a Cutting Away Clause, which stipulates that the lot owner is responsible for maintenance of any slope which was formed for the purpose or in connection with the development of the lot.

A detailed review of the available aerial photographs was carried out to determine the formation history and cutting evidence for Slope A. In the 1976 aerial photograph (Plate 1), neither the building nor Slope A had been formed, while in the 1977 aerial photograph (Plate 2), both the building and Slope A were visible. Such records indicated that Slope A was formed between 1976 and 1977, most likely in association with the development of Lot 1. Based on this cutting evidence and the Cutting Away Clause in the Lease, the owner of Lot 1 was held responsible for Slope A. Hence, a DH Order was served on the lot owner.



Plate 1: 1976 Aerial Photograph  
(no building or slope)

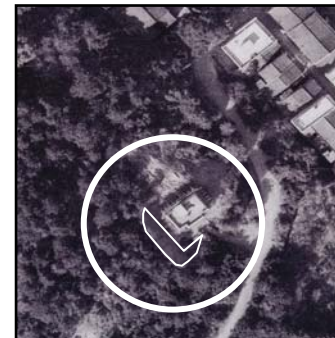


Plate 2: 1977 Aerial Photograph  
(building constructed and Slope A formed)

On receipt of the DH Order, the owners lodged an appeal on the MR of Slope A. The owner argued that: (1) Slope A was located wholly outside Lot 1 and (2) Slope A had previously been maintained by Lands Department and Government had carried out maintenance works on the slope. However, the BD Appeal Tribunal dismissed the case after the full hearing as there was strong evidence that the slope was formed in association with the development of the village house.

### 5.3 Case 3: Slope Wholly Outside the Lot but Wholly Within Short Term Tenancy (STT)

Slope A was located wholly within an STT area and wholly outside Lot 1. The MR of Slope A was originally under the tenant of the STT. The site layout plan is shown in Figure 3.

As a general practice, DH Order will not be served on a STT slope and instead a Warning Letter will be issued by the Lands D to require the tenants to upgrade the slope if they are held responsible under the STT. Hence, a Warning Letter was issued to the tenant of the STT based on the results of the Stage 2 Study. However, the tenant did not take any action on Slope A. Subsequently, a minor landslide occurred.

In view of the danger and the tenant's ignorance of the Warning Letter, Lands D terminated the STT and then carried out an MR review of Slope A. It was found by a detailed Aerial Photograph Interpretation (API) that Slope A was formed between 1956 and 1961, likely in association with the development of Lot 1. The Lease of Lot 1 also contains a General Maintenance Clause (GMC), which stipulates that the owners are responsible for maintenance of slopes which are formed in association with the development and are essential to the survival of the building. In this case, Slope A was considered essential to the survival of the building and the MR of Slope A was re-assessed to be under the owner of Lot 1 based on the new cutting evidence. Eventually, a DH Order was served on the owner of Lot 1.

### 5.4 Case 4: Unregistered Man-made Slope

DHO was served on the owner of Lot 1 for Slope A based on the slope boundary defined in the Slope Information System (without detailed survey). The owner of Lot 1 appointed an Authorized Person (AP) and a Registered Geotechnical Engineer (RGE) to undertake an investigation of Slope A. Based on the topographic survey carried out as part of the investigation, the AP/RGE pointed out that an unregistered man-made slope adjoining Slope A was of similar conditions as Slope A and should also be investigated. Subsequently, GEO registered the slope as Slope B. The plan showing Slopes A and B is shown in Figure 4.

A Study 2 Study was then carried out for Slope B and the results indicated that Slope B was also liable to become dangerous and another DH Order was served on Slope B. The responsible AP/RGE of Lot 1 had correctly brought out the issue and the dangerous slopes were duly dealt with.

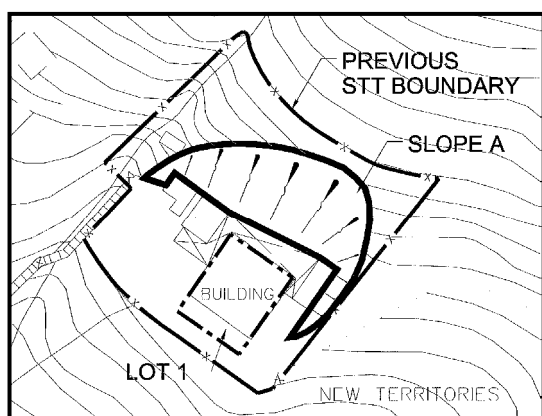


Figure 3: Case 3, Site layout plan

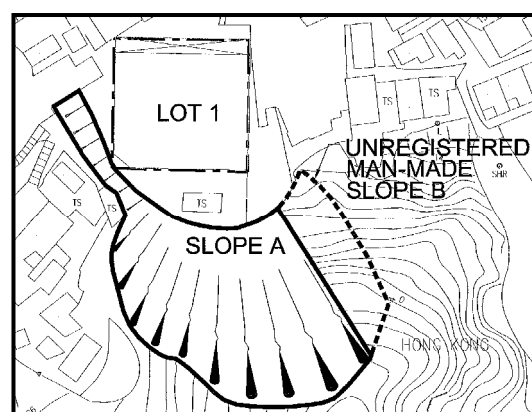


Figure 4: Case 4, Site layout plan

## 6 CONCLUSIONS

Community involvement plays a key role in enhancing slope safety in Hong Kong. Whilst the Government maintains government slopes and helps private owners to maintain their slopes through public education, publicity and information services and community advisory services, safety-screening of private slopes has proved to be an effective means to require private owners to take timely actions to deal with slopes which are dangerous or liable to become dangerous. Safety-screening is a multi-disciplinary task that requires professional input from various disciplines including geotechnical engineers, structural engineers, land surveyors, estate surveyors, building surveyors, and lawyers. Under the LPM Programme completed in 2010, about 5,200 private slopes have been safety-screened resulting in the service of DH Orders on some 2,500 slopes. The investigation and works associated with these Orders have improved the stability of the problematic private slopes and hence resulted in a significant reduction in landslide risk. In the interest of public safety, the safety-screening exercise on private slopes will continue under the ongoing LPMit Programme commenced in 2010.

## ACKNOWLEDGEMENTS

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# Stakeholder Participation in the Implementation of Landslip Preventive Measures Projects

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## ABSTRACT

Stakeholder participation has been a key element in the implementation of Landslip Preventive Measures (LPM) projects. Over the years, the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department has engaged various stakeholders in the project to solicit their views on the design and construction of LPM works. The process has been proved to be successful, leading to effective and efficient delivery of LPM projects. This paper describes four cases of stakeholder participation in LPM projects. These cases illustrate how an effective communication channel enables the project team to address public's concerns and in turn foster a partnering environment. By sharing a common goal in the implementation of an LPM project, any unnecessary disputes and complaints can be avoided and the project can be completed in a timely manner.

## 1 INTRODUCTION

As a pluralistic society with different interest groups, the people in Hong Kong are looking for more opportunities to give their opinions on various issues relating to the delivery of public works projects. This is no exception for Landslip Preventive Measures (LPM) projects. Public participation in the evaluation of LPM designs and logistic matters has embarked upon a new era of project implementation. This paper will share the experience of 4 LPM cases in which stakeholders were invited to actively get involved in the planning and design of slope upgrading works. These show that the partnering approach with stakeholders can effectively eliminate communication blockages, establish shared commitment to continuous improvement, and seek ways to improve the process performance to the benefit of all parties.

## 2 CASE STUDY

### *2.1 Public Engagement at Sai Wan Estate*

Public engagement is a key step for carrying out slope works in developed residential areas, particularly when unconventional construction methods are adopted. One of the notable cases is the upgrading works for a 140m high sizable slope behind Sai Wan Estate. The 40-year-old public housing estate is located at Kennedy Town of Hong Kong Island with five medium-rise housing blocks. It accommodates some 600 households with approximately 2,200 residents and is managed by the Housing Authority.

The proposed upgrading works, which commenced in October 2005, entailed construction of some 19 Nos. 2.5 m to 3 m diameter hand-dug caissons and installation of 1,600 nos. soil nails. Access to the site was identified to be the major constraint as the slope was surrounded by housing blocks of the estate and there was only a narrow vehicular access to the slope toe.

In order to facilitate transportation of construction plants, materials and excavated debris, it was proposed to utilize a tower crane so that the construction period could be shortened and hence the disturbance to the residents in Sai Wan Estate could be minimized. The proposed gigantic tower crane undoubtedly could arouse great concerns from the residents and, in view of this, a series of public engagement to this logistic method was held. It was important to have the public engagement at the early stage of the project, as the site was located close to a densely populated residential area.



Figure 1: Residents' Forum



Figure 2: The operation procedure of tower crane presented in the Residents' Forum

With the assistance from a member of Central and Western District Council, the residents were invited to join a forum held at a children playground of the estate. The forum provided a useful platform for the project team to brief the residents, the management office of the estate about the problem of slope safety in Hong Kong and the need for LPM works. All relevant issues including site constraints, construction difficulties, site safety etc. were discussed during the forum and attendants raised a number of questions about the construction works. Some residents expressed concerns on the safety of the tower crane operation. With the aid of sketches and photos, the contractor presented the operation procedure of the tower crane and pointed out that the extent

of crane movement would be controlled that would not impair damage to the buildings. Residents were satisfied with the illustration. The chairman of the Management Advisory Committee of the estate also suggested the telephone contacts of the key site personnel to be displayed at prominent locations to improve communication. The suggestion was implemented immediately after the forum. The concerns of the residents and the management office were addressed with a view to minimize the impact and inconvenience caused to the public as far as practicable. The works were eventually completed in a timely manner and this was partly attributed to early engagement with the stakeholders.

## *2.2 Slope Works on the Lantau Island*

Stakeholder participation is also a key to the success of delivery of LPM projects in rural areas. Under another project, 24 roadside features located along the Mui Wo to Pui O Section of South Lantau Road were upgraded in 2001 - 2004. The upgrading works mainly involved trimming back of steep slopes having hard surface covers, installation of soil nails, replacement of loose fill with rockfill, and rock slope stabilization works. All the upgraded slopes were provided with vegetation covers and various species of trees, shrubs and groundcovers were planted on the slopes. This section of South Lantau Road is about 2 km long and it is the sole vehicle access to Mui Wo.

As these 24 features needed to be upgraded in 2 to 3 years and the features were located within a short section of the sole access, it was recognized that a number of stakeholders would be interested in or affected by the upgrading works. In particular, environmental, landscaping and temporary traffic arrangement issues were the major concerns.

In view of the above, two Project Briefing Meetings were arranged. One was held at the preliminary design stage, in which the general design concepts for the 24 features and the approaches for construction works were presented. Another one was held 2 months before the commencement of the LPM contract in order to update the stakeholders on the progress of project and present the detailed arrangement of the construction works including temporary traffic arrangement, landscaping design and environmental protection. Relevant government departments, green groups, rural committees, District Council members, Legislative Council members, local taxi & bus companies and tourist association were invited to attend. The aims of the Project Briefing Meetings were to inform concerned stakeholders about the project and to obtain feedback and views from them. The meetings also reassured the public and the green groups the importance of the slope upgrading works under the project. The meetings helped engender trust and a sense of openness, and establish communication channels and continuing development of relationship with the public and environmentalists to minimize complaints and misunderstanding.

With the assistance of the Islands District Office (DO/I), the meetings were held in August 2000 and October 2001. Both meetings included extensive discussions among stakeholders and the minutes of the meetings were distributed to all parties, whether present or not, afterward. Moreover, project information sheets were distributed at the second briefing meeting and later through DO/I to the residents affected by the works.

The Project Briefing Meetings were considered successful. The stakeholders appreciated the arrangements as their concerns were addressed and incorporated in the detailed design of the slope works where feasible. This was the first LPM project of which application of an Environmental Permit (EP) was required. After the first Project Briefing Meeting in August 2000, a Project Profile regarding the slope upgrading works was submitted to Environment Protection Department (EPD) for the application of an EP in April 2001. A Project Profile Presentation and Public Consultation of the Project Profile were made subsequently. As the stakeholders had been fully aware of the project, only minor comments were received. Eventually, an EP was issued by EPD in August 2001 and the project proceeded as scheduled.

Public liaison was continued in the course of the construction works. To raise the level of understanding of slope safety amongst children and within the community, a hoarding painting activity was jointly organized with three local schools in January 2002. This was arranged about one month after the commencement of the LPM contract. The theme of the hoarding design was "Lantau, Slope and Conservation" and this aimed at promoting "green-safe slopes" to students. This activity was also intended as a family function and family members of the students were encouraged to participate. The painted hoardings were erected and displayed at the depot and near the Mui Wo Pier roundabout for public viewing. Although different kinds of site difficulties were encountered during construction, the slope upgrading works were successfully completed in 2004.

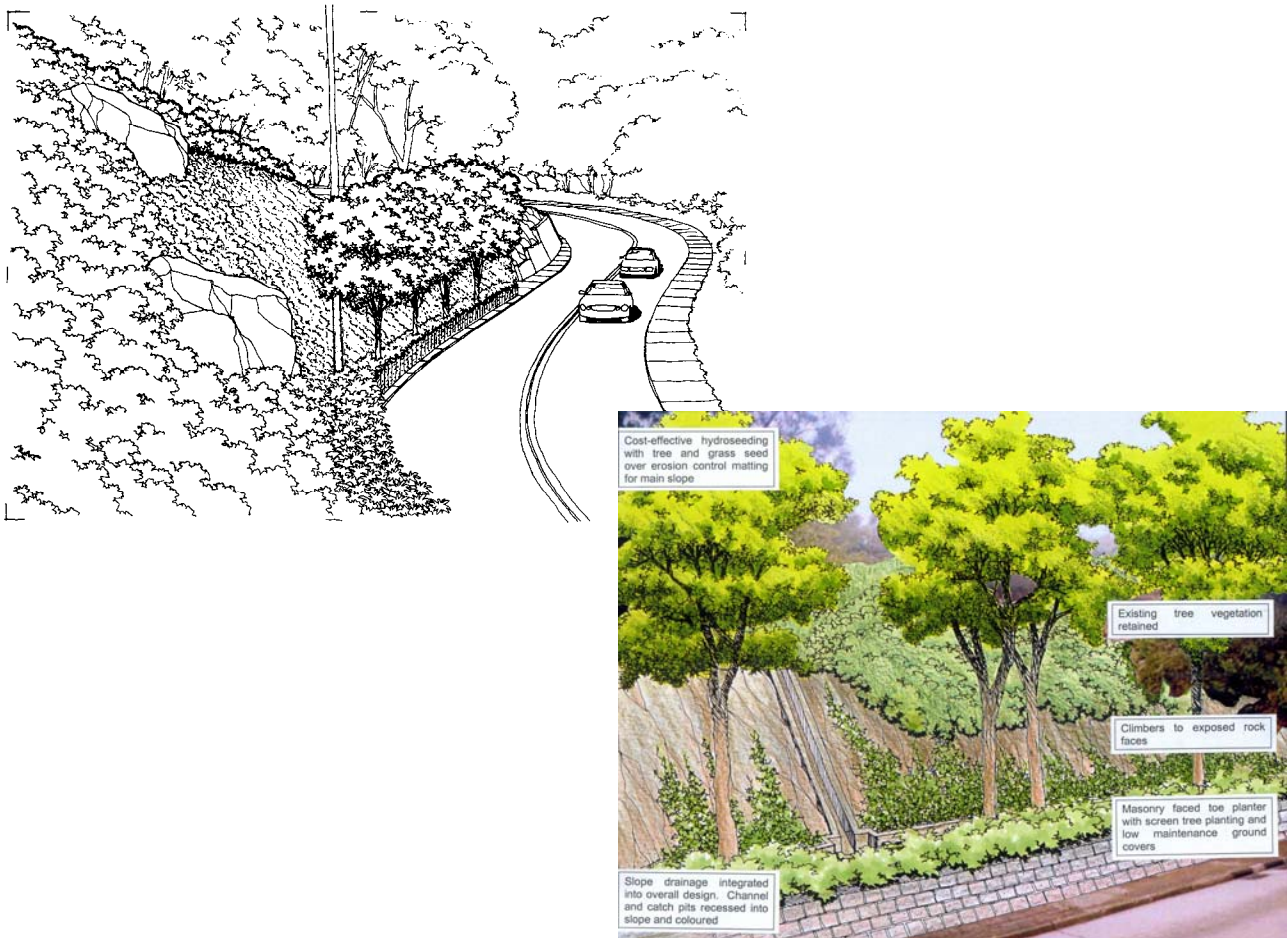


Figure 3: Artist's Impressions Presented to Interested Parties

### 2.3 Upgrading a Loose Fill Slope at King's Park Garden

Stakeholder participation can also be a dynamic process in a project and this is reflected in the upgrading works at King's Park Garden. King's Park Garden is located at the central portion of the Kowloon Peninsula in a valley to the northeast of an old service reservoir situated on top of the King's Park hill. Surrounded by built-up areas of Yau Ma Tei and Homantin, the park becomes a daily leisure area for many morning walkers and locals who consider the park as their "backyard garden" and an oasis inside the concrete jungle.

The service reservoir on top of King's Park hill was built some 70 years ago. During the process, the loose fill slope 11NW-D/F142 was formed. A study of the slope carried out under the LPM programme in 2006 confirmed that the fill was loose and upgrading works were required to address the risk of liquefaction. The initial design scheme involved the installation of over 700 soil nails, the construction of a concrete grillage over the fill, a large concrete trough along the slope toe to house a 600mm diameter replacement water main and the formation of a concrete platform next to the service reservoir near the slope crest, which was designed to serve as an additional leisure area for the morning walkers after completion. In association with the construction of the pipe trough and concrete platform, excavation would be carried out and 33 numbers of healthy existing trees would be removed.

Circulation of the project plan had been conducted like most of the LPM works through the responsible District Office and the relevant District Councilors had been consulted prior to the commencement of works. However, when the works commenced in early December 2007, complaints mostly from daily users of the park started to pour in the first week of site works. Most of the complainants were concerned about the clearance of undergrowth on the slope during the site clearance operation by the contractor. District Office

and District Councilors were called on by the complainants to stop the works. On 12 December 2007, the site works were suspended for further public consultation.



Figure 4: First public consultation meeting at local community centre

Meeting with the relevant District Council were arranged shortly to understand the park users' concern and opinion about the upgrading works. Countless negative feedbacks were received for the tree removal required by the construction of the pipe trough and crest platform. In order to gather more views from the locals and explain to them about the necessity of the slope works, the first public consultation meeting was arranged with the assistance of the District Office at a community centre on 27 December 2007. During the first meeting, many people expressed their concern about the environmental impact especially the anticipated felling of healthy trees and the disturbance to the natural appearance of the slope. A few citizens even opined that the slope works were not necessary due to some reasons which were mostly misinterpretation: the slope had been standing for many years without incidents, or tree roots could penetrate deep into the ground and hold the slope safe. To rectify these misunderstandings, the project team elaborated the need for slope upgrading works by explaining the risk of liquefaction of fill slope with reference to the disastrous landslide at Sau Mau Ping. The project team further explained details of the works and how existing trees would be preserved in the grillage system. To relieve their emotional discomfort due to tree felling, the project team proposed to modify the original design by deleting the crest platform and realigning the pipe trough such that all existing trees could be preserved. The change immediately received some positive response from the crowd. However, some attendees still resisted the project, purporting that the natural environment would be damaged. They were skeptical about the landslide risk and the need for the upgrading works.

After the first public consultation and subsequent group meetings, phone enquiries and discussions about the impact of the works, more voices from the locals on preserving their "backyard garden" were heard. Knowing that the public was receptive to the modified scheme, the project team swiftly modified the design to prepare for the second public consultation meeting on 30 January 2008. Prior to the second meeting, a media briefing was arranged on 29 January 2008 to inform the public and emphasize the urgency of the slope works for public safety and the well tried method of concrete grillage in preserving existing trees. Notices with detailed project description were also posted near the pedestrian access for public information.

During the second consultation meeting, questions were raised and answered. In the end, the negative sentiment of the locals had gradually subsided. A communication channel between the park users and the site staff was established after the meeting so that enquiries and complaints could be responded in an efficient manner. This demonstrated a positive step towards a co-operative spirit and the establishment of trust.

The site works resumed on 31 January 2008. Communication with the park users has continued since then. From time to time, the project team received good suggestions from the park users on site safety and cleanliness and the suggestions were implemented. Trust between the park users and the project team was established through the process and the LPM works progressed smoothly.



Figure 5: Media briefing before the second public consultation meeting

#### 2.4 A Retaining Wall at the Backyard of Private Premises

Resolving land matters and obtaining access permission from private lot owners is never an easy task in LPM projects. However, a good and well-planned liaison strategy can help to tackle the issues effectively. The case at Yik Kwan Avenue, Tai Hang is a good example in which the project team could win the confidence from the public and tackle the corresponding access problems through the successful liaison work.

The retaining wall at Yik Kwan Avenue was jointly maintained by Government and 12 private lot owners. The privately owned portions were served with Dangerous Hillside (DH) Orders which later went into default in 2005. The Buildings Department (BD) then entrusted the design and construction of upgrading works for the private portion to GEO for joint action. However, as the retaining wall was inaccessible due to the presence of unauthorized building works at the toe, BD subsequently issued orders and removed the unauthorized building works in 2009. Anticipating that the private lot owners might have a misconception that slope safety was only a pretext for the clearance work and were not willing to give access permission for carrying out the ground investigation and upgrading works for the retaining wall, the consultants adopted a proactive approach in order to build up a friendly and cooperative environment. They sent out consultation letters which included preliminary design options of upgrading works to the private lot owners. In parallel, with the assistance from a District Council, a briefing meeting was organized with the lot owners and local residents. The proposed schemes, construction arrangement and the estimated cost were presented and discussed openly in the briefing meeting. The owners' concerns such as maintaining the original clearance between their houses and the retaining wall after upgrading works were also addressed in the briefing meeting. This strategy greatly helped establishing the mutual trust among the participants and let the private owners realize that the project was for their best interest as well. The liaison work with the stakeholders was worthy and could avoid any unnecessary misunderstanding in a project.

### 3 CONCLUDING REMARKS

The Lantau case is among the first of the LPM projects for public participation. The step was taken in recognition of the increasing public expectation on the quality of the living environment, and the sensitivity of earthworks in the scenic environment of the south side of Lantau Island. It has been the practice since then to engage the public at an early stage of LPM projects judged to be potentially controversial. The three other cases described are those that came to the mind of the authors and with information at hand. There are many others, some more interesting, some less.

Whilst public participation exercises would require a lot of time and effort, it can do much to develop public consensus and help the government implement the LPM works with the support from stakeholders and the public. In addition, there are strong elements of active learning, reflection and deliberation in the course of public participation, which could lead to significant improvement to the works. It is effort worth investing.

This practice of the LPM projects matches the paradigm shift in the mid-2000s described by Hui (2007). The shift from public consultation to public engagement is embodied in the programme of public sector reform being promoted then. The practice is also in line with that elaborated by Mak (2007) regarding infrastructure development, which has since been widely adopted in taking forward public works projects in Hong Kong.

## ACKNOWLEDGEMENTS

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# Construction of Slope Upgrading Works Along Busy Roads in Hong Kong

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## ABSTRACT

Construction of slope upgrading works along the busy roads in Hong Kong presents numerous challenges to designers and site managers. Roads formed in the past through Hong Kong's hilly terrain created numerous cut and fill slopes which were largely non-engineered and prone to instability causing a risk to life and property particularly during intense rainstorms. Closure of such roads results in severe traffic disruption and complaints from the road users. Restrictions on road closures imposed by various authorities create unique challenges. Working space is severely limited to the minimum to allow works to proceed.

This paper describes the constraints and methods used to allow the necessary slope upgrading works to proceed safely and at the same time minimize disruption to traffic. The design and approval process of appropriate traffic diversion schemes will be described as well as the control measures required during the works. The design of the slope upgrading works was tailored to suit the actual site constraints with several options developed before final selection for detailed design. Methods chosen minimized excavation so as to speed up the works and allow works to proceed during all weathers and in a minimum working space. Specialist construction plant including modified drilling rigs was deployed. Difficulties encountered during the works including traffic issues and public complaints will also be discussed.

## 1 INTRODUCTION

Roads formed in the past through Hong Kong's hilly terrain created numerous cut and fill slopes which, before formation of the Geotechnical Control Office (now the Geotechnical Engineering Office), were largely non-engineered and are prone to instability, particularly during intense rainstorms, causing a risk to life and property. A comprehensive risk-based slope safety management system has been established over the past 30 years in parallel with the progressive development of slope engineering practices in areas of slope stabilisation and landslide mitigation works. Working space to carry out the necessary slope stabilisation is often severely limited due to narrow or absence of footpaths. Closure of such roads results in severe traffic disruption and complaints from the road users. Restrictions on road closures are therefore imposed by various authorities principally the Transport Department, Highways Department, the Hong Kong Police Force and local stakeholders such as District Councils.

The design of the slope stabilisation works has to be tailored to suit the actual site constraints with several feasible options considered before final selection for detailed design. Design options chosen are robust but generally minimize works duration. This is often achieved by minimizing excavation and reinforcing the existing slope, typically with soil nails so as to speed up the works and allow works to proceed during all weathers and in a minimum working space. Site-specific temporary works and specialist construction plant including mobile platforms and modified drilling rigs are deployed.

## 2 TRAFFIC

### 2.1 Typical Constraints and Solutions

The roads under discussion are generally a single carriageway with 2 lanes and footpath on one side only or occasionally absent. See plate 1.



Plate 1: Typical narrow and busy road with cut slope, Repulse Bay Road, Hong Kong.

To carry out works on the slope, a temporary traffic management (TTM) scheme is normally required. Temporary closure of one lane is preferred for working space due to the steepness of the slopes. Typical restrictions imposed by authorities include:

- 100m, 50m or 30m maximum length of lane closure
- 500m minimum separation between temporary lane closures
- Minimum road width
  - 3.5m – 1 Lane
  - 6.5m – 2 Lanes
- Traffic signal lights at night with manually operated "STOP/GO" sign during daylight hours

Site specific conditions may also apply such as a day-time ban on lane closures during the school term and the "swimming season" during summer months. On more heavily trafficked roads, lane closure may only be permitted during School Holidays and between 9:30 a.m. – 3:30 p.m. Monday to Friday excluding Public Holidays. For some cases, only night time closure is permitted. In order to identify the likely working conditions and assist the approval process a Traffic Impact Assessment may have to be carried out. The traffic engineer and slope designer work together to select a most appropriate temporary traffic management (TTM) scheme to suit the site specific situation such as:

- - 1 lane, 2-way working for 24 hours, 7 days per week
  - 1 lane, 2-way working for 24 hours, 5 days per week
  - 1 lane, 2-way working for restricted hours during daytime or, rarely, nighttime only.
  - Temporary modification of the carriageway alignment to maintain 2 lanes and 2 way working.
  - Construction of temporary platform to maintain the existing traffic flow
  - Construction of covered walkway over a footpath to maintain the existing traffic and pedestrian flow
  - Others such as alternative routes for long vehicles, buses etc

The final developed TTM scheme should be in compliance with current requirements, (HyD 2006 and 2011). The selection of the final TTM scheme has significant cost and time implications for the works and may also result in design changes for the permanent works. The TTM schemes also have to be selected bearing in mind the overall programme for implementing the slope works which is typically carried out in batches. See figure 1. There maybe programming clashes created by TTM issues that have to be resolved. A

realistic programming strategy for slope works projects for road side slopes in close proximity should be formulated at an early stage.

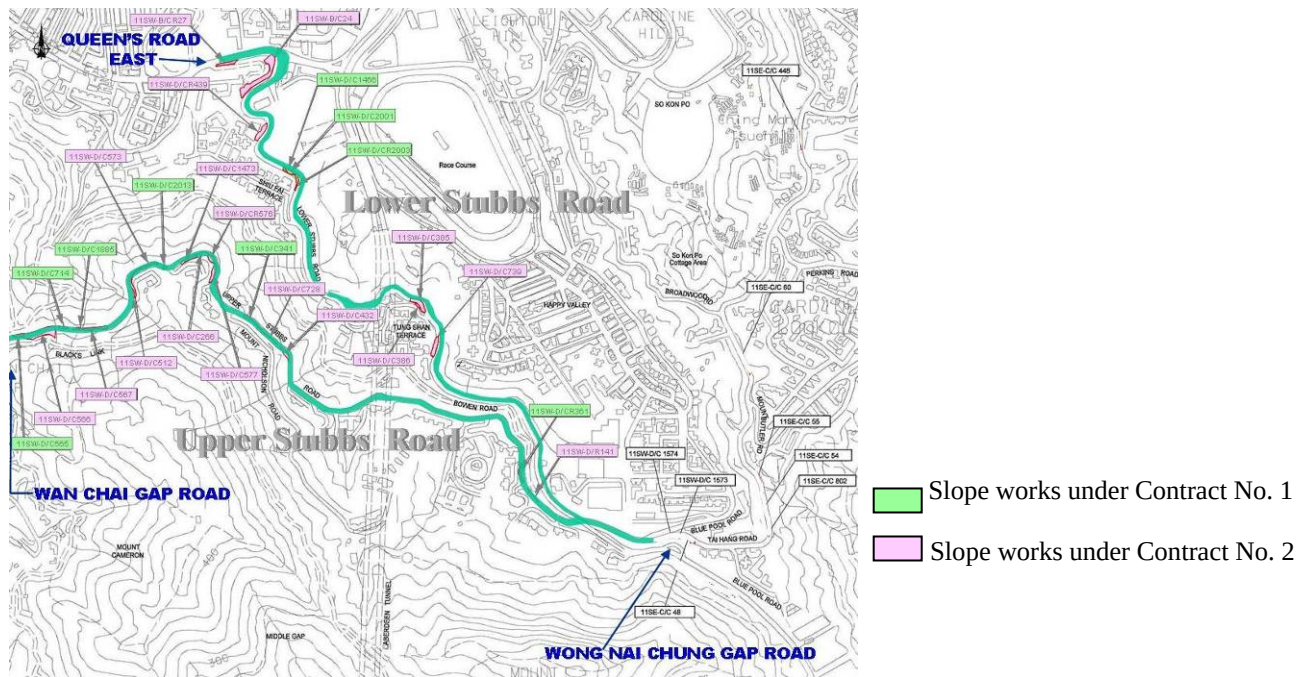


Figure 1: Slope works in close proximity along Stubbs Road, Hong Kong, 2000 to 2003.

## 2.2 Traffic related complaints

Although the TTM approval process may result in a workable TTM scheme, difficulties and objections are often encountered during the works. Some of the difficulties and mitigation measures are given in Table 1.

Table 1: TTM related complaints and mitigation

| Cause of Complaint                                                                       | Complaint Mitigation Measure                                                                                                                                                                                                                                                           |
|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Long traffic queue/waiting time :                                                        | Record typical traffic conditions before works start. Ensure that a representative trial run is carried out to the satisfaction of all parties before works start.<br>Investigate exact cause of subsequent problems<br>Consider additional traffic information signage, publicity etc |
| Delayed completion /repeated change of anticipated completion date on site notice boards | Set a realistic completion date allowing for likely EOT<br>Make the design less sensitive to exact site conditions.                                                                                                                                                                    |
| Poor operation of STOP/ GO boards:                                                       | Make provision in the Contract for fair reimbursement of costs for STOP/ GO sign operation<br>Allow for sufficient rest periods for operators<br>Ensure proper welfare facilities are provided<br>Provide manually controlled synchronized traffic signal lights                       |
| Traffic signal light breakdown                                                           | Contractor to provide 'mains' power supply instead of batteries or generator<br>Carry out regular maintenance<br>Contractor to provide rapid call-out by competent person                                                                                                              |
| Too many TTMs close together:                                                            | Ensure thorough initial programming<br>Ensure that the proposed Works Contract duration is realistic.                                                                                                                                                                                  |

Repeated complaints may force the works method to be reviewed with heavy impact on the programme and costs with likely knock-on effects. Prompt and sympathetic handling of complaints is necessary to minimize impact on the Works.

### 3 SLOPE WORKS

Most slope works along busy roads have involved stabilisation of cut slopes above the carriageway. Typically the cuts were made in decomposed rock, weathering grade IV and V, with less frequent cuts wholly or partly in rock, weathering grades I, II and III. During intense rainfall, local and transient perched water develops resulting in local failures often involving relict jointing. See plate 2.



Plate 2: Landslide in weathered volcanic rock, Repulse Bay Road, Hong Kong, June 2008

The preferred slope stabilisation option would typically comprise soil nailing in combination with a slope surface protection system selected based on the soil angle, slope environment, slope forming material and local stakeholder input for slopes in sensitive areas. Typically the factor of safety is required to be raised to a minimum of 1.4 under the conditions of a 1 in 10 year rainstorm, (GEO 1984 and 2000a). A vegetated slope is preferred. A typical arrangement is shown in Figure 2.

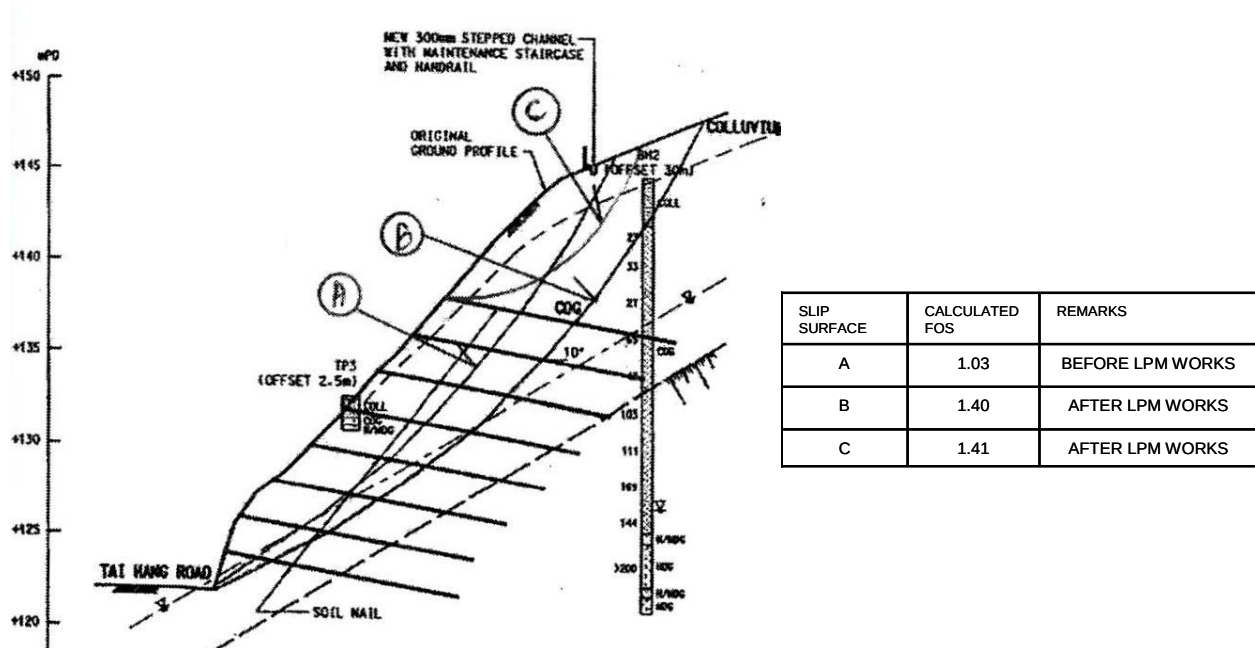


Figure 2: Typical road side slope stabilisation scheme

Soil nailing provides a robust and flexible approach that can be adjusted easily to match the exact site conditions encountered. Old roadside slopes are frequently inaccessible for detailed site inspection before the works. Unexpected slope conditions such as over-steepened portions, abandoned structures or accumulated waste should be expected. To date no major failure of a soil nailed slope has been reported in Hong Kong. Soil nails are not suitable for all applications. For example, where nails would encroach into private land, alternative stabilization methods such as a retaining wall maybe necessary.

Working space is normally at a premium near the slope toe, particularly where a footpath is narrow or absent. The stabilization works design should take this into account, for example by minimising the number of soil nails, rock dowels etc at very low levels. To install soil nails within a limited working time window such as 9.30 am to 3pm a drilling rig can be mounted on a temporary moveable platform, lorry or hydraulic mobile platform. See plate 3. Using such methods nails or dowels can be installed upto 15m above the carriageway. Time has to be allowed for daily mobilization and de-mobilisation of plant and equipment. A nearby over-night parking place is useful, particularly if a hydraulic mobile platform is necessary.

Safety of works is paramount. Works alongside busy roads are hazardous and accidents involving workers and members of the public have occurred. Risk assessments must be carried out by qualified safety personnel and workers properly equipped with personal protection equipment. Operators of traffic control equipment and plant such as mobile platforms should receive adequate training. The risk of a vehicle accidentally entering a lane closed for a temporary working area should be assessed as well as the risk of plant, such as mobile platforms, colliding with other road users. As a robust safety fence may not be practical to erect, measures and work practices to prevent objects, and materials escaping from the works site must be adopted. A contingency plan and procedure should be in place in case of landslide or other unplanned event during the work that may prevent timely re-opening of the road.

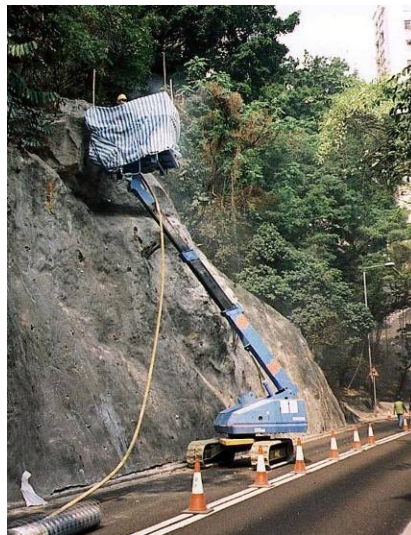


Plate 3: Hydraulic mobile platform, Stubbs Road, Hong Kong

Where lane closure has to be restricted to a minimum, temporary steelwork structures founded at or near the slope toe are erected to support narrow platforms. Specially modified pneumatic and electric powered drilling rigs are used to install soil nails or rock dowels. Tight control of safety and environmental issues is necessary under those circumstances. See plate 4.



Plate 4: Temporary working platform, 1.1m width, Repulse Bay Road, Hong Kong

#### 4 LANDSCAPE AND SLOPE FINISHING

Roadside slopes are highly visible to the general public and hence a pleasing appearance is a high priority. Government policy requires hard surfaces to be minimized. On the other hand the finished works must be robust and require minimum maintenance. Local failures of soil nailed vegetated slopes have been reported, (Ng et al 2008). Many existing slopes are covered with a hard surfacing such as chunam or shotcrete. Removal of existing hard surface and replacement with erosion control mat and wire mesh fixed to nail heads has enabled many slopes to be vegetated particularly for slopes upto about 55 degrees, (GEO 2000 and 2007). See Plate 5.



Plate 5: Slope with existing shotcrete surface before and after slope works, Stubbs Road, Hong Kong

Ground investigation of slopes cannot fully characterize the slope forming material over the whole slope. Often removal of existing hard surface reveals unexpected conditions, for example underlying hard material that cannot support vegetation. Under such circumstances a new hard surface may have to be applied, such as sprayed concrete with colour painting and planter holes reserved for climbing plants. Where lane closures are restricted there is little time to review and revise the landscape scheme. Under such circumstances a conservative assumption about ground conditions is warranted to ensure timely completion of works. An alternative approach is to adopt a slope greening system such as continuous fibre reinforced soil which can be applied over hard surfaces and provides a growing medium for grass and shrubs, (Ho & Mak 2005). See Plate 6.



Plate 6: Slope with existing shotcrete surface before and after slope works including application of continuous fibre reinforced soil, Peak Road, Hong Kong

Before applying slope surfacing and landscape on roadside slopes consideration should be given to impact on future road users. Such impacts include sightlines of drivers affected by growing vegetation, works encroaching into the carriageway such as catchpits, buttresses and soil nail heads and fixings for wire mesh. Particularly at bends in roads there is a need to trim back projecting or over hanging portions of slope as part of the slope works to improve road safety and traffic flow.

Discharge of water onto the carriageway should be minimized by proper detailing of outlets for surface water channels and raking drains.

## 5 CONCLUSIONS

Successful implementation of slope stabilization works along busy roads requires an holistic approach. Key to success is an early involvement of traffic engineering professionals and staff familiar with contractors working methods and practice. The ability to adopt a workable but flexible project programme with contingency is preferred. A fast reaction to changed circumstances arising is necessary, being of a technical or public relations nature. A partnering type approach to working with contractors and stakeholders has helped overcome obstacles that arise.

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# Challenges of Landslip Preventive Measures Works with Complex Site Constraints : Case Study – Four Slope Features at Coombe Road

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## ABSTRACT

To some engineers working on major civil engineering works, Landslip Preventive Measures (LPM) works are merely minor slope works with construction cost ranging from a few hundred thousand dollars to a few million dollars. In fact, LPM works for those features with severe site constraints can be very demanding and involve significant planning, design and liaison work as well as tactful problem solving. This paper illustrates a case study for LPM works for four contiguous slope features, which are of mixed Government/private maintenance responsibility, located at Coombe Road, the Peak. The LPM works involved construction of a piled retaining wall and full lane closure of a section of the narrow Coombe Road was required. This paper summarizes the challenges faced in the process of design and construction of the LPM works for these four features including design option assessment, detailed design, traffic impact assessment and temporary traffic diversion, Advisory Committee on the Appearance of Bridges and Associated Structures (ACABAS) submission, tree felling application, district council consultation, liaison with local residents, land matters and construction difficulties. Lessons learnt for dealing with this kind of complex sites are also highlighted.

## 1 INTRODUCTION

Feature nos. 11SW-D/C524, 11SW-D/C529, 11SW-D/CR530 and 11SW-D/CR1225 are four contiguous roadside slope features located at the western end of Coombe Road, the Peak, with a total length of about 185m. The location of these features is shown in Figure 1. The features are of mixed Government/private maintenance responsibility. As these features were not up to the current safety standard, upgrading works were required. In general, soil nailing method is a common and cost-effective solution to upgrade cut slopes as soil nail drill rig is a simple and light-weight machine and the method requires shorter construction period and causes less disturbance to surroundings. However, in this case, as the extent of Government portions of the features was very narrow in plan, it was inevitable that proposed soil nails would intrude into the private lots. The views of the affected private lot owners and the maintenance department of the Government portion of the features were sought at the very initial stage, but it was found that intrusion of soil nails into private lots was not possible and soil nailing option was therefore not feasible at this site. An unconventional scheme of LPM works was adopted for the Government portions of these features which involved mainly a cantilevered retaining wall of maximum 5.5m high founded on socketed H-piles with backfilling behind the wall to form a gentle slope for landscaping works. Compared with typical LPM works on small man-made cut slopes, the adopted scheme involved more difficult site operations, such as piling works, and heavier construction plant and equipment, and it also required longer construction period and was more likely to cause disturbance to surroundings. This paper outlines the LPM works carried out and describes the challenges and difficulties encountered during planning, design and construction stages and the efforts made by the project team to resolve the problems for smooth implementation of the works.

## 2 DESCRIPTION OF THE SITE AND THE ADOPTED SCHEME OF LPM WORKS

Before LPM works, Feature nos. 11SW-D/C524, 11SW-D/C529, 11SW-D/CR530 and 11SW-D/CR1225 varied from 9m to 25m in height and slope angles ranged from 30° to 75°, and the Government portions of these features were covered by chunam with presence of some mature trees. General view of the features before LPM works is shown in Plate 1. The section of Coombe Road in front of the features was about 4m to 5m wide. Typically, this kind of roadside cut slopes can be upgraded by conventional soil nailing method. However, as mentioned, the commonly adopted soil nailing method was not feasible at this site because intrusion of soil nails into private lots was not possible.

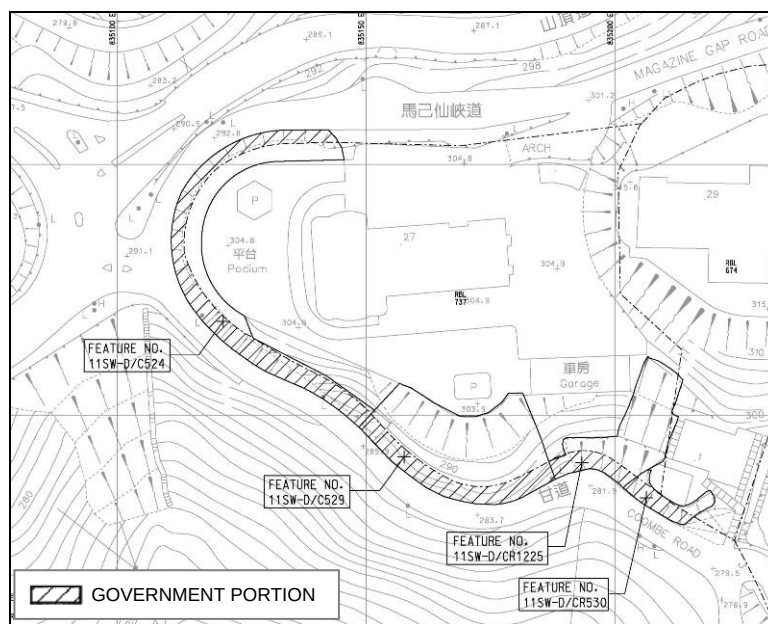


Figure 1: Location of the features with demarcation of the private and Government portions



(a) Feature no. 11SW-D/C524



(b) Feature no. 11SW-D/C529



(c) Feature no. 11SW-D/CR1225



(d) Feature no. 11SW-D/CR530

Plate 1: General view of features before LPM works

The first major challenge is to identify a practical option which could upgrade Government portions of the features while the permanent works could be accommodated within such a limited area of less than 4m in plan width. After a thorough exercise of option assessment, a cantilevered retaining wall of maximum 5.5m high founded on socketed H-piles with backfilling behind the wall to form a gentle slope for landscaping works was accepted as a practical and suitable option for this site. The final design revealed that a total of 104 nos. of socketed H-piles at 915mm or 1,220mm spacing would be required. The proposed piles would have a maximum length of 17m and a maximum 6m long rock socket and would be constructed by placing 305 x 305 x 223 universal beam (UB) in 550mm diameter drillholes.

The project team was fully aware that the adopted scheme would result in significant traffic impact and disturbance to nearby residents, and therefore, careful planning of works and liaison with relevant stakeholders beforehand were of paramount importance to ensure smooth implementation of the works.

## 2 PLANNING PHASE

### 2.1 Traffic Impact Assessment (TIA) and Temporary Traffic Arrangement (TTA)

The preliminary design showed that the required pile diameter was about 600mm. This would require a heavy pile drilling machine. As the narrowest part of the section of Coombe Road in front of the features was only 4m wide, which was just wide enough for manoeuvring of the piling machine, the whole section of the affected Coombe road would have to be closed during construction.

It was anticipated that the closure of the western section of Coombe Road would result in a significant traffic impact to the nearby residents. A traffic impact assessment (TIA) was carried out during planning stage and the corresponding temporary traffic arrangement (TTA) was proposed. In the TTA proposal, the affected section of Coombe Road would be closed and all traffic between Magazine Gap Road and Coombe Road had to be diverted to travel through Peak Road and the eastern section of Coombe Road (see Figure 2).

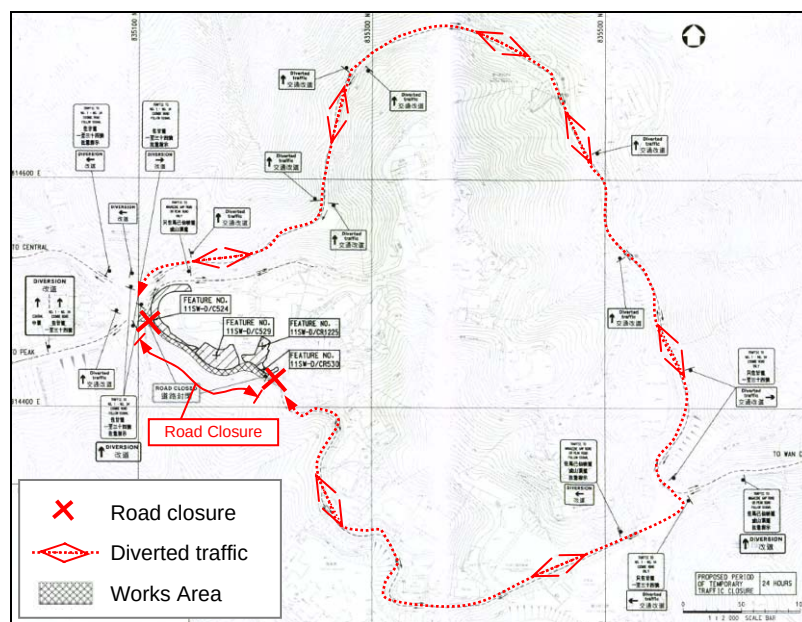


Figure 2: Temporary traffic diversion

The TIA and TTA were circulated to the Police, the Transport Department (TD) and the Fire Services Department (FSD) for approval. While the Police and the TD had no major comment on the proposed TTA scheme, the FSD had serious concern as their response time to incidents would be lengthened due to the longer distance (about 1.5km longer) of the diverted route. FSD insisted that a thorough passage for fire appliances at Coombe Road should be provided which seemed almost impossible for the proposed piling works.

To address the FSD's concern, the project team proactively arranged meetings with FSD to explain to them the site constraints and the genuine need for road closure. Several trial runs were then carried out to allow better understanding of the potential impact of the road closure to operation of FSD. Eventually, FSD did not insist on the thorough passage for their fire appliances and they had no objection to the proposed TTA scheme on the condition that a thorough pathway through the works site should be maintained.

## *2.2 Tree felling*

Another issue to be dealt with in the planning stage was tree felling application. Although felling of some trees was unavoidable for construction of the pile retaining wall, the project team tried the best to preserve as many trees as possible and included adequate compensatory planting in the tree felling application. By working closely with landscape architect and adjusting the arrangement of the works, the project team managed to retain most of the existing healthy trees at the slopes and reduce the number of trees to be fell to a minimum. The project team also optimised greening opportunity within the site despite the major constraint of limited planting space and managed to propose compensatory planting using native tree species with a ratio more than 1:1 together with shrubs and groundcovers. Although a lot of comments on the tree felling application were received from various parties, the project team adequately addressed their comments and eventually the application was approved.

## *2.3 District Council Consultation*

The proposed TTA scheme and tree felling were sensitive issues. The relevant approving authorities requested the project team to obtain support from the Wan Chai District Council and the Central & Western District Council. At the beginning, the project team submitted project papers to the two District Councils for circulation and subsequently the Wan Chai District Council requested the project team to make a presentation to the District Council members to describe the details of the project. In the meeting, the project team explained the genuine need for the upgrading works and the site constraints leading to traffic diversion and tree felling and also described the proposed landscaping measures to improve the slope appearance and other measures to be implemented during construction to ensure safety, security and adequate control on environmental nuisance. Eventually, the project team managed to solicit the support from the two District Councils on the proposed LPM works including the TTA scheme and tree felling.

# **3 DESIGN PHASE**

## *3.1 Adoption of precast reinforced concrete panels for construction of the retaining wall*

In view of the site constraints on access and limited working area and the FSD's requirement on provision of a pathway for emergency, the project team considered that the option of constructing the retaining wall including fixing steel reinforcement and erecting formwork on site was not preferable. The project team adopted an unconventional design for the retaining wall in which the installed socketed H-piles would be extended to top level of the retaining wall and then precast reinforced concrete panels would be installed between the extended H-piles to form the retaining wall followed by backfilling behind the installed panels. This unconventional design had the advantage that the scale and quantity of construction works required at the site could be minimised because casting of precast panels could be carried out outside the site and welding of steel beams and installation of precast panels would be a relatively fast and simple process.

## *3.2 Unconventional aesthetic design of the retaining wall using precast concrete cladding panels*

In this case, the detailed design of the LPM works involved not only those routine technical issues such as geotechnical, structural, drainage and landscape design. Highways Department (HyD), the maintenance department of Government portion of the features, requested a submission of the design proposal of the retaining wall to the Advisory Committee on the Appearance of Bridges and Associated Structures (ACABAS) for vetting of the aesthetic appearance of the new retaining wall.

The focus of the ACABAS submission was the aesthetic, visual and greening treatment of the roadside retaining wall. The project team realised that Coombe Road was narrow, meandering and sloping and heavy vegetation with mature trees existed at the downslope side of the road and therefore, appearance of contemporary construction materials such as concrete or use of regular patterns of stone facing or special finishes to concrete surface which would give an artificial appearance or texture would not blend well with the surroundings. In view of this, the project team proposed an unconventional landscape design to the new retaining wall using “random patterned stone” precast concrete cladding panels to cover the surface of the wall. The project team, in consultation with landscape architect, proposed using rustic brown panels of random pattern with an aim to simulate a natural granitic rock slope to blend well with the natural surroundings. The photomontages included in the ACABAS submission showing the appearance of the proposed retaining wall and the relationship between the wall and its surroundings are shown in Figure 3.

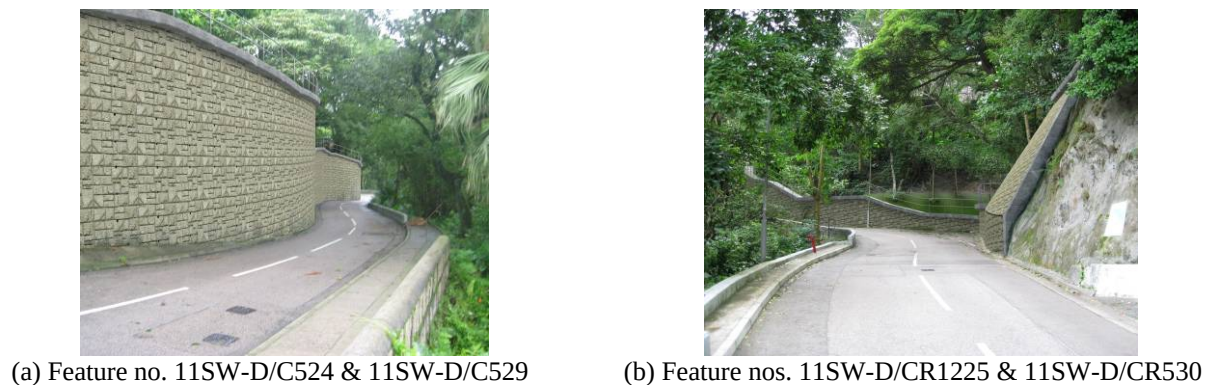


Figure 3: Photomontages of the proposed retaining wall

After submission of the design proposal to ACABAS for consideration, the project team attended an ACABAS meeting to give a presentation on the design proposal and respond to members' enquiries. Samples illustrating the colour and texture of the precast panels were also presented in the meeting. The committee generally accepted the scheme with a comment that some creepers should be planted along the crest of the wall as far as practicable. Although this was only a minor comment, it involved quite a lot of amendments in detailing of the works. These included addition of a planter wall along the crest of retaining wall and shifting the alignment of maintenance access and drainage channels. This was not an easy task due to the limited area at the crest of retaining wall constrained by the private lot boundary. Moreover, as the new planter wall was at the crest of retaining wall, HyD requested provision of water points at the crest of retaining wall and this required additional design consideration and administration work.

#### 4 CONSTRUCTION PHASE

After all the issues necessary for commencement of construction, such as TTA, excavation permit (XP), tree felling, had been resolved, works orders were issued and the LPM works commenced in January 2008. While a lot of consultation and liaison works had been carried out during the planning and design stages, challenges were still encountered and had to be resolved during the construction stage as described below:

##### 4.1 Temporary traffic arrangement

With all necessary approvals/permissions in hand, the contractor was ready to start the site works. With the aim of informing the affected residents in advance about implementation of the road closure, the contractor sent a notice to the nearby residents at Coombe Road shortly after they took up the site. Unexpectedly, this immediately provoked a strong reaction from some of the local residents who expressed dissatisfaction on the inconvenience and disturbance arising from the TTA. The project team immediately arranged a meeting with the affected residents to explain to them the site constraints and the genuine need for the road closure. The discussion was productive and it came up with a mutually acceptable solution. It was agreed that before

implementation of the road closure, a temporary walkway of about 120m long would be provided outside the site boundary, i.e. at the sloping ground alongside Coombe Road, to maintain pedestrian flow. The project team then immediately submitted urgent applications to District Lands Office (DLO) and HyD for simplified temporary land allocation (STLA) and excavation permit (XP) for construction of the elevated temporary walkway. DLO and HyD were helpful to process the applications and the applications were approved within short period of time. While the STLA and XP applications for the walkway were still in process, the contractor prepared the design of the temporary walkway in advance and also implemented a partial lane closure at Coombe Road to carry out pre-drilling for socketed H-piles. This could minimise the effects of the temporary walkway on the overall site progress. The completed temporary walkway is shown in Plate 2.



Plate 2: Temporary pedestrian walkway



Plate 3: Congested works site during piling works

#### 4.2 Public concerns

The project team noted that several residential houses were located immediately above the crest of the features and the residents there could be directly affected by the construction works. In order to address their concerns on noise, dust and security arising from the construction works, the project team implemented close monitoring and mitigation measures during the construction period to avoid or minimise the effects to the nearby residents. The project team also maintained regular communication with management offices of the nearby residential houses during the construction period and arranged regular site meetings to discuss and resolve the issues on the spot. Through close liaison, the project team better understood the views and concerns of the nearby residents and this facilitated modifying or fine-tuning details of the LPM works. For example, a permanent fence was built along the boundary between Government and private portions of the features to address the residents' concerns on long-term security of their premises after provision of a maintenance access at the crest of retaining wall. The local residents were very appreciative of the efforts made by the project team. The arrangement made by the project team to address public concerns was successful. During the construction period, no major complaints on the construction works were received.

#### 4.3 Limited working space

The minimum width of the working space in front of the features was only 4m. The works site was very narrow for manoeuvring and operation of the down-the-hole drilling machine and lifting crane mobilised for construction of the socketed H-piles (see Plate 3). The difficulty of very congested site area was further exaggerated by very frequent unloading operation of steel beams, steel casings, precast panels, etc. The contractor managed to deal with this challenge by good planning in work sequence, schedule of delivery of material, and layout of storage of construction material and equipment. The supervision team also provided

many useful suggestions to the contractor on this aspect. Moreover, additional efforts were made by the project team to ensure site safety in such congested works site.

#### 4.4 Curved alignment of proposed piled retaining wall

The alignment of proposed piled retaining wall followed the toe line of the features which was smoothly curved in plan (see Plate 4). For this reason, the position and orientation of the socketed H-piles had to be very precise, otherwise, a small deviation would result in difficulty in subsequent installation process of precast reinforced concrete panels between the piles and adversely affect the intended smooth visual appearance of the retaining wall. To achieve this, the survey teams from the contractor and the site supervision team worked closely together and carried out frequent joint surveys and the contractor also worked diligently and adjusted the orientation of the piles throughout grouting operation. Apart from the orientation of the piles, construction of the capping beams along the crest of retaining wall was also a challenging task. The contractor deployed skilful and experienced labour and supervision staff for setting out and erection of formwork to ensure the smoothly curved alignment of the structure.



Plate 4: Construction of retaining wall



Plate 5: Coombe Road was reopened while installation of precast cladding panels was still in progress

#### 4.5 Reinstatement of street lighting columns

There were three existing street lighting columns in front of the features before the LPM works. Originally, it was proposed to form recesses to the retaining wall to keep the lighting columns in place. Shortly after commencement of the slope works, the project team approached Lighting Division of HyD and proactively discussed with them with an aim of identifying a better arrangement. The discussion was productive and it was agreed that the affected lighting columns could be removed and upon completion of the LPM works, three new street lights would be installed at the same location by mounting on the new retaining wall. By working closely with HyD and early involvement of the contractor, the designers were able to promptly issue amendments to details of the retaining wall taking into account suggestions from the contractor and the completed lighting works were smoothly handed over to HyD upon completion of the LPM works.

#### 4.6 Design review necessary for dealing with actual site conditions

The findings of pre-drilling for socketed H-piles revealed that the actual rockhead level was generally deeper than that adopted in design. The designers immediately reviewed the findings and issued a revised piling schedule so that the contractor could have sufficient time to arrange ordering of additional steel beams. During piling works, it was occasionally observed that the actual rockhead was slightly deeper than that

inferred from pre-drilling. Close communication was maintained between the design and supervision teams so that any necessary changes in the founding levels of the piles could be immediately confirmed and instructed to the contractor. The designers also made frequent site inspections during construction and the designers, site supervision team and contractor all worked closely and cooperatively as one team so that all potential conflicts of the proposed works with actual site conditions were identified beforehand and resolved promptly.

#### 4.7 Early re-opening of Coombe Road

During construction stage, there were a number of requests from nearby residents for re-opening of Coombe Road as early as possible. In order to minimise the disturbance to the residents, the designers, site supervision team and contractor worked closely and cooperatively as an united team to overcome the difficulties and challenges encountered, and managed to complete all critical works in June 2009. This allowed early re-opening of Coombe Road (see Plate 5) and the disturbance to the nearby residents was minimised. The local residents were very appreciative of the efforts made by the project team. Eventually, the LPM works on the four features at Coombe Road were successfully completed in October 2009. The completed retaining wall at Coombe Road is shown in Plate 6, and its aesthetic design blended very well with the surroundings.



(a) Feature no. 11SW-D/C524



(b) Feature no. 11SW-D/C529



(c) Feature no. 11SW-D/CR1225



(d) Feature no. 11SW-D/CR530

Plate 6: Completed retaining wall founded on socketed H-piles at Coombe Road

## 5 CRITICAL FACTORS FOR SUCCESSFUL COMPLETION OF THE WORKS

The review of this case has demonstrated a number of factors that contributed to successful completion of the LPM works which involved unconventional design at slope features with complex site constraints. These factors were involved not only in a single but all different stages of the project, throughout the process of option assessment, planning, design and construction. As described in the preceding sections, the factors critical to successful completion of the project included:

- Identification of project/site constraints at the initial stage of the project;
- Thorough technical considerations, e.g. adoption of unconventional design scheme or construction method, to deal with site constraints;
- Close communication and partnership approach within the project team;
- Early liaison and close communication between the project team and local residents, District Councils and other relevant Government departments;
- Good planning of work sequence, schedule of delivery of material, and site layout for storage of construction material and equipment by the contractor;
- Deployment of skilful and experienced labour and supervision staff;
- Full support of the client office to the project team; and
- Prompt and proactive approach to resolve site problems or complaints on the spot.

## **6 CONCLUSIONS**

The LPM works on the four features at Coombe Road, the Peak (Feature nos. 11SW-D/C524, 11SW-D/C529, 11SW-D/CR530 and 11SW-D/CR1225) is a good example to demonstrate that LPM works are not always simple and straightforward. Because of the constraints imposed by the private lot boundary, conventional soil nailing method was not feasible in this case and the features had to be upgraded by construction of a new retaining wall founded on socketed H-piles. Full closure of a section of Coombe Road was required. Unconventional design and construction method involving two types of precast panels for construction of the retaining wall and aesthetic purpose respectively were adopted. Facing the challenges and site constraints, the parties within the project team worked closely and co-operatively with each other and the same between the project team and relevant stakeholders. Owing to their full commitment and devoted efforts, the project team managed to resolve the challenges and site constraints and successfully completed the LPM works at Coombe Road, the Peak.

## **ACKNOWLEDGEMENTS**

This paper is published with the permission of the Head of the Geotechnical Engineering Office and the Director of Civil Engineering and Development Department, the Government of the Hong Kong Special Administrative Region.



# Construction of Hand-dug Caissons for Slope Stabilization near the Peak Lookout

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## ABSTRACT

This paper presents the slope improvement works of a sizable loose fill slope using hand-dug caisson method. The 27m high fill slope, Feature No. 11SW-C/F50, was located near the Peak tram terminal. At the slope crest was the Peak Lookout (formerly called Peak Café) which is a Grade II Historic Building with masonry load bearing wall and shallow footing foundation. The site was located within the Pok Fu Lam Reservoir Catchment Site of Special Scientific Interest and the existing vegetation was required to be preserved. Slope improvement works had previously been attempted by installation of concrete piles with soil nail tie-back. However, during the construction of the concrete piles, excessive settlement was observed in the Peak Café and the installation of the tie-back soil nails was withheld. An alternative slope improvement scheme was required to bring the slope up to current safety standard. Conventional slope improvement schemes such as soil nailing, piling, re-compaction of soil were considered not suitable for this vibration sensitive site. Eventually, Hand-dug Caissons, which would cause the least vibration and the smallest anticipated settlement of the Grade II Historical Building, were considered to be the most practicable solution for improving this slope.

This paper presents the design aspects, the justification for seeking approval for the use of Hand-dug Caissons, construction procedures and the health and safety precaution measures of Hand-dug Caisson construction for this slope.

## 1 INTRODUCTION

### 1.1 Site Description

The site, Feature No. 11SW-C/F50, is a fill slope located at the junction of Peak Road and Harlech Road near the Peak Galleria and the Peak tram terminal (as shown in Figure 1). The fill slope is approximately 60m in length and has a maximum height of 27m with an average gradient of  $30^\circ - 33^\circ$ . A restaurant, Peak Lookout (formerly called Peak Café) is located at the slope crest and it is a Grade II Historic Building. Vegetated natural terrain is located to the northwest and at the toe of the site.

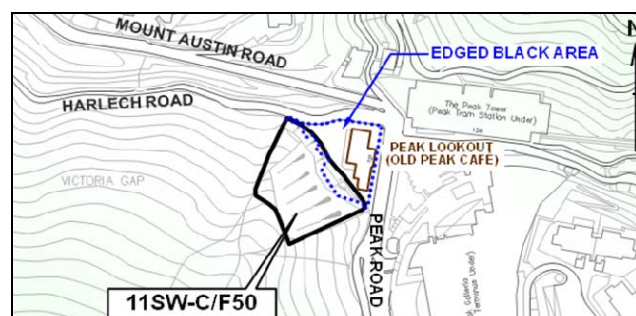


Figure 1: Site location plan

### *1.2 Previous Study and Improvement Works*

The subject slope was previously studied in 1997. This slope was found to possess inadequate factor of safety and the fill material was loose. Slope improvement works comprising mainly the installation of concrete pile (450mm diameter) wall with tie back by soil nails were proposed.

The previous slope improvement works were subsequently carried out in 1997. During the construction of the concrete piles, excessive settlement was observed in Peak Café, the Grade II Historic Building. A decision was made to terminate construction early, the concrete pile wall and surface drainage were constructed. Further improvement works were to be carried out later.

Condition surveys of the Peak Café premises were carried out between 1997 and 1998 due to the occurrence of cracks during the construction of concrete piles in 1997. Sixteen cracks, with width up to 35mm, were recorded on planters, fence wall and on ground. No observable change in conditions and extent of cracks was noted since October 1997.

### *1.3 Ground Conditions*

The subject slope consists of a thick layer of fill overlying Completely Decomposed Tuff and subsequently Moderately to Slightly Decomposed Tuff.

The maximum fill thickness encountered was about 10m. According to the in-situ density tests conducted in some trial pits, the average degree of compaction of the fill is about 72.3%, which indicates that the fill is loose. The laboratory testing results also indicated that some of the fill samples exhibited a contractive behavior under undrained condition. Liquefaction of fill is therefore also a cause of concern.

## **2 DESIGN ASPECTS**

The Peak Lookout (formerly called Peak Café), which is a Grade II Historic Building, is located at the slope crest. Settlement had been observed in Peak Café during the construction works carried out in 1997. In order to prevent further settlement in the Grade II Historic Building, care should be taken to minimize the disturbance to the fill slope.

The site is located within Water Supplies Department water gathering grounds and Pok Fu Lam Reservoir Catchment Area Site of Special Scientific Interest (SSSI). Agriculture, Fisheries and Conservation Department requested that existing greenery should be preserved. Tree felling should be avoided as far as possible and any vegetation disturbance should be kept to the absolute necessity.

As mentioned in section 1.2, a row of concrete pile wall was previously installed in 1997. In order to make use of this concrete pile wall as one of the elements for slope improvement measures, an additional row of pile wall was proposed below the existing concrete pile wall. This new wall would then be connected by concrete beams to the existing concrete wall to form a frame structure to retain the slope.

The excavation for the additional pile wall by machine was considered to be too risky as the Grade II Historic Building at the slope crest had a history of distress. Hand-dug caisson was considered the only option. A row of total seventeen hand-dug caissons of 1.8m diameter and 3m spacing was proposed to improve the stability of the slope. The proposed hand-dug caissons would be located at an elevation of about +380.0mPD at mid-height of the study feature. To gain sufficient lateral resistance, the caissons were socketted at least 7m in Grade III or better rock. As a result, the length of the caissons ranged from 18m to 23m (see Figures 2, 3 and 4).

A row of 10m long prescriptive raking drains and surface drainage channels were also proposed in the detailed design. Soft landscaping works would then be provided to the slope surface to enhance the aesthetic appearance of the slope.

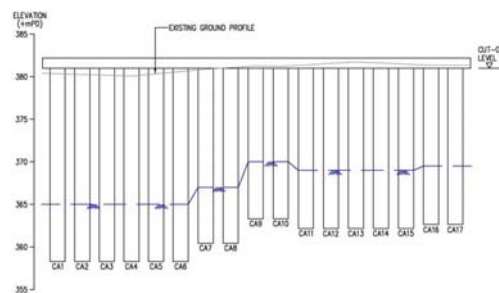
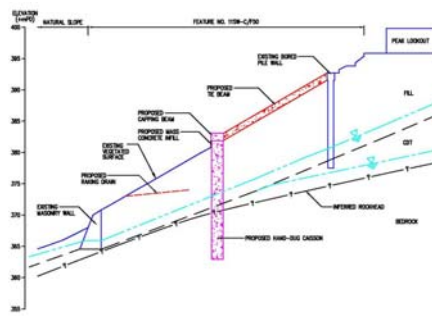


Figure 2: Layout of improvement works

Figure 3: Section of improvement works

### Figure 4: Elevation of Caissons

### 3 CONSTRUCTION ASPECTS

### 3.1 Construction Constraints

The construction constraints of the slope improvement works of the subject slope mainly consisted of three aspects:-

- (1) Limited working space
- (2) Safe working procedure and arrangement for hand-dug caisson excavation, and
- (3) Safe working procedure and arrangement for reinforcement fixing of caissons

### 3.1.1 Limited working space

The site is only accessible at the crest and is located at the junction of two major vehicular accesses of the Peak, Peak Road and Harlech Road. As consulted with TD and RMO for Temporary Traffic Arrangement (TTA) for loading and unloading activities, 24 hour lane closure at either Peak Road or Harlech Road for temporary occupation as works area is not allowed. Such activities would only be allowed during non-peak hours from 10:00 to 15:00, excluding Saturday, Sunday and Public Holiday, and should be limited to a maximum closure of 2 hours. During the implementation of the TTA, no encroachment upon the carriageway is allowed and the vehicular flow should be adequately maintained. Therefore, mobilization of large construction plant and delivery of materials to the site would be very difficult.

Apart from that, the site is located within WSD water gathering grounds and Pok Fu Lam Reservoir Catchment Area Site of Special Scientific Interest (SSSI), the existing dense greenery should be preserved as far as practicable. Therefore, the working space within the site is very limited.

In order to facilitate the construction works, a temporary stockpiling platform and other temporary working platforms were erected prior to the commencement of the hand-dug caisson construction. The temporary steel stockpiling platform was erected at the northeast to the site as shown in Plate 1. This temporary stockpiling platform was used for providing space for temporary storage of construction material and excavated materials.

Apart from the temporary stockpiling platform, a temporary working platform was also erected over all seventeen hand-dug caissons to provide working space for access, material transportation and hand-dug caisson construction works. A structural steel gantry was erected along the seventeen caissons with electric chain blocks for transportation of workers and materials within the caissons and along the working scaffolding platform (see Plate 2). All electric chain blocks together with the gantry were tested and thoroughly examined by a competent examiner.



Plate 1: Temporary stockpiling platform



Plate 2: Temporary working platform and steel gantry

### 3.1.2 Safe working procedure and arrangement for hand-dug caisson excavation

The use of hand-dug caissons had been generally banned due to a disturbing history of high rate of accident and fatalities and health hazards to the workers. Previous accidents include workers being struck by object falling into the excavation, or being trapped by the collapse of an excavation, both during the course of excavation and material transportation.

In order to prevent occurrence of such kind of accident, a safe system of work for hand-dug caisson construction including the employment of competent persons for supervision of caisson construction and certified workers for working inside caisson was required to be developed. The system should be in compliance with the requirements of the Particular Specifications, Factories and Industrial Undertakings (Confined Spaces) Regulation, “Code of Practice – Safety and Health at Works in Confined Space” and other relevant publications issued by Labour Department, and “Code of Safe Working Practice for Hand-dug Caissons” published by the Occupational Safety and Health Council.

The edges of the caisson openings had been fenced with guard-rails with height of 1150mm in accordance with F&IU regulations to prevent any persons from falling. Toe boards with minimum height of 200mm were also provided to the caisson openings to prevent objects from falling (Plate 3). The caissons were securely covered and locked with warning sign when no works were carried out within the caissons to prohibit unauthorized entry.



Plate 3: Provision of barriers and toeboards at caisson opening



Plate 4: Chain blocks

Above each caisson opening, a pair of chain blocks was established at the steel gantry (see Plate 4), one chain block would carry a material bucket (Plate 5) and the other chain block would carry the man-cage (Plate 6). The lifting of the material bucket and man-cage inside the caisson requires specific sequence in order to

ensure that no person would be stayed inside the caisson when a bucket is being raised or lowered inside the caisson.



Plate 5: Material buckets



Plate 6: Man-cage

### 3.1.3 Safe working procedure and arrangement for reinforcement fixing of caissons

The reinforcement of the caissons consisted of a layer of 66 nos. of 40mm-diameter high yield steel bars as the main vertical reinforcement and 25mm-diameter high yield steel bars at 225mm spacing as the circular links along the depth of caisson.

The biggest challenge of hand-dug caisson construction at the subject slope is the reinforcement fixing. Due to the site location and its limited working space, the reinforcement cage of the caisson could not be fabricated off-site and lifting crane could not be set up on site for lifting the reinforcement cages into the caissons.

In order to minimize the hazard to the workers during reinforcement fixing of the caisson, a set of pre-fabricated steel scaffold (named as “climbing mast”) was developed and transported into the caisson by electric chain blocks to allow workers to move up/down inside the caisson (Plates 7 and 8). A site specific lifting derrick had also been set up adjacent to the caisson for lifting vertical reinforcement bars into it (Plate 9).

The reinforcement fixing of the hand dug caisson would be divided into two portions, the lower portion of caisson with length of 12m and the upper portion of caisson with maximum length of 12m.



Plate 7: Climbing mast



Plate 8: Climbing mast inside caisson



Plate 9: Lifting derrick

Firstly, a reinforcement cage of the 25mm-dia. circular links would be fixed with some temporary 25mm-dia. vertical steel bars above the caisson opening. The reinforcement cage were hung and gradually lowered by the electric chain block at the gantry (Plate 10). Once a 12m long reinforcement cage completed, the cage would be lowered to the bottom of the caisson by the chain blocks. The 40mm-dia. steel bar would be then lifted and lowered to the bottom of caisson one by one using the lifting derrick (Plate 11). The workers would then enter the caisson through the climbing mast and fix the 40mm-dia. steel bars to the 25mm-dia. circular links (Plate 12). The temporary 25mm-dia. vertical bars of the cage would then be lifted up by the derrick.



Plate 10: Reinforcement cage



Plate 11: Lowering of 40mm dia. steel bar by lifting derrick

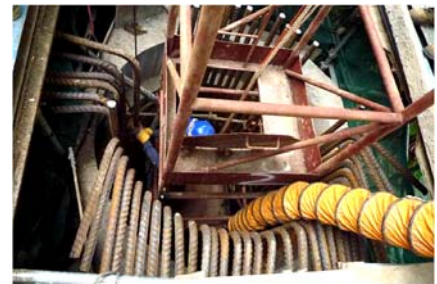


Plate 12: Reinforcement fixing inside caisson

After completing the reinforcement fixing of the lower portion of caisson, workers would repeat the procedures of reinforcement fixing for the upper portion of the caisson.

Most of the reinforcement fixing of the caisson would be carried out outside the caisson in order to shorten the time of workers staying inside caisson. Although the fixing of the 40mm-dia. main vertical reinforcement inside the caisson was unavoidable due to the limitation of the working space for powerful lifting appliance, the workers could stay inside the caisson with the protection by the climbing masts, which reduce the risk of hazards, such as the collapse of reinforcement and falling objects.

## 4 SAFETY AND HEALTH ASPECTS

### 4.1 Permit-to-Work System

Hand-dug caisson is classified as “confined space” in accordance with Factories and Industrial Undertakings (Confined Spaces) Regulation, the Contractor therefore was required to appoint a competent person and to establish a Permit-to-Work system to ensure comprehensive and stringent supervision were maintained during the course of caisson construction.

### 4.2 Ventilation and Dewatering

Ventilation system including both supply and extraction of air were installed at each caisson. The ventilation system was regularly inspected and checked to ensure well-functioning throughout the working period.

During the excavation of the caissons, groundwater was encountered inside the caissons. The dewatering pump was provided to ensure the groundwater level inside caisson not higher than 500mm. The standing water inside the caisson would also act as a dust suppression agent during the rock excavation to minimize the spreading of silica dust.

### 4.3 Electrical Safety

All electrical equipment used inside the caisson shall be of splash-proof type and operated at a voltage of 25V AC centre-tapped. Portable and hand-held electrical tools were effectively earthed or with double insulation designs. Lighting should be of the shatterproof type, with heavy-duty wiring and fully sealed connection protected against accidental breakage or damage.

#### 4.4 Personal Protective Measures and Measures for Emergency Escape

The worker entering the caisson should put on adequate personal protective equipment, including suitable safety helmet, eye protector, ear protectors, and respirator (see Plate 13). A portable alarm device would also be equipped with the caisson worker. The alarm device had been designed with significant loud buzz to draw the co-worker's attention on ground when the carrier is motionless for a specific time inside the caisson.



Plate 13: Personal protective measures for caisson workers

The worker entering the caissons should wear safety harnesses attached to an independent lifeline so that he could climb up or be pulled out by co-workers on ground. The independent lifeline should be worked with a lifting aid such as pulleys, chain block or electric hoist.

## 5 CONCLUSIONS

With thorough study and investigation on the site geological conditions and constraints, careful consideration and planning on the construction sequence and methodology, detailed risk assessment and implementation of safety system of works and adoption of suitable safety precautionary measures, hand-dug caisson could still be constructed in a safe manner.

## ACKNOWLEDGEMENTS

This paper is published with the permission of the Head of the Geotechnical Engineering Office and the Director of Civil Engineering and Development, the Government of the Hong Kong Special Administration Region.



# Innovative Materials and Drilling Method adopted for Soil Nailing Works at Po Shan Road

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The Government of the Hong Kong SAR*

## ABSTRACT

Soil nailing is one of the most commonly adopted slope stabilization methods in Hong Kong. A 25m high anchored slope, Feature No. 11SW-A/C172 located at the uphill side of No. 30 Po Shan Road, Mid-levels, was a difficult site for soil nail installation. The site constraints included a thick layer of colluvial boulders, high groundwater table, existence of ground anchors with sizable anchor heads and stringent requirement of maintaining the existing anchored soil stress condition. Collapse of drillholes and grout loss during soil nailing installation were anticipated in the thick layer of colluvial boulders zone and it might in turn affect the existing anchored soil stresses. Traditional method to overcome drillhole collapse and grout loss by installation of left-in casings using eccentric drilling method was considered not adequate to minimize change of soil stresses and overcome jamming of drill bits in the colluvial boulder zone. The existing anchor heads also hindered the soil nails to be installed at a normal spacing of about 2m. Furthermore, wider spacing of soil nails was required in order to avoid damming up of groundwater that might affect the stability of the natural terrain above the slope. Innovative materials using high tensile steel bars with yield strength over 1000MPa and concentric drilling method with much less ground loss were applied to overcome the difficult ground condition for upgrading this slope.

This paper presents both the design consideration and construction aspects of upgrading this slope with particular discussion on the use of concentric drilling method.

## 1 INTRODUCTION

### 1.1 Site Description

The site, Feature No. 11SW-A/C172, is a soil cut slope located to the south of No. 30 Po Shan Road, Mid-levels (see Figure 1). The subject slope is approximately 45m in length and has a maximum height of 25m. The average slope gradient is about 50°. Heavily vegetated natural terrain is located immediately behind the feature crest. Immediately at the toe of the subject slope is a retaining wall, Feature No. 11SW-A/R888. No. 30 Po Shan Road, a low-rise resident building, is located at about 4m from the toe of Feature No. 11SW-A/R888.

The subject slope was covered with chunam surface, which was in poor condition that cracks were noticeable and vegetations were found growing through the surface at various locations of the slope. A total of 22 anchors with anchor heads of 2.3m x 2.3m were scattered on the slope surface (see Plate 1). Some boulders were located on the natural hillside to the south of the feature, which suggests the presence of colluvial deposits.

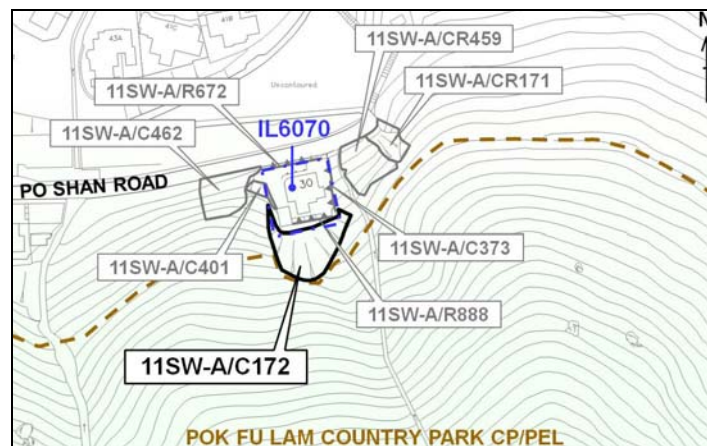


Figure 1: Site location plan



Plate 1: Existing anchors

### 1.2 Previous Study and Upgrading Works

A Landslide Study was carried out in Po Shan Road Area by Binnie & Partners (Hong Kong) Consulting Engineers in 1976; it was concluded that the slope did not have an adequate factor of safety. Subsequently, Binnie & Partners were requested to further investigate the stability of the slopes behind Nos. 24 – 30 Po Shan Road. Stabilization of the slopes by ground anchors was then recommended. A total of 22 anchors were installed at subject slope under Contract No. 662/77. The anchors were VSL's seven-strand system having an ultimate tensile strength (UTS) of 1288kN. The design working load of the anchors was initially proposed to be 774kN (60% of UTS).

### 1.3 Ground Conditions

The Hong Kong Geological Survey Map, Sheet 11 – Solid and Superficial Geology of Hong Kong and Kowloon, published by the Geotechnical Control Office (GCO, 1986) indicates that the area of the feature is underlain by debris flow deposits (Qd) overlying fine ash vitric tuff (JAC). Based on a Mid-levels Study (MLS) Report prepared by Geotechnical Control Office in 1982 (GCO (1982)), a north-south trending major fault line is passing through the eastern portion of the subject slope. Some GI drillholes indicate that there are dolerite dyke and decomposed basalt located at the subject slope. The presence of fault and dyke increases the complexity of the geology of the subject slope.

Based on the ground investigation, the geological sequence anticipated in the subject slope consists of a thick layer of colluvium overlying Completely Decomposed Tuff and subsequently Moderately Decomposed Tuff.

The GI results indicate that the feature generally comprises a layer of colluviums with thickness ranging from 6m to 10m (Maximum colluvium thickness of 10m located at the eastern portion) of the subject slope. Based on GCO (1982), the colluvium at the subject slope is about 0 – 5m thick and is a Class 3 colluvium, which is the youngest and least decomposed class of colluvium under the MLS system of classification. The boulder content in colluvium varies between 25% and 50%.

The rockhead level at the subject slope is generally 10m below ground. However, the rock at the eastern portion is presumed to be more deeply weathered and the rockhead level is about 15m to 20m below ground due to the presence of a major fault line.

## **2 DESIGN ASPECTS**

### *2.1 Design Constraints*

#### *2.1.1 Spacing of soil nails*

In Hong Kong, soil nails are commonly installed at a spacing of 1.5 m to 2.0 m and the horizontal rows of soil nails should be staggered to improve the integral action between the soil nails and the ground. Widely-spaced soil nails may not be effective in ensuring that the soil nails and the ground would act as an integral mass, and in preventing local instability between soil nails.

The normal soil nail spacing of 1.5m to 2.0m is not applicable to this slope for two reasons. Firstly, the presence of 22 sizable anchor heads has precluded such close spacing. Secondly, the estimated damming up of the groundwater at the natural terrain above the subject slope due to close nail spacing would adversely affect the required stability. Taking into account these two factors, the proposed soil nails need to be spaced horizontally at 2.4m to 4m and vertically at 2m.

#### *2.1.2 Existing Anchors*

Available monitoring data on the existing anchors were found between 1988 and 2000. The data indicated that there was a trend of reduction of lift-off loads since the time of installation. No more records of monitoring and maintenance works were found since 2000.

Since the existing anchors do not have adequate corrosion protection, they may eventually lose their anchor loads. Therefore, the loads of any existing anchors had not been included in the stability analysis for soil nail upgraded slope.

### *2.2 Detailed Design*

In order to cope with the required wider spacing, soil nails using high strength steel bars with yield strength of 1080MPa as the reinforcement were proposed to upgrade the subject slope. The soil nails had lengths range from 14m to 28m and were socketted into Grade III or better bedrock.

As the inclination of the existing ground anchors mainly ranges from 15° to 18.5°, the soil nails were proposed to be inclined at an angle of 17° to minimize the possibility of clashing with the existing ground anchors.

The slope shows constant seepage and high groundwater levels. Based on the chemical tests in the adjacent sites, the soil at the subject slope is considered as potentially aggressive. Corrosion protection measures were proposed to the soil nails.

Concrete grillage was proposed on the subject slope to tie the soil nails and to prevent local instability of the slope due to the large horizontal spacing.

## **3 CONSTRUCTION ASPECTS**

### *3.1 Installation of Permanent Casings*

The primary concern during the course of slope upgrading works was to minimize the ground disturbance and the damming effect to the groundwater levels, which might adversely affect the existing ground anchors and the slope stability. As the subject slope has a layer of bouldery colluvium and a high groundwater table, the

possibilities of collapse of drillholes and damming effect caused by grout loss would be substantially high. Therefore, installation of permanent casings for the portion of soil nails embedded in the colluvial layer was required during the course of soil nailing works.

### 3.2 Limitation of Eccentric Drilling Method

Eccentric drilling method, also known as Overburden Drilling with EXcentric bit (ODEX) method, is a widely recognized casing drilling technique in Hong Kong. The ODEX system consists of a bottom pilot bit and an eccentric “swing out” reamer bit which rides along its shaft. The bottom pilot bit and the eccentric reamer are connected with a casing shoe with guide device ahead of the casing tubes bottom. The rotation of the drill string forces the eccentric reamer to swing out and drill a hole slightly larger than the outside diameter of the casing (see Figure 2).

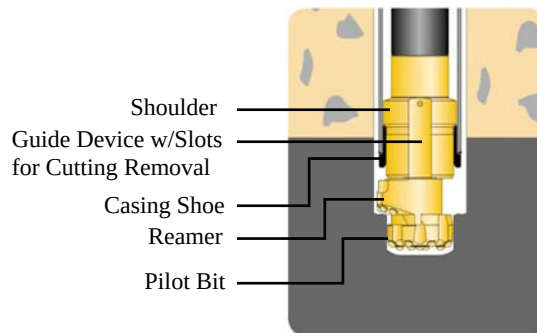


Figure 2: The ODEX system drills a hole slightly larger than the casing

Once the full length of the bit assembly has advanced ahead of the casing, the shoulder on the guide device impacts the inner lip of the casing and pulls the casing down as drilling proceeds. Counterclockwise rotation of the drill string causes the eccentric reamer to retract to a diameter which is small enough to pass through the casing shoe and pull out of casing tubes. Additionally, the casing may be retracted without resistance since the drillhole was drilled to a slightly larger diameter than the casing.

Although the guide device above the eccentric ODEX bit contains flutes which allow pathways for returning the flushing air, it is unavoidable that some cuttings would be flushed up outside the casing as the drillhole is made slightly larger than the outside diameter of the casing. This would make the drillhole larger than the casing. With drilling through bouldery colluvium, such increase in the drillhole sizes would be even more pronounced. Since the subject slope is under high stresses from the existing anchors, any ground loss arising from drilling should be avoided. Therefore, the eccentric (ODEX) drilling was considered not suitable for use at this site and an innovative drilling technique, Concentric drilling method, was considered to use for this sensitive site.

### 3.2 Use of Concentric Drilling Method

Concentric drilling method comprises a casing system with a pilot bit with large internal flushing holes and external flushing grooves, a ring bit with internal bayonet coupling and a casing shoe (see Plates 2 and 3). The pilot bit is attached to the ring bit with a bayonet coupling (See Plate 4). Both rotate clockwise and together cut the hole, which is sufficiently large to allow the casing shoe to pull down the casing. The ring bit rotates freely on the casing shoe, which is welded to the first casing pipe. During drilling the casing pipe does not rotate.



Plate 2: Ring bit and pilot bit for concentric drilling

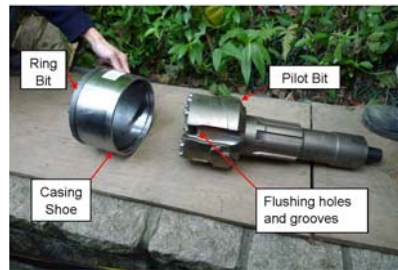


Plate 3: Side view of ring bit and pilot bit



Plate 4: Spiral locking system for coupling the pilot bit and ring bit

The drill bit is connected with the conventional Down-The-Hole hammer drilling rig and powered by compressed air from an air compressor machine. Compressed air has two functions in the drilling rig. One is as a power source to drive the rotation of the drill bit and push the drilling mast inward into the slope. The other function is when the drilling rig is operating, the compressed air can force the soil debris out of the hole. The flushing air is ejected through the holes in the face of the pilot bit and returns immediately up via groove between the pilot bit and ring bit and further to the annulus between the casing pipe and the drill pit (see Figure 3). This ensures high flushing velocity with low hole degradation and the disturbance to the surrounding soil is minimized significantly. The penetration force is transmitted only through the drill string to the pilot bit, which strikes the ring bit.

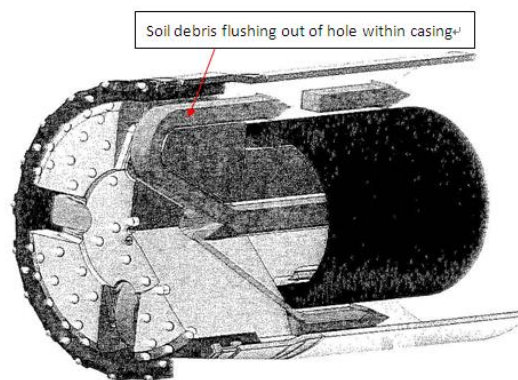


Figure 3: Schematic diagram showing the flushing system of concentric drilling

When the hole through the colluvial layer is complete, the pilot bit is unlocked from the ring bit by a slight anticlockwise motion and withdrawn up through the casing pipe. Drilling can be continued using a standard bit through the casing pipe and ring bit into the relatively stable ground formation below the casing. It should also be noted that the ring bit is to be left in place with the permanent casing and could not be re-used.

The concentric drilling method will perform more efficiently in minimizing the disturbance to the surrounding ground during the drilling process. The patented designed pilot bit and ring bit allow both bits rotating together to cut the hole which is sufficiently large for the casing tubes. The hole will be straight and the gap between the drillhole and casing is insignificant. The return flushing air is guaranteed to be forced up the casing pipe immediately after exiting the pilot bit. Moreover, there is no gap between the casing shoe and pilot bit such that jamming of drilling bit would not occur even for the drilling works through boulderly materials.

#### 4 CONCLUSIONS

Concentric drilling method is a newly introduced method for soil nailing works in Hong Kong. By considering the efficiency of minimize ground loss and disturbance during casing installation, it can be widely adopted for slope upgrading works in sensitive sites in Hong Kong in the future.

## ACKNOWLEDGEMENTS

This paper is published with the permission of the Head of the Geotechnical Engineering Office and the Director of Civil Engineering and Development, the Government of the Hong Kong Special Administration Region.

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# Innovative Approach for Landslide Prevention – A Tunnel and Sub-vertical Drain System

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## ABSTRACT

The Po Shan Tunnel Landslide Preventive Works consist of two 3m diameter tunnels in deep rock and 172 nos. of sub-vertical drains drilled and installed upward from inside the tunnels and extended into the overlying soil layer. It is the first of its kind in Hong Kong and even in the world to utilize tunnels and a network of sub-vertical drains to form a robust subsurface drainage system to regulate the groundwater table for enhancing the long-term stability of the hillsides. The performance of the system has proven to be satisfactory. The success of the project demonstrates a feasible and effective solution for future landslide prevention and risk mitigation on steep and hilly terrain in Hong Kong.

In this paper, the design philosophy of this innovative landslide prevention approach is briefly discussed, the construction issues are also described, and the performance of the system for landslide prevention purposes are highlighted.

## 1 INTRODUCTION

In 1972, a catastrophic landslide occurred on the hillside of the Po Shan area in Hong Kong, which took the lives of 67 people. Among other major landslides in Hong Kong, this incident formed the historical background for the slope safety efforts made by the Hong Kong Government. A number of detailed investigations and research studies were carried out and the results indicated that the natural hillside of the Po Shan area was affected by high groundwater level and unfavorable geology. Sub-surface drainage measures by means of sub-horizontal drains were installed in 1984-85. These measures have been successful in lowering the main groundwater table, thus improving the stability of the slopes such that large-scale failures have not occurred over the last two decades. After some twenty years, the monitoring data however showed signs that the groundwater levels in the drained area could be high during periods of heavy rainfall. The hillside was susceptible to small-scale shallow movements, which could damage the existing horizontal drains and render them ineffective in drawing down the main groundwater level.

In 2005, AECOM was appointed by the Geotechnical Engineering Office (GEO), Civil Engineering and Development Department of the Hong Kong SAR Government to design a robust landslide preventive system to protect the residents at the Po Shan Area. With this clear ultimate goal, AECOM came up with a creative and yet practical design. Many design options had been considered, and eventually a tunnel and sub-vertical drain system was adopted.

This paper presents the process leading up to the innovation being developed, the design philosophy of this innovative approach, the construction issues, and the performance of the tunnel and sub-vertical drain system for landslide prevention purposes.

## 2 SITE DESCRIPTION

The site is located at NW flank of Victoria Peak and south of Po Shan Road. The project area can be broadly defined as encompassing the mostly undeveloped hillsides above No. 4 Po Shan Road in the west to No. 20 Po Shan Road in the east, beyond the man-made cut slope, 11SW-A/CR175, at the site of the catastrophic 1972 Po Shan Road failure.

The project area falls largely within the Pok Fu Lam Country Park and is mainly covered by dense vegetation comprising grasses, shrubs and trees. The hillside is about 210 m high, with crest and toe levels at around +390 mPD and +180 mPD respectively. The maximum span of the site is approximately 730 m in

length. Generally, the site is mainly natural terrain with an average gradient of  $25^{\circ}$ . Lugard Road is located at the crest whilst residential buildings are located along the toe of the project area. Figure 1 shows the perspective view of the project area and Figure 2 shows the as-built plan for the tunnels and the sub-vertical drains.

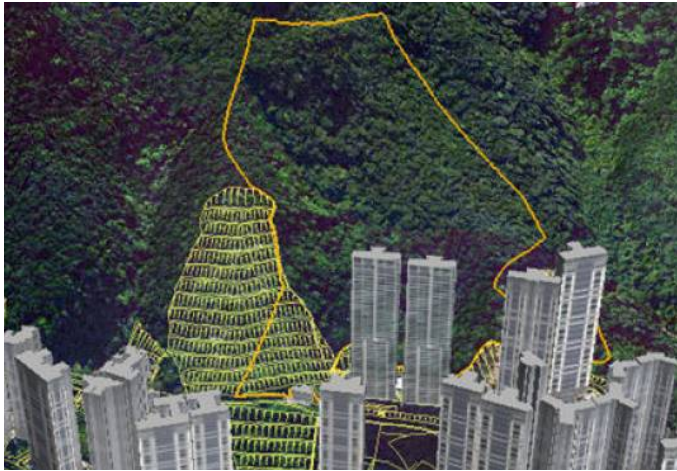


Figure 1: Perspective View of the Project Area

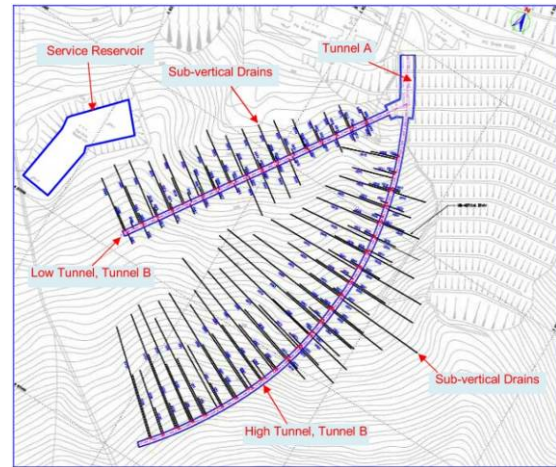


Figure 2: As-built Plan of the Tunnels and Sub-vertical Drains

### 3 HISTORICAL LANDSLIDES

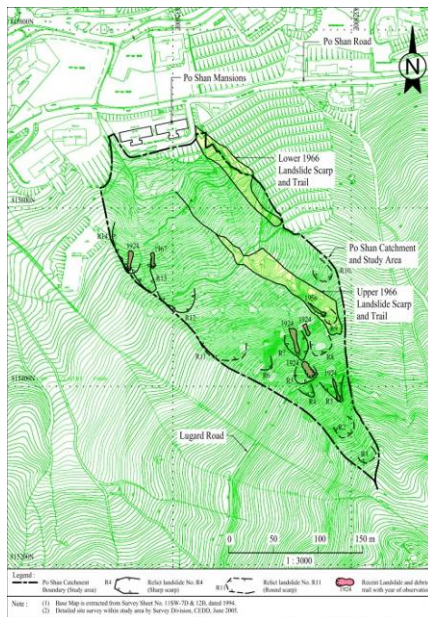


Figure 3: Natural Terrain Landslide within Po Shan Catchment

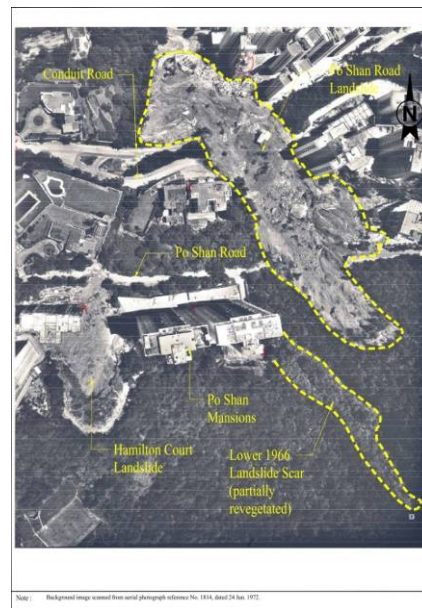


Figure 4: 1972 Po Shan Road and Hamilton Court Landslides

The Po Shan catchment and adjacent hillsides have been affected by significant historical instabilities. FSW (2005) summarized those natural terrain landslides, which are illustrated in Figure 3 and Figure 4. The key landslide events in the Po Shan area include: a) Fourteen relict landslides identified on 1949 aerial photographs; b) Seven small ( $<50 \text{ m}^3$ ) recent landslides identified on 1924, 1956 and 1967 aerial photographs; c) Two large ( $500 \text{ m}^3$  and  $1500 \text{ m}^3$ ) recent landslides identified on the 1967 aerial photographs (both occurred in June 1966); d) 1972 Po Shan Road landslide; and e) 1972 Hamilton Court landslide.

#### 4 GEOLOGICAL CONDITIONS, LANDSLIDE HAZARDS AND MITIGATION WORKS

Very extensive desk study and ground investigations including two horizontal directional coring (HDC) holes (Lam et al. 2008) were carried out within and in the close vicinity of the proposed tunnels and associated sub-vertical drains before construction to confirm the geological stratification. The site investigation data revealed that the geology of the site comprises three major geological strata, namely Colluvium, Completely and Highly Decomposed Tuff, and Moderately Decomposed Tuff or better rock. However, special geological features such as rock intrusions, granitic vein, quartz vein, pegmatite vein, aplite vein and rhyolite vein, were encountered in both tunnels during construction.

Previous (GCO 1987) and more recent subsurface investigations (FSW 2005) indicated that the majority of the Po Shan catchment is covered with Colluvium, which is often considerably thick (>20m). Saprolite is also found and is generally covered with a thin layer of Colluvium. Four main groups of landslide hazards were also identified from previous studies and are summarized as follows:

- (1) Landslide Hazard 1 – Retrogressive / retreating failures of the residual Colluvium on the eastern and western spurs of the site area within the locally steeper portion of slope. These failures probably include debris avalanche (open hillside failures) becoming debris flow landslides if sufficient channelization occurs and if sufficient water is present. Development of perched water conditions within the Colluvium and at the Colluviums-Saprolite boundary are considered to be significant factors for landslide initiation.
- (2) Landslide Hazard 2 – Debris avalanche and debris flow type failures sourcing from the upper rock dominated part of the site area, between the cliffs. Development of perched water conditions at the Colluviums-Saprolite-bedrock boundaries are considered to be significant factors for landslide initiation.
- (3) Landslide Hazard 3 – Rock slide (wedge and planar) and rock fall failures on the rock cliffs in the middle to upper portions of the catchment, which have produced significant talus deposits overlying Colluviums on the middle portion of the catchment, particularly below the lower cliff.
- (4) Landslide Hazard 4 – Deep-seated failures may have occurred in the past within the residual Colluvium and possibly within the buried Saprolite below the Colluvium. This was suggested from the disturbed nature of the CDT recovered from some Mazier samples above the upper 1996 landslide scar. Development of high main groundwater conditions within the Colluvium / Saprolite could have been significant factors for possible deep-seated relict landslide initiation.

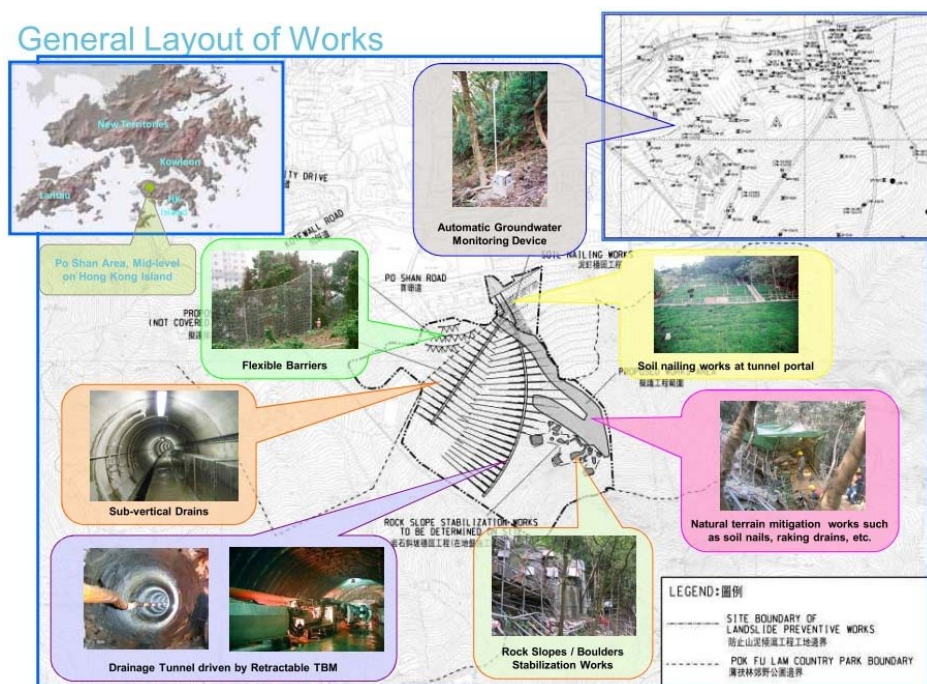


Figure 5: General Layout of Works

Based on quantitative risk assessment (FSW 2005), the natural terrain landslide risk mitigation works including protective measures (e.g. debris barriers, surface drainage improvement, bio-engineering measures, etc.) and preventive measures (e.g. soil nailing, rock slope stabilization and raking drains) were schematically proposed. The detailed landslide preventive works in all identified hazard areas were designed by AECOM in 2005 and the construction works were successfully completed in December 2009. The scope of works include the innovative tunnel and sub-vertical drain system, natural terrain risk mitigation works comprising soil nails, rock slope treatment works, bio-engineering works, and flexible barriers. These works are shown in Figure 5. This paper mainly describes the tunnel and sub-vertical drain system in following sections.

## 5 INNOVATIVE DESIGN OF THE TUNNEL AND SUB-VERTICAL DRAIN SYSTEM

There are two 3m inner diameter (ID) TBM tunnels, namely High Tunnel and Low Tunnel, extended from the portal chamber and run underneath the natural hillside behind No. 16 Po Shan Road. The High Tunnel is 259 m long and is located at elevations between +184.24 mPD and +197.19 mPD. The Low Tunnel is 188 m long and is located at elevations between +184.06 mPD and +185.95 mPD. The sub-vertical drain system consists of 172 nos. of drains with a total length of approximately 10 km and a maximum individual length of 102 m. The drains were constructed from the two TBM driven tunnels at different orientations and angles from 30° to 125° to the horizontal. The plan and cross-sectional views of the tunnel and sub-vertical drain system are shown in Figure 2 and Figure 6 respectively.

The prime objective of the tunnel and sub-vertical drain system is to reduce the risk of deep-seated landslide. The drains were designed to cover the area of the entire concerned drainage zone of the catchment. From Figure 6, it is clear that the drains take care of the drainage zones of the upper hillside and lower hillside. Each drain consists of an outer 114 mm diameter Stainless Steel (S.S.) or High-density Polyethylene (HDPE) perforated casing, and a geotextile-wrap protected, 50mm diameter, slotted well-screen inner tube. Inside the tunnel, a connection pipe connects every sub-vertical drain and extends to a half round channel. A valve is installed on the connection pipe to control the flow of groundwater from the sub-vertical drain. The arrangement is shown in Figure 7. The tunnel and sub-vertical drain system provides a controllable mechanism through opening and closing of the sub-vertical drains to regulate the groundwater level and ensure that the variation of groundwater level is in line with the design purposes.

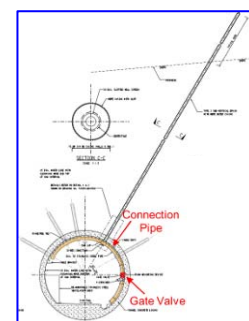
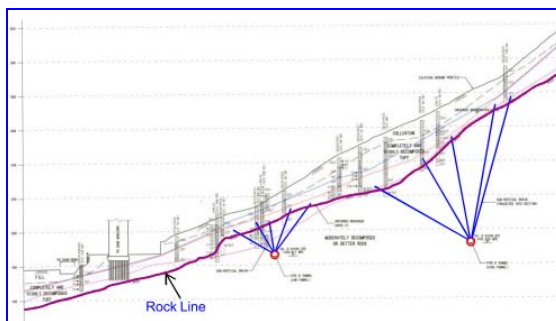


Figure 6: Cross-sectional view of the tunnel and sub-vertical drain system      Figure 7: Sub-vertical drain and connection pipe arrangement

## 6 CONSTRUCTION OF THE SUB-VERTICAL DRAINS

In consideration of the drilling method for the sub-vertical drains, percussive upward drilling from the drainage tunnel was selected as it would give a much higher penetration rate. Water hammer, instead of air hammer, was also adopted to reduce the chance of jamming. The maximum average drilling rate was approximately 32 m/day/rig.

The experience gained in the early stage of the construction suggested that rapid drawdown in groundwater levels usually occurred during drilling or just after completion of drilling. Therefore, the newly constructed drains were temporarily plugged to avoid uncontrolled and excessive drawdown of the main groundwater table. For most of the sub-vertical drains, the actual construction sequence is briefly described as follows:

- a) a hole was drilled by using the sub-vertical drilling rig with the high water pressure system;
- b) a perforated outer casing was inserted by using the same drilling rig;

- c) an inner drain was inserted manually or using the same drilling rig;
- d) a locking device was installed onto the tunnel crown and sealed with water sealant and water-proof materials; and
- e) an end cap was installed to temporarily cease water drainage from the sub-vertical drain.

Chau et al. (2011) summarized the experience of the sub-vertical drain construction and described the detailed drilling and installation processes of sub-vertical drains, the problems encountered and the corresponding solutions adopted during construction, as well as the valuable experiences gained from the project.

## 7 PERFORMANCE OF THE TUNNEL AND SUB-VERTICAL DRAIN SYSTEM

Based on the observations obtained during construction, Lo et al. (2011) postulated a simple hydrological conceptual model to depict the variation in groundwater level during and after construction of the entire drainage system. The simple conceptual model is shown in Figure 8 and is briefly described as follows:

- Stage 1: Tunnel Construction – Rock storage drainage with limited groundwater drawdown
- Stage 2: Drains Construction – Effective groundwater drawdown
- Stage 3: Drains Plugged – Groundwater drawdown stops (pressure starts to build up)
- Stage 4: Construction Completed – Groundwater rise and back to original

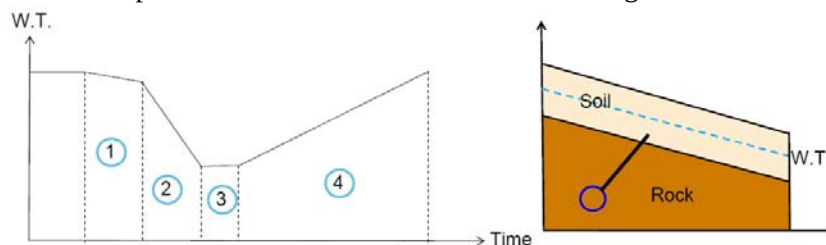


Figure 8: Hydrological Conceptual Model

The hydrological conceptual model has been verified by actual piezometer records. A total of 52 piezometers, some of which were double (upper and lower) tip installation, have been in operation and the readings have been recorded automatically on a real-time basis since the beginning of the construction. Lo et al. (2011) summarized the groundwater monitoring data from November 2006 to September 2010. This paper further updates the monitoring data to December 2010 and a peak groundwater level in 2011 can be shown.

In general, the groundwater levels at most of the piezometers vary with seasonal fluctuations throughout the monitoring period, although some construction activities have affected the groundwater flow regime; the groundwater variation in piezometer SP/022 shown in Figure 9 is a typical example. The groundwater variations at piezometers SP/026U and LPW12/UPZ are also shown in Figure 9.

During tunnel excavation (Stage 1), the variation of groundwater levels was not sensitive, although some of the piezometers exhibited minor groundwater drawdown (0.1 m to 0.2 m). The minor drawdown in piezometers during tunnel excavation was in agreement with the minor inflows measured inside the tunnel (Lo et al, 2010). This is due to the limited local water storage in rock layer and therefore high inflow rates only occurred at the onset of HDC drilling. Once the initial water storage had been dissipated, the amount of water seeping into the tunnel reduced significantly.

During drilling of the sub-vertical drains (Stage 2), the groundwater level in some piezometers exhibited sudden and dramatic drawdown ranging from 1 m to 20 m. The drilling of the sub-vertical drains connected the tunnel to the main groundwater table in the soil layer and/or local water storage in rock layer. The direct drainage paths increased the overall hydraulic conductivity of the rock mass; this resulted in rapid and significant groundwater drawdown in some piezometers in the sensitive areas.

After effectively plugging the drilled sub-vertical drain holes in the High Tunnel and the Low Tunnel (Stage 3 to 4), recovery of groundwater table was observed and the groundwater level varied in accordance with the anticipated seasonal fluctuation in most piezometers. The period for groundwater pressure building up (Stage 3) and recovery of groundwater level (Stage 4) depended on the intensity of rainfall, the duration of the wet season and local material conductivity. For piezometer SP/026U, the groundwater level exhibited two obvious drops in relation to drilling of sub-vertical drains Nos. U100 and U106 on 24 April 2008 and 10 May 2008 respectively, however, the groundwater level immediately recovered after the heavy rain in late May and

June 2008 and thereafter experienced seasonal fluctuation. For piezometer LPW12/UPZ, the groundwater level was affected by drilling of sub-vertical drains Nos. D70, D72, D78 and D80 on 30 July, 31 July, 7 August and 8 August 2008 respectively, remained at a low level, and finally recovered in the wet season of 2009.

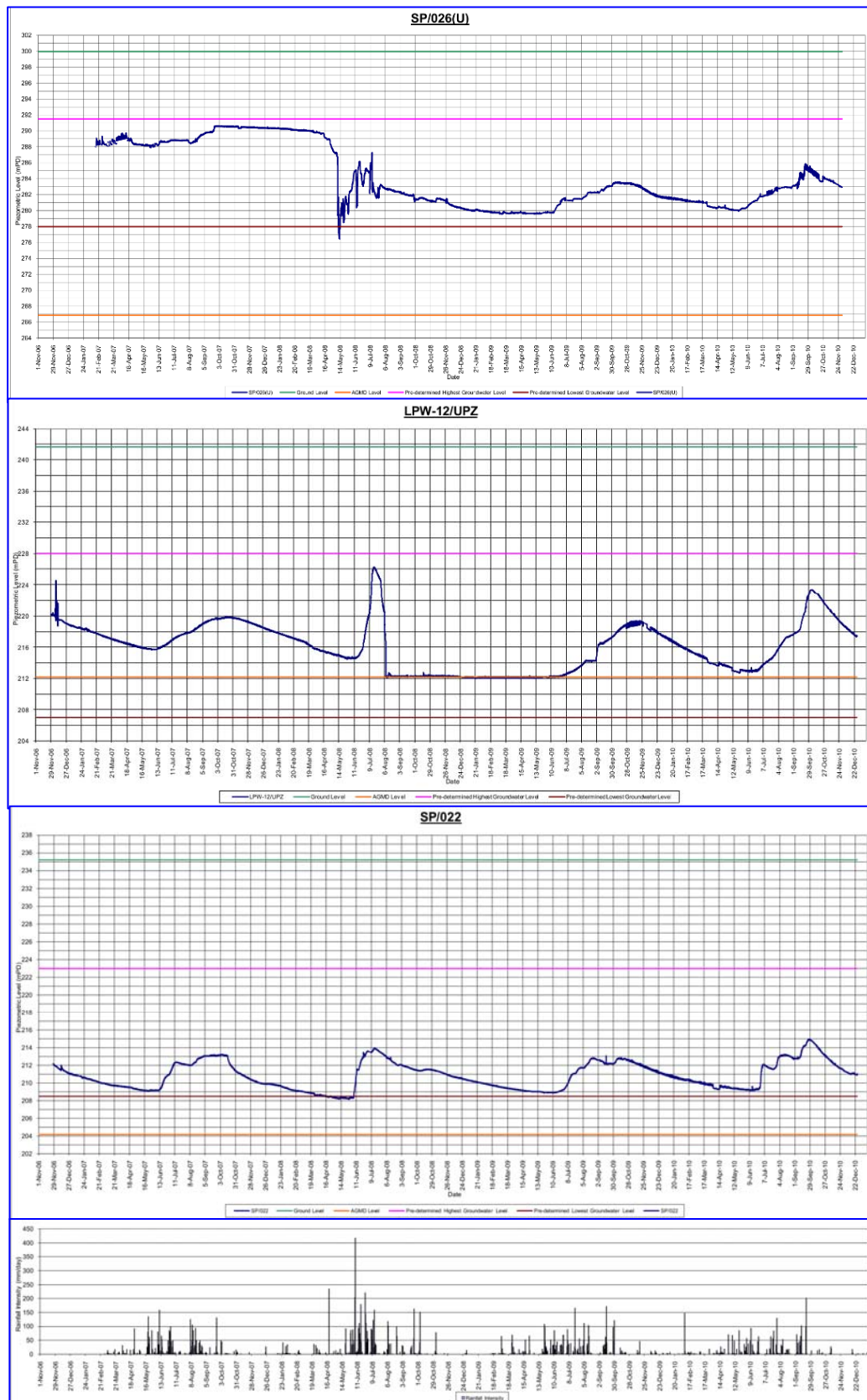


Figure 9: Groundwater Monitoring Results for Piezometers No SP/026U, LPW12/UPZ and SP/022

From the groundwater monitoring results, it is evident that the level of groundwater drawdown due to the presence of sub-vertical drains (when opened) is in line with the design function of the drainage system and the low groundwater levels could recover to the original levels through natural replenishment when drainage from the sub-vertical drains is stopped.

During operation of the drainage system, the valves of the sub-vertical drains can be opened during the wet season when groundwater levels exceed the alarm levels, and be closed when the groundwater table drops to a safe level. The highest and lowest safe levels are the groundwater levels fulfilling minimum factor of safety for overall slope stability and the historical lowest groundwater levels respectively; however, the alarm levels would be within the highest and lowest safety levels. These operational procedures to regulate the groundwater table are in effect replicating Stage 2 to Stage 4 during construction.

## 8 CONCLUSIONS

The Po Shan Tunnel Project is an innovative solution for slope stabilization, where tunneling has seldom been exploited. The Project is part of the efforts made by the Hong Kong SAR Government to improve slope safety under the Landslip Preventive Measures Programme since the 1970's. The performance of the system has proven to be satisfactory. The success of this project demonstrates a feasible and effective solution for future landslide prevention and risk mitigation on steep and hilly terrain areas.

## ACKNOWLEDGEMENTS

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# Challenges of Emergency Works and Landslide Risk Mitigation Works at Tai O, Lantau Island in the Aftermath of 7 June 2008 Rainstorm

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## ABSTRACT

On 7 June 2008, Hong Kong was hit by an exceptionally severe rainstorm. This resulted in more than 2,500 landslides on natural hillsides and most of them were located in western Lantau Island. The areas in Tai O of Lantau Island were adversely affected by numerous landslides, leading to the temporary evacuation of 7 squatter huts and 22 village houses. The most serious landslides occurred at Nam Chung Tsuen, Tai O San Tsuen and Wang Hang Village. In order to remove the immediate danger and allow re-occupation of the village houses, the Geotechnical Engineering Office mobilized its contractors to carry out emergency repair works on those landslides affecting these three villages. Landslide risk mitigation works were then carried out to mitigate the potential risk of the natural terrain overlooking these villages. The scale and complexity of the works were much larger and more difficult than the normal upgrading works on man-made slopes. Based on the works on Nam Chung Tsuen at Tai O, this paper summarizes the challenges encountered, strategies developed and measures implemented by the project team for the successful completion of the works.

## 1 BACKGROUND AND INTRODUCTION

The intense rainfall on 7 June 2008 triggered many natural terrain landslides at Tai O, Lantau Island. One of the most damaging landslide incidents, which included three landslides (named NC6, NC7 and NC7a in Plate 1), occurred on the natural hillslopes above Nam Chung Tsuen and neighboring villages. In view of the potential danger of further landslides, a total of 12 village houses had to be temporarily evacuated on safety grounds. At the time, the resources of the contractors of Highways Department had been fully deployed and exhausted in dealing with the large number of emergency works and repairs to landslides. In view of the public outcry and the need to remove the immediate danger and allow early re-occupation of the evacuated village houses at Nam Chung Tsuen, Geotechnical Engineering Office (GEO) mobilized one of its contractors to carry out the emergency repair works to these three landslides. The emergency repair works were successfully completed in July 2008. In spite of the completion of the emergency works, the residual landslide risk at Nam Chung Tsuen was still considered high and not acceptable. Therefore, it was necessary to arrange for further landslide risk mitigation works on the natural hillsides above this village as an extension of the emergency repair works. The landslide risk mitigation works to these three landslides were progressively completed between July 2009 and March 2010.

The emergency repair works and the subsequent risk mitigation works at Nam Chung Tsuen mainly involved the application of more than 1,700 m<sup>2</sup> sprayed concrete, construction of a total of 165 m long 5 m high flexible barriers with substantial anchored foundations and a 5 m high check dam at high elevation on inaccessible hillside. The works were much larger and more difficult than the routine landslip preventive works on smaller man-made slopes. During construction of the works, various challenges and difficulties were encountered and therefore needed to be addressed by the project team. This paper outlines the works carried out at Nam Chung Tsuen, the challenges encountered during construction and the efforts made by the project team in resolving the problems and successful implementation of the works.

## 2 DESCRIPTIONS OF THE SITE

Nam Chung Tsuen is located at approximately 500 m to the south of the Tai O Bus Terminus. The three landslides are all situated at the upper levels of the natural hillsides immediately behind the villages. The nearest vehicular access available for loading and unloading is from the Leung Uk Playground which is linked by a small road to Tai O Road. After clearance of the landslide debris, the playground and open space at the toe of NC7 were used as site depot by GEO for the works. The NC6 and NC7a were located much further away and they were only accessible through narrow and winding footpaths through the villages. A view of these three landslides and the surrounding areas is shown in Plate 1.

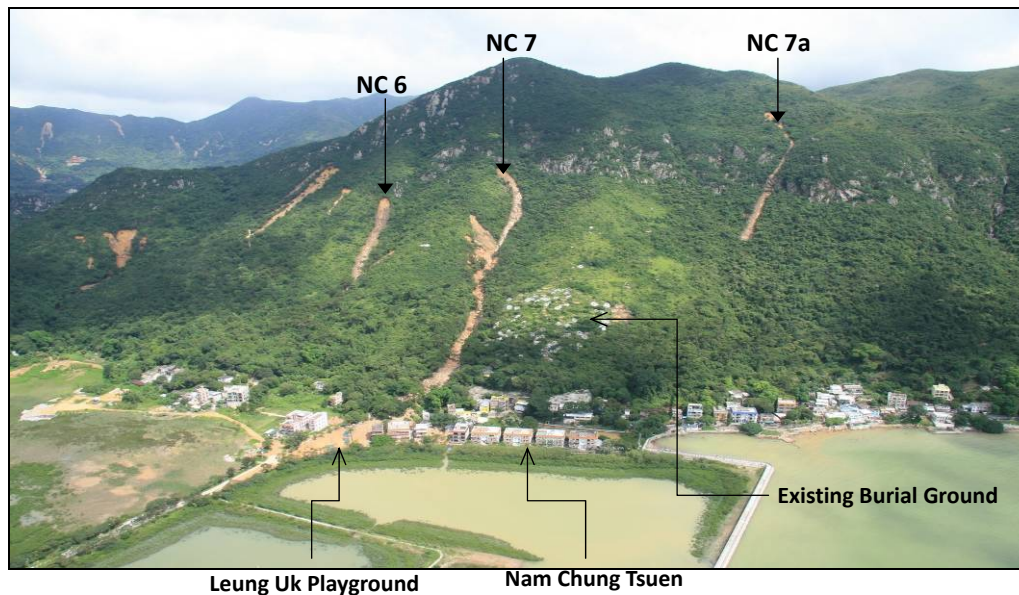


Plate 1: Landslide locations

## 3 THE EMERGENCY REPAIR AND LANDSLIDE RISK MITIGATION WORKS

The emergency works included removal of all loose materials and covering the failure scars at NC6 and NC7 with sprayed concrete and erection of a temporary safety barrier at the downstream area of NC7a. The subsequent landslide risk mitigation works mainly comprised of the installation of debris-resisting flexible barriers at NC6 and NC7a and construction of a reinforced concrete check dam and re-profiling of stream course at NC7. The risk mitigation works were taken on by the same contractor, not only because of its prior knowledge of the site but also the good partnership established during the construction of the emergency works.

A summary of the emergency repair and subsequent risk mitigation works to the three landslides at Nam Chung Tsuen is shown in Table 1. Location of the landslides and the works carried out is shown in Figure 1.

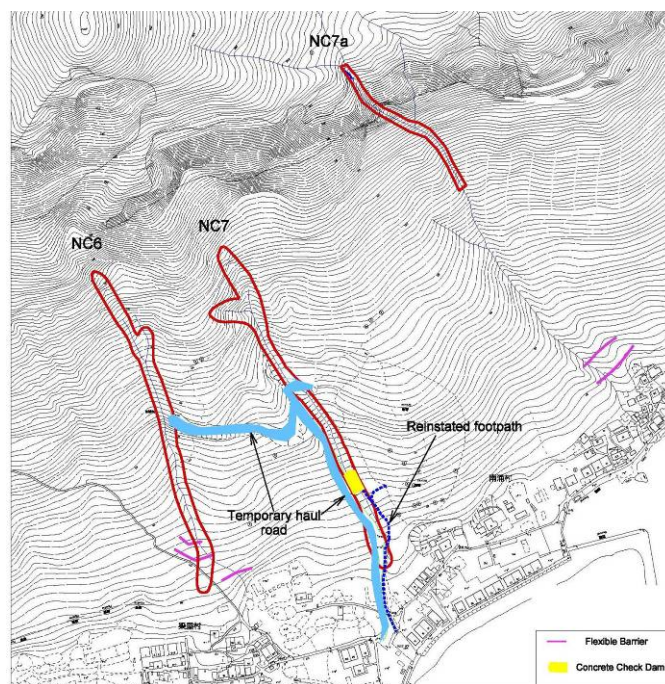


Figure 1: Locations of the landslides and the works carried out

Table 1: Summary of emergency repair works and landslide risk mitigation works for NC6, NC7 and NC7a

| Landslide No. | Emergency Repair Works                                                                                                                                                                                                                      | Landslide Risk Mitigation Works                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NC6           | <ul style="list-style-type: none"> <li>Removal of loose materials.</li> <li>Application of spray-concrete on failure scar surface on upper natural hillside (i.e. from about +60 mPD to +120 mPD and about 700 m<sup>2</sup>).</li> </ul>   | <ul style="list-style-type: none"> <li>Construction of 3 rows of 5 m high flexible barriers (total length about 85 m) with 56 anchored foundations and 11 steel baffles. The flexible barrier is capable of sustaining an impact energy of minimum 3,000 kJ and able to retain a debris volume of at least 450 m<sup>3</sup>.</li> <li>Greening works on sprayed concrete surface, including painting and provision of planter plots.</li> </ul>                                                                 |
| NC7           | <ul style="list-style-type: none"> <li>Removal of loose materials.</li> <li>Application of spray-concrete on failure scar surface on upper natural hillside (i.e. from about +60 mPD to +180 mPD and about 1,000 m<sup>2</sup>).</li> </ul> | <ul style="list-style-type: none"> <li>Construction of a 5 m high reinforced concrete check dam (about 18 m (L) x 10 m (W)) supported by 30 minipiles. The check dam is able to retain a debris volume of at least 600 m<sup>3</sup>.</li> <li>Re-profiling of stream course, including removal of the temporary haul road.</li> <li>Greening works on sprayed concrete surface, including painting and provision of planter plots, and landscaping works on check dam and re-profiled stream course.</li> </ul> |
| NC7a          | <ul style="list-style-type: none"> <li>Installation of temporary safety barriers at downstream area.</li> </ul>                                                                                                                             | <ul style="list-style-type: none"> <li>Construction of 2 rows of 5 m high flexible barriers (total length about 80 m) with 43 anchored foundations and 9 steel baffles. The barrier is capable of sustaining an impact energy of minimum 3,000 kJ and able to retain a debris volume of at least 450 m<sup>3</sup>.</li> </ul>                                                                                                                                                                                   |

#### 4 CHALLENGES ENCOUNTERED DURING THE CONSTRUCTION PHASE

In light of the nature of the works, remote location and various constraints of the sites, there were a number of challenges to be addressed and resolved by the project team during the construction phase. The major items would be discussed in the following paragraphs.

##### (i) Access

The works required were located at the upper level of the natural hillsides behind Nam Chung Tsuen, with a maximum height of approximately 200 m above the slope toe, and the failure scar surfaces were very steep. Shortly after GEO took up the site, the project team and the contractor realized that it would not be possible for the air compressors to have enough power and support shotcreting of the slip scar at the high elevation. In order to complete the emergency repair works as soon as practicable and allow early re-occupation of the evacuated village houses, it was necessary to form a temporary haul road, using the landslide debris and in-situ materials, alongside the buried stream course of NC7 to the upslope areas. A temporary lateral access was also formed between NC6 and NC7, at about +70 mPD, to facilitate the delivery of construction plants and materials for the emergency repair works and subsequent risk mitigation works at NC6. With the provision of the temporary haul roads, the emergency repair works at NC6 and NC7 were successfully completed in 6 weeks. The villagers were allowed to return to their evacuated houses, in accordance with the agreed schedule.

For NC7a, the failure scar was at a height over 220 m with no access. The formation of a temporary access from NC7 was not feasible due to the presence of an existing burial ground that separated the two landslides. The transportation of plants and materials to NC7a had to be carried out manually.

(ii) *Construction of Debris-resisting Flexible Barriers at NC 6 and NC7a*

For the remote site at NC7a, it was necessary to transport the plants and flexible barrier components manually to the works area located behind the terraced village houses through small village footpaths, private lots and heavily-vegetated slopes. The walking distance between the unloading point and the works was over 300 m. In addition to the 5m high by 80 m long steel wire mesh for the flexible barriers, the contractor was required to deliver 15 steel posts and 9 steel baffles, each about 1 tonne in weight, to the works area (Plates 2 & 3).



Plates 2 & 3: Manual handling of the wire mesh and steel baffle of flexible barrier at NC7a

It was necessary to deploy at least 6 labourers for the delivery of each of these heavy structural steel members. In addition, the contractor had to construct many temporary access and working platforms to bridge over the undulated ground profile and deep drainage channels for the delivery of materials. Tripods with hand-held lifting gears and blocks were also used to assist the fabrication and erection of the flexible barriers on site. The transportation of plants and materials to NC7a was very demanding for the labourers and progress of works was slow.

Unlike NC7a, the contractor was able to mobilize a small backhoe to the works area of NC6 to assist in the fabrication and erection of flexible barriers. In addition, the alignment of the flexible barriers was set on a relatively even ground profile (Plate 4). Hence, the construction of flexible barriers at NC6 was completed faster and with less difficulty as compared to that at NC7a.



Plate 4: Flexible barriers and baffles erected at NC6



Plate 5: The shotcrete at failure scar of NC6

### *(iii) Application of Sprayed Concrete on Steep Failure Scar Surfaces*

The emergency repair works mainly consisted of removal of all loose materials and application of spray-concrete to the failure scars (Plate 5). The major challenges in spray-concreting works were the substantial height of work (+180 mPD), steep failure scar surfaces and the need to complete the works within a very tight time schedule.

Due to the substantial height of the failure scars, it was necessary to transport 2 powerful air compressors with all required accessories to the upper hillside level through the temporary haul road to enhance the efficiency of the works. To allow early re-occupation of the evacuated village houses, the spray-concreting works were carried out continuously on shift basis 7 days a week until the completion of the works. As a result of the time pressure and long hours of work, a large number of the nozzle-men and labourers were sick. Some of them quitted their job due to the hardships of works in particular in the hot summer days and on-going rainy weather. There was a high demand for shotcreters necessitated by many emergency repair works as a result of the 7 June rainstorm and the contractor experienced great difficulties finding replacement workers.

### *(iv) Construction of Reinforced Concrete (RC) Check Dam*

To provide adequate sliding resistance to the RC check dam, a total of 30 raking minipiles were installed. Each minipile consisted of four T50 steel bars. A thick bouldery layer was encountered before reaching the bedrock level and Odex drilling method with permanent steel casing had to be adopted to avoid hole collapse. The drill bit was susceptible to jamming and damage in drilling through the bouldery layer. Considerable time and care had to be spent during the drilling process, frequent replacement of the drill bits and fixing the piling machine as necessary in an on-going basis.

One of the major constraints at NC7 was the concreting works for the check dam, which was located at a higher level of the natural hillside (+40 mPD). The only concrete supplier available in Lantau Island to serve the site was at Mui Wo, but they had only 8 concrete trucks available for delivery of the concrete. It would take at least 40 minutes for the concrete truck to deliver concrete from the batching plant to Tai O. In addition, the works area for concreting works at NC7 was very limited, and there was no space for the concrete truck to turn around. Therefore, the driver needed to reverse the concrete truck each time for about 100 m to the works area along the steep and narrow winding uphill temporary haul road. Due to the site constraints, it was estimated that concrete pouring of the 1.2m thick base slab of the check dam (about 250 m<sup>3</sup> concrete) would take 10 hours to complete.

To ensure the quality of the concreting works, casting of the check dam was carried out in several portions. At the time, the demand of concrete in South and West Lantau Island was very high due to various construction works, including other urgent slope repair and upgrading works, being carried out concurrently. The project team and the contractor maintained close liaison with senior management of the concrete supplier who subsequently agreed to reserve all concrete trucks on the dates of concreting of the check dam with adequate advance notification. With proper planning and sorting out of all necessary details beforehand, concreting of the check dam was completed in a smooth manner (Plate 6).

### *(v) Re-profiling of the Stream Course*

Another challenge was re-profiling of stream course at NC7, including removal of the temporary haul road. The original natural stream course was completely buried with the landslide debris and boulders. Many of the boulders were as large as 3m<sup>3</sup> spreading over the landslide trail. To reinstate the stream course to its original condition, the large boulders were broken up and the splitted rock blocks were used to form the embankment of the stream course (Plate 7).

However, breaking-up of the boulders and re-profiling of the stream course were a very tedious and

time-consuming process, and the works were behind schedule. To expedite the progress of work, additional excavators and backhoes were deployed to site by the contractor. With the additional plants and labour resources, the re-profiling of the stream course was back on track.



Plates 6 & 7: Completed RC check dam and re-profiled stream course at NC7

#### (vi) Community Feed-back Handling

While the local residents in Tai O was very appreciative of the prompt actions and timely completion of the emergency works that allowed the affected villagers to return home, there were a number of complaints and grievances, from nearby residents, against the dust and noise nuisances generated from the prolonged risk mitigation works. The project team ensured that frontline staff were fully aware of their roles and responsibilities, and were encouraged to resolve complaints on the spot. Briefings and trainings were conducted to ensure that the attitude and manner of frontline staff were always courteous and positive when they were dealing with the public. The contractor was also very co-operative in facilitating the liaison with local residents and implementation of additional improvement/control measures to their satisfaction.

The breaking up of large boulders in the stream course re-profiling work was a noisy operation and generated a large amount of dust. A number of complaints were received from nearby residents. The project team spent numerous hours to liaise and discuss with the concerned residents for re-arrangement of the works and implementation of additional control measures. To minimize the noise and dust nuisance, barriers and screens were erected around the point of work and water was sprayed regularly to suppress the dust generated. The villagers were satisfied with the prompt actions taken and control measures implemented.

The sprayed concrete surfaces at NC6 and NC7 turned the natural hillsides above Nam Chung Tsuen into an eyesore (Plate 5) which attracted numerous criticisms from the residents, tourists and a local environmental green group. Greening of the sprayed concrete scar surfaces was, therefore, included as a major item in the risk mitigation works in order to improve the slope appearance. Under the close supervision of a landscape architect, many trials had been carried out on site to determine the most suitable landscaping works on the sprayed concrete surfaces. Finally, the scheme entailing the use of khaki pattern painting with large planter plots on the sprayed concrete surfaces was adopted (Plates 8 & 9).

Because of the steep terrain, greening of the sprayed concrete surface was a difficult and time consuming process. For safety reasons, it was necessary to erect double layers of bamboo scaffolding on the scar surfaces in order to carry out the painting works, and remove part of sprayed concrete surface for plot planting. After the completion of these landscaping works, the two large eye-catching sprayed concrete surfaces disappeared and the scars had successfully blended in with the surrounding natural hillsides (Plate 10).



Plates 8 &amp; 9: Painting and planter plots at NC 6



Plate 10: Completed landscaping works on slip scars of NC6 and NC7

## 5 CRITICAL FACTORS FOR SUCCESSFUL COMPLETION OF THE WORKS

There were a number of factors that facilitated the successful and timely completion of the emergency repair and risk mitigation works. That included technical considerations to overcome site constraints such as early formation of the temporary haul road to upslope area. Above all, the main factor for successful completion of the works was the adoption of a full partnership approach between the project team, contractors, local residents, green group and other Government Departments throughout the process of planning, design and construction. Through close liaison and frequent meetings among the stakeholders, all major constraints were reviewed and differences resolved prior to commencement of work on site.

The risk mitigation works involved re-profiling of the stream course and construction of flexible barriers and concrete check dam on upper natural hillsides. The designer and project team discussed with the contractor on the preliminary design of the risk mitigation works, which was subsequently modified and fine-tuned to suit the actual site condition and site constraints, with significant input from the contractor. The manufacture of proprietary flexible barriers was being carried out in Switzerland and fabrication of the product including shipment to Hong Kong would take about three months. The main contractor worked closely with the specialist sub-contractors on flexible barriers and took the initiatives in making suitable

planning and arrangements in advance (e.g. prepare design submission and shop drawings, order materials, arrange resources, etc). While the contractors were working on flexible barriers, the project team focused on the design of the whole risk mitigation works for the three landslides, including issues on access, land requirements, programme of works and method of construction. The project team and the contractor worked as an united team, and joint decisions were made regarding the final location of various items of the risk mitigation works. In essence, the contractor became a member of the project team and they worked hand in hand in resolving problems encountered.

The local residents were actively involved during the construction of the risk mitigation works. With the assistance of District Office (DO), regular meetings were held on site and at DO's office to update the progress of works and associated details to the village representatives. The contractor was most co-operative and always promptly addressed the residents' concern related to the site activities and works. Through close liaison, some risk mitigation works were modified or fine-tuned taking into consideration the views of the residents. For instance, the damaged footpath to the burial ground on upper hillside was reinstated to facilitate the future maintenance of the check dam while providing a safer access for the villagers at the suggestion of the local communities.

Regarding greening of the sprayed concrete scar surfaces, the project team worked closely with a local Green Group. Many trials were carried out with their input. The hard work managed to turn a potential complainant into a working partner and all stakeholders were satisfied with the final greening and landscaping works on the sprayed concrete scar surfaces. Full commitment and devoted efforts by the project team in introducing an effective early liaison and maintaining close communication with the village representatives and all concerned parties proved to be invaluable, and the ongoing process helped to increase understanding and avoid unnecessary confrontation.

## 6 CONCLUSION

In the aftermath of 7 June 2008 rainstorm, GEO promptly mobilized its in-house project team and LPM contractors to undertake the emergency repair and risk mitigation works to the three landslides above Nam Chung Tsuen. Extensive shotcrete, flexible barriers and a check dam have to be completed at high elevation in a short time on inaccessible hillside amongst tense residents and alerted green groups. The project team worked with the communities and managed to cope with the situation. By adopting a full partnering approach, they won the goodwill and support of all stakeholders and successfully completed the works at Nam Chung Tsuen on schedule.

## ACKNOWLEDGEMENTS

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# Characteristics of Highways Department Roadside Slope Upgrading

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## ABSTRACT

To meet the Government's performance pledge, Highways Department had carried out Enhanced Maintenance Programme to deal with those man-made slopes and retaining walls constructed before 1978, which, given their locations, might affect major developments, squatters and major roads. As most of the Highways Department maintained slopes and retaining walls are located adjacent to commuter roads including high speed roads such as expressways, as well as the pedestrian sidewalks alongside them, a number of administrative procedures have to be followed through before slope upgrading works to the road side slopes are approved. As most of the Highway Department's slopes and retaining walls are located in urban areas, they presented challenges for both design stage and construction stage in the EMP.

The present paper primarily deals with the special issues encountered during the design stage of Enhanced Maintenance Programme, and site issues and constraints encountered during the course of the slope upgrading works in urban area and the appropriate measures taken on sites to tackle them.

## 1 INTRODUCTION

To meet the Government's performance pledge to deal with all pre-1978 high consequence man-made slopes and retaining, which may affect major developments, squatters, and major roads, Highways Department (HyD) had implemented Enhanced Maintenance Programme for roadside man-made slopes and retaining walls. As most of the features under HyD's maintenance responsibility are located at road sides and near to public, these presented challenging issues which needed to be address during the planning, designing and the construction of the upgrading works. This paper will focus on the special issues encountered during the planning and design phases as well as the constraints and problems encountered during the construction stage and the ways to tackled them under the Enhanced Maintenance Programme.

## 2 PLANNING AND DESIGN CONSIDERATION

As most of the features maintained by HyD were along roadside or footpath and close to the public, they presented special challenges during the planning and design stages and careful considerations were required to minimize nuisance to the general public and the road users. Two common characteristics shared by Highway Department's features are:

- (a) Adjacent to roads and footpaths
- (b) Close to public

Planning and design considerations related to these two characteristics are discussed below:

### 2.1 Features adjacent to roads and footpath

For features in close proximity of the roads and footpaths, careful considerations would be required during the planning and designing stages of the upgrading works in order to minimize the disturbance to the road users

and public during the construction works. When planning the extent of the works area for the upgrading works, avoiding closure of footpath and road were treated as high priority. Special construction method might be considered if feasible and cost effective, such as using hand drilling rig for soil nail construction to minimize the required working space in front of the feature.

However, if road / footpath closure was inevitable, proper temporary traffic diversion was planned. Liaison with Transport Department (TD) and Road Management Office of Hong Kong Police Force would be carried out in early planning stage so the design of the upgrading works could cater the comments from them. For some cases, only part time road closure would be allowed for certain road. Special measures would be designed. For the case of a cut slope at Clear Water Bay Road, single lane closure was only allowed during 10:00 a.m. to 4:00 p.m. on the weekdays. As a result, working platform could not be erected for soil nail installation at the lower portion of the slope as it would occupy one traffic lane. Innovative method of mounting the drilling rigs on a lorry had been planned so that the soil nail could be installed at the required height without using a working platform and the site setup could be clear on time before the reopening of traffic lane after working hour.

In order to minimize nuisance to public, Transportation Department would limit the numbers of land closures setup at a road, such as for the case at South Lantau Road and Tai O Road. During planning stage, attending Project Coordination Group Meeting would be required to liaise with other parties on the timing of the temporary traffic diversion. Careful planning would be required to avoid affecting the construction programme.

Besides seeking the views from government departments, it was equally important to consult general public. Early consultations with public via district councils, village representatives and District Office would be carried out to minimize nuisance to the public and avoid future complaints. For example, early discussion with village representative had been carried out to determine a suitable spot for temporary re-location of bus stop to reduce walking distance required by villagers. When designing temporary traffic diversion, public safety would place at the highest priority. Some previous example of safety measure adopted included proposing transparent hoarding at the road bend to allow adequate sight distance for road users seeing a head. Also, the opportunity of upgrading the existing roads / footpaths as part of the upgrading should be explored to provide added-value service to the public. Some of the common upgrading works included constructing railing and crash barrier along slope crest, and widening the existing footpath at slope crest as part of the upgrading works.

Underneath the roads and footpaths in Hong Kong, there were numerous utilities, which posed as constraints to the design and construction of the upgrading works. When designing upgrading works, it would be idea to avoid installed permanent works beneath existing roads. However, as one of the most effective upgrading methods for slopes and retaining walls was by soil nail, it would be difficult to avoid install soil nails beneath existing road. For such case, the soil nail should be designed to avoid clashing all existing utilities and also should be designed to allow a minimum 2m clearance between soil nail and the road surface to allow future laying of utilities. It would be important to liaise with the district division of HyD and utilities undertakers at early planning stage to obtain their comments as well as the utilities plans. Also, during the design of the upgrading works, the potential leakage of water carrying services beneath existing roads should be taken into consideration.

## *2.2 Close to Public*

Another common characteristic of HyD's Features was in close proximity to public, such as residential areas. During the design stage, it was critical to obtain land status plan from Lands Department to ensure the proposed works would not encroached into the private lots. When selecting the method of stabilizing the slopes and retaining walls, the anticipated nuisances to public from different construction method should be part of the considerations. Early liaison with the local residents would be conducted to address their concerned as far as possible. For example, strong objections from local villagers against adopting soil nail in loose fill as upgrading works for a slope near the Ancestral Hall due to Fung Shui issue had been resolved by changing the stabilization method to replacing existing loose fill with compacted fill.

As the most of the Highways Slopes and Retaining are prominent in public view, their aesthetic appearances were important design element. It was important that the proposed landscaping works should match with the adjacent environment with appropriate greening measures. Early consultation with Landscape Unit of HyD should be conducted to seek their valuable advices. The proposed upgrading works should avoid

felling existing trees as much as possible. Also, the adequate tree protection measures should be designed to protect the health of the trees from being deteriorated during and after the construction works.

### 3 CONSTRUCTION CONSIDERATIONS

Safety, environmental protection, traffic impact and construction duration were the key public concerns during construction stage. The major construction considerations from previous experiences of HyD slope works projects included excavation permit (XP), landscaping works, working near sensitive areas, underground utility and overhead cable, and traffic restriction would be discussed below.

#### 3.1 Excavation Permit

Excavation permit (XP) was required for excavation works carrying out in unleased government land under the Land (Miscellaneous Provisions) Ordinance (Cap. 28). The HyD was responsible for issuing XP for the excavation works within the existing roads and roadside areas.

XP was normally required for the slope works in HyD's features. Applicants were required to follow the guidelines of the Excavation Permit Processing Manual for application and administration of XP. The process included registration, case co-ordination, consents of government departments, issuing of XP, advance notification, audit inspection and report for completion.

The XP application was required to be registered on or before the minimum lead-time of 1 to 6 months depending on the location and duration of the excavation works. The XP Section would identify the conflicting works after receiving the registration. The applicant was then required to liaise with other applicants (i.e. case co-ordination) and report the agreed works programme to the XP Section. Consents of relevant government departments were also required in case the excavation works would affect the amenity area/old and valuable tree, traffic/pedestrian flow, or require night works or piling works. The XP would be issued once the case had been co-ordinate and the consents were obtained.

Advance notification was required before the commencement of works through the Excavation Permit Management System (XPMS). Audit inspections would be carried out by the audit inspection team of the HyD during construction. Non-compliances (NC) were commonly been identified in relating to poor quality on publicity board, site cleanliness, lighting, signing and guarding. The identified NC items were required to be rectified and reported to the XP Section as soon as possible.

The affected area was required to be reinstated upon completion of the slope works. Report for completion through XPMS was normally not required unless for some exceptional cases (e.g. permanent reinstatement was carried out by others).

#### 3.2 Landscaping Works

As discussed previously, most of the HyD's features were situated in eye catching locations. Landscape treatment such as planting of trees and shrubs, hydroseeding and applying stone facing were commonly used to enhance the visual effect. The Landscape Unit of HyD could be consulted during construction if necessary. The Landscape Unit would also offer advice to the maintenance section of HyD when taking over the new soft landscaping works. All dead trees identified on site were required to be removed before handing back the features to HyD.

Wall trees were sometimes been found in HyD's features, especially in Hong Kong Island. They were usually be maintained in view of environmental protection. An example of wall tree protection was described below.

A mass retaining wall was proposed to be constructed at Feature No. 11SW-A/R88 in Ladder Street, Sheung Wan, Hong Kong in June 2004. However, the proposed mass wall was in conflict with the tree roots of three numbers of existing wall trees as shown on Plate 1. It was proposed to remove part of the roots to facilitate the construction works. The Landscape Unit was then consulted and they requested the root pruning works to be carried out by specialist contractor and supervised by a chartered landscape architect. Furthermore, one year maintenance period was required after completion of the pruning works.



Plate 1: Proposed mass wall was in conflict with the roots of existing wall trees at Feature No. 11NW-A/R88 in Ladder Street (photo taken before works on 18 May 2004).

The root pruning works was carried out in three stages with one month after each stage. Some branches of the trees were also pruned in order to reduce water lost by evaporation. The trees were closely monitored and progress reports were submitted to Landscape Unit on monthly basis. The mass wall construction works was completed in May 2005. No abnormal sign (e.g. fallen leaves) was observed on the wall trees during the construction and in the maintenance period. The wall trees were still in good condition after five years of the construction works as shown on Plate 2.



Plate 2: Wall trees were still in good condition after five years of the works (photo taken on 7 February 2011).

### 3.3 Working near Sensitive Areas

Some of the HyD's features were located near to sensitive areas such as baby care centre, hospital, school and park. It was necessary to arrange site meetings with the responsible persons of the sensitive areas before the works in order to identify the site restrictions. Site safety and pollution control were the most important elements to be considered during construction. Restricted working hours might be required sometimes to

cope with the daily activities of the people in sensitive areas. An example of working near sensitive area was presented below.

Soil nails and concrete skin wall were proposed at Feature No. 11SW-B/R199 in Hong Kong Zoological & Botanical Gardens in Robinson Road, Hong Kong. It was necessary to fence off the children playground in front of the feature for construction, and storage of equipment and materials. The representative of Leisure and Cultural Services Department (LCSD) was invited to attend a site meeting before the works. LCSD requested the works to be carried out under the following conditions:

- (a) Part of the children playground had to be opened for public during construction;
- (b) The bird cage and children playground were very close to the works site, noise and dust should be minimized; and
- (c) No noise could be generated during the feeding time of the birds.

The following control measures were implemented in response to LCSD's comments:

- (a) The construction works was divided into two stages. Part of the children playground was opened to public while the remaining area was closed for construction at each stage.
- (b) Noise absorption material was installed in front of the bird cage and on top of the hoarding to reduce the noise level. A wooden enclosure and tarpaulin sheets were installed to prevent dust generation from drilling rig.
- (c) Soil nail drilling works was suspended during the feeding time of the birds.

#### 3.4 Underground Utility and Overhead Cable

Underground utilities such as electric cables, optical fibres, drainage pipes and watermain were usually buried underneath the carriageways and footpaths. As most of the HyD's features were located near the carriageways and footpaths, attention should be paid when carrying out excavation or drilling works. Damage of the underground utilities might cause fatal accident and economic lost.

Further to the findings during the planning and design stage, the alignment and depth of the underground utilities were required to be confirmed before commencement of the works. Detection of electric cables was required to be carried out by a Competent Person and according to the guidelines of the Code of Practice on Working near Electricity Supply Lines. In general, the following steps were adopted in utility detection:

- (a) Obtain latest utility plans from utility companies;
- (b) Locate the utilities on site by using electronic detector and trial pit method; and
- (c) Arrange site visit with the utility companies to identify the utilities on site.

The underground utilities were required to be protected during construction works. Damage of electric cables could be an offence under the Electricity Ordinance (Cap.406). The following control measures were usually been used for protection of the utilities:

- (a) Construction works were carried out with sufficient clearance from the utilities;
- (b) Hand tools in lieu of mechanical equipment were used when working near the utilities;
- (c) Temporary support was provided for exposed underground utilities;
- (d) Shoring was installed for excavation works near the utilities; and
- (e) Monitoring equipment such as settlement marker and vibrograph was installed.

Overhead electric cables might be found in the vicinity of some HyD's features. The protective measures between overhead and underground cables were significantly difference. An example of working underneath the overhead cables was illustrated below.

Soil nails were proposed at Feature No. 7SW-D/CR322 in Tai Wai New Village, Tai Wai, New Territories. Overhead cables supported by cable tower were found on top of the feature. The following safety measures were taken to protect the cables during construction:

- (a) Updated cable drawings were obtained from the China Light and Power Hong Kong Ltd. (CLP);

- (b) Joint site visits with CLP were arranged to obtain safety advice;
- (c) Minimum safety working distance was maintained;
- (d) Ground level barriers were installed;
- (e) Warning notices were display;
- (f) Gateways were installed for the passageway of plant and equipment; and
- (g) Signaler was assigned to guide the movement of plant and equipment.

### 3.5 Traffic Restriction

Temporary traffic arrangement (TTA) was usually required for the construction works of HyD's features with the following purposes:

- (a) Loading/unloading activities;
- (b) Used for working area; and
- (c) Used for storage area of materials and plants.

The TTA scheme was required to be submitted to the TD and the Hong Kong Police Force for approval before the works. TD and HKP might impose some conditions (e.g. restricted working hours, limited loading/unloading frequency, installation of infra red sensor for temporary traffic lighting, etc.) in the TTA consent. An example for implementation of TTA was illustrated below.

An L-shaped reinforced concrete retaining wall supported by mini-piles was proposed to be constructed at Feature No. 11SW-C/R62 in Peak Road, Hong Kong Island. It was necessary to close one of the two traffic lanes for the piling works. The works site was close to a signalized junction and a bus stop. The traffic flow was heavy during peak hours. TD required the TTA to be implemented only in non peak hours from 10:00am to 4:00pm in order to reduce the traffic impact. The contractor was required to set up and remove the traffic signs and cones each day. Trial run was conducted before implementation of the TTA scheme. The TTA set up was illustrated on Plate 3.



Plate 3: TTA for piling works at 11SW-C/R62 in Peak Road.

## 4 CONCLUSIONS

The planning, design and construction considerations mentioned above were required to be taken into account when designing and carrying out upgrading works for HyD's features. The Excavation Permit Processing Manual was required to be followed when application and administration of XP. The existing trees including wall trees were required to be properly protected during construction. The Landscape Unit of HyD might be consulted in case there was a site problem on landscaping issue. Close liaison with the responsible persons of

the sensitive areas was required before and during construction. Special arrangement might be required to meet their needs in some circumstances. Damage of underground utilities and overhead cables would cause serious accident and affect the works progress. All of these utilities were required to be located before commencement of the works and they were required to be protected properly during construction. Traffic impact such as temporary lane closure was required to be avoided whenever possible. Consents were required to be obtained from TD and Hong Kong Police Force before implementing the TTA scheme.

## **ACKNOWLEDGEMENTS**

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# Upgrading Catchwater Slopes in Hong Kong

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## ABSTRACT

AECOM Asia Company Limited (AECOM) was appointed by Water Supplies Department (WSD) to carry out design and construction of upgrading works since 2001 under various agreements not only for the safety of slopes but also for the safety of the catchwater system. The 2005 torrential rainstorm with breaching of catchwater in Tsuen Wan area highlighted the importance of the safety of the catchwater system including the catchwater slopes. WSD has started capital works projects for improving the existing catchwater system, stabilizing the sub-standard man-made slopes and providing hazard mitigation measures for natural terrains near the catchwaters where necessary. In recent years, AECOM has completed the design and construction of upgrading works for about 126 WSD slopes. A series of long-term enhancement maintenance programme involving slope upgrading and preventive maintenance, catchwater and natural hillside improvement works has been launched by WSD.

This paper briefly presents some key considerations during the design and construction of upgrading works based on AECOM's experience. The review of landslide and debris flood incidents, characteristics and typical upgrading works of catchwater slopes, and natural terrain hazards and mitigation works near the catchwaters have also been discussed.

## 1 INTRODUCTION

There are 45 catchwaters with a total length of about 120 km in Hong Kong. About 57 km of these catchwaters were constructed during the pre-war era. They are usually situated on natural terrain with numerous cuttings along the uphill side of the catchwaters together with downhill fill slope. The natural terrain above catchwaters is typically an undeveloped green belt overlain by vegetation, boulders and rock outcrops. There are more than 2,000 registered man-made slopes adjoining the catchwaters. They are normally designed and constructed to intercept surface runoff from the uphill natural terrain catchment. The collected water is then conveyed to the impounding reservoirs. The catchwater system was generally designed to cater for an average rainfall intensity of approximately 20 to 25 mm/hr with overflow weirs which were designed to discharge excess water from catchwater channel for a 1 in 200 years storm.

Catchwater may pose significant hazards when uncontrolled flows occur as a result of either breaching, or blockage and overtopping beyond the limits of designed overflow weirs. Some severe failures can trigger channelized debris flow leading to flood, damage or even pose significant risk of life at downstream areas. There are several notable catchwater-related landslide and flooding incidents which had caused disruptions to the general public including temporary evacuation of local residents, damage of structures, closure of traffic lane etc. in the past.

From overview of catchwater failures, most of the causes are related to catchwater blockage arising from debris slides from man-made cut slopes adjacent to and above the catchwater channels, debris flows from failures on uphill natural terrain, surface erosion from uncontrolled overbank flows of catchwater to downslope area and erosive flows from catchwater breach. Improving the stability of the slopes adjoining the catchwater channels is therefore an essential task to reduce the risk of catchwater failures.

## 2 REVIEW OF LANDSLIDE AND DEBRIS FLOOD INCIDENTS

### 2.1 Landslide and Debris Flood Incidents for WSD Slopes in 2005 and 2008

Landslide incidents data were retrieved from GEO Slope Information System. It was recorded that major landslide and debris flood incidents were occurred in 2005 and 2008 for the period from 2001 to 2010. There are 48 and 114 WSD man-made slope failure incidents reported to GEO in 2005 and 2008 respectively. 100% and 96% of landslides occurred in the wet season (i.e. between April and September) particular on the days of heavy rainstorms. The majority of landslides were mainly caused by intense and prolonged rainfall. A summary of reported landslide incidents in 2005 and 2008 is shown in Table 1.

Table 1: Summary of Reported Landslide Incidents in 2005 and 2008

|                                                                              | Year 2005 | Year 2008 |
|------------------------------------------------------------------------------|-----------|-----------|
| Total Nos. of Reported Landslide Incidents                                   | 48        | 114       |
| Nos. of Reported Landslide Incidents for Failure Volume $\geq 50\text{m}^3$  | 14        | 10        |
| Nos. of Reported Landslide Incidents for Failure Volume $\geq 100\text{m}^3$ | 7         | 7         |
| Nos. of Reported Landslide Incidents for Soil & Rock Cut Slopes              | 44        | 103       |
| Nos. of Reported Landslide Incidents for Fill Slopes                         | 4         | 11        |

In 2005, it was the third wettest year on record since 1947 and the annual rainfall of 3214.5mm was 45.2% above normal. The rainfall in June 2005 and August 2005 amounted to 1865.2mm, about 84% of the normal annual rainfall. 43 out of 48 landslides occurred in these two months. 2 landslip warnings were issued on 25 June and 22 August 2005. A summary of rainfall and reported landslide incidents in 2005 is shown in Figure 1.

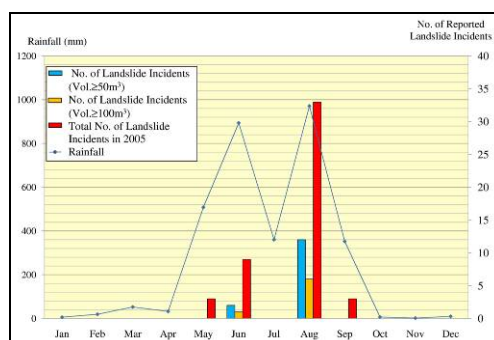


Figure 1: Summary of rainfall and reported landslide incidents in 2005

In 2008, the annual rainfall of 3066.2mm was about 29% above normal. The weather of June 2008 was marked by heavy rain and squally thunderstorms. The hourly rainfall of 145.5mm recorded on 7 June 2008 was the highest since record began. The monthly total of 1346.1mm was also a record high among all months since 1884. 82 out of 114 landslides occurred in June 2008. 5 landslip warnings were issued in April 2008, June 2008 and July 2008. A summary of rainfall and reported landslide incidents in 2008 is shown in Figure 2.

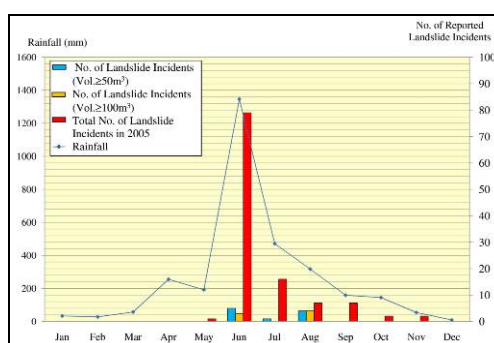


Figure 2: Summary of rainfall and reported landslide incidents in 2008

## 2.2 Landslide and Debris Flood at Lo Wai, Tsuen Wan

On 20 August 2005, a debris flow occurred at the Shing Mun Catchwater, north of Lo Lai, Tsuen Wan. The debris flow was probably triggered by major upslope landslide i.e. slope no. 7SW-A/CR134 involving a failure volume of about 600m<sup>3</sup>. Based on the investigation results, the probable cause of the debris flood and associated landslides was due to intense and prolonged rainfall and inadequate slope maintenance. The resulting blockage of the catchwater channel by the landslide debris from slope no. 7SW-A/CR134 caused the water in the catchwater to back up, resulting in large amount of discharges at the two upstream overflow weirs. The large amount of discharges of stormwater through the catchwater overflow weirs caused significant scouring of a streamcourse that was susceptible to erosion, which led to the development of a debris flood and damaged the pier of a footbridge. As a result of the incident, five squatter structures were recommended for permanent and compulsory evacuation. The incident also gives rise to temporary evacuation of 118 residents and 84 visitors to the temples and a temporary closure of a section of Lo Wai Road.

## 2.3 Landslide and Debris Flood at Route Twisk, Tsuen Wan

On 20 August 2005, another debris flow occurred at the Shing Mun Catchwater, Route Twisk, Tsuen Wan. The debris flow was probably triggered by a major upslope landslide on slope no. 6SE-D/CR249, involving a failure volume of about 50m<sup>3</sup>. A debris flood was caused by the debris from 6SE-D/CR249 similar to the Lo Wai case described above. As a result of the incident, one registered squatter structure was undermined and subsequently recommended for permanent evacuation. The incident also resulted in temporary closure for a section of Route Twisk.

## 2.4 Landslide at South East of Hong Kong Gun Club, Tsuen Wan

On 21 August 2005, a major landslide occurred at slope no. 6SE-B/DT15, Shing Mun Catchwater, Tsuen Wan. The failure volume was about 1000m<sup>3</sup> and approximately 15m catchwater was broken with water pouring down about 20m to the bottom of backscarp. Record photos of landslide are shown in Plate 1 and 2. No development or facilities were affected as a result of the landslide. Immediate remedial works including diversion of the flow from upstream side, laying of DI pipes along the broken catchwater, shotcreting the bare slope surface, sealing all observed cracks in the vicinity of failure areas, backfilling of no-fines concrete, construction of gabion structures for earth-retaining structure and installation of soil nails were proposed. Schematic arrangement of remedial works is shown in Figure 3. Based on the investigation result, the cause of the failure was possibly due to prolonged heavy rainfall to build up a high groundwater table and leakage from catchwater to the downhill side which led to the destruction of a section of catchwater by deep-seated slope failure.



Plate 1: General view of slope failure



Plate 2: Water scouring out the downslope area



Plate 3: As-constructed remedial works

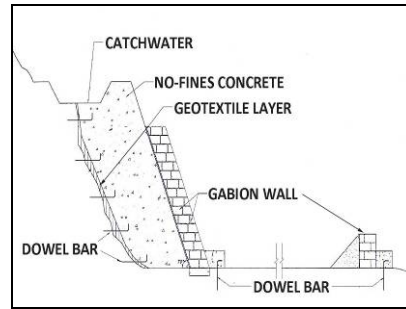


Figure 3 - Schematic arrangement of remedial works

### 3 CHARACTERISTICS OF CATCHWATER SLOPES AND TYPICAL UPGRADING WORKS

#### 3.1 Cut Slopes at Uphill of Catchwater

Cut slopes generally have a height of about 5m to 15m and a gradient of 50 to 65 degree to horizontal. Most of them are protected by rigid shotcrete cover and some have previous instability record.

Up to now, about 38 cut slopes at uphill of catchwater studied by AECOM were upgraded. Soil nailing technique is generally applied for improving the stability of these soil cut slopes. It offers greater advantages over re-profiling and other conventional retaining structures in terms of programme, cost, impact to environment and flexibility in stabilizing soil cut slopes along catchwater channel in view of site constraints of the catchwater system. In addition, it could minimize disposal of C&D materials which does not only reduce the burden of public fill bank but also avoid felling of the existing trees.

Convex upslopes are common along catchwaters and special attention shall be paid to its design where the orientation of soil nails shall be carefully designed to avoid clashing each other.

To improve the visual impact of upgraded slope and to blend with the natural environment, hydroseeding with shrub seedling and other special greening techniques were applied on the final slope surface.

#### 3.2 Fill Slopes at Downhill of Catchwater

Fill slopes generally have a height of about 5m to 25 m and a gradient of 30 to 40 degree to horizontal and some of them are retained by masonry wall at slope toe. They are generally covered with dense vegetation. Based on the ground investigation results available for about 24 fill slopes at downhill of catchwater studied by AECOM, it revealed that the existing filling material was not adequately compacted to the current standard and thus, appropriate upgrading works were considered necessary.

The methods of upgrading works for the fill slopes include replacement and re-compaction of the existing fill material, thickening of the existing masonry wall, construction of concrete toe wall, soil nailing with grillage or concrete slab, etc.

To improve the visual impact and to blend with the natural environment after slope upgrading works, the fill slope surface was treated by hydroseeding, planter bags with shrubs and planter wall at slope toe where considered necessary.

#### 3.3 Design Groundwater Table

The groundwater level was designed for a 1 in 10 rainfall return period. However, it was generally assumed to be 1/3 of the slope height when it was measured in dry condition for one complete wet season.

### 4 SITE CONSTRAINTS AND SPECIAL CONSIDERATIONS

#### 4.1 Clearance Application

For catchwater slopes near village areas including squatter, licensed structures, grave, plants and crops and the like, these may be required to be cleared to make way for the proposed works. Land resumption and clearance

procedures are lengthy in which re-housing of the occupants at risk is needed. Thus, sufficient time should be allowed in the programme for land clearance. The estimated time for site handover is generally about 20 months from the submission of the final Clearance Application Form subject to no substantial changes in the project boundary.

#### *4.2 Ecology and Environmental Review*

Some rare or protected plants and animals are known to exist in the vicinity of the catchwater channels and catchwater tunnels. For examples, bats occupying the water tunnel systems and pitcher plants alongside the catchwater channels are to be protected. Qualified ecologists are engaged to visit the sites regularly throughout the course of the slope upgrading works to ensure minimal disturbance to the surrounding habitats. A detailed ecological assessment should be carried out to evaluate the potential impacts on the ecology of the study feature from the proposed works in the early design stage. The locations of plant species in the interest of conservation should be identified and mitigation measures to alleviate potential ecological impacts arising from the proposed works should be taken prior to the commencement of works.

For vegetated slopes within country parks, the proposed slope upgrading works may be considered as a designated project under EIAO (Cap. 499) and environmental review based on field study during the investigation and design stage to find out if the proposed works will have any adverse ecological impact may be needed.

#### *4.3 Traffic and Site Access*

Catchwaters are usually situated at the middle of natural terrain. Although vehicular access is generally available, it is a single lane access road with passing bay facility only. Temporary traffic arrangement (e.g. STOP/GO traffic control) may be required to divert or ban incoming traffic from the access road to mobilise machinery, excavation, and removal of C&D materials. To better share the catchwater access road with other road users, frequent liaison meetings with village representatives should be made so as to ensure programme of works is not affected.

Due to limitation on the width and capacity of the access road, it may not be possible to deploy heavy machinery or large truck onto the works site. Special-made 'mini-cartage' can be deployed for transportation of materials on some occasions. Sometimes, helicopter service may be required to transport materials for some remote areas. Thus, construction methods have to be reviewed in order to minimize the use of access road under special circumstances.

#### *4.4 Working Space*

There is often limited working space and storage area available for catchwater slopes. Temporary working platforms are necessary for upgrading works. It shall be designed to provide access for visual inspection and to the channel itself.

#### *4.5 Interface with Villagers*

The views of the villagers shall be solicited prior to the works commence. The structural appraisal and condition survey of nearby squatter and its surrounding area, if necessary, shall be made to avoid unnecessary conflict with the residents during construction.

#### *4.6 Existing Utilities*

Presence of existing utilities shall be thoroughly investigated to avoid damages due to the proposed works during the ground investigation and design stage. In addition, allowance should be made in the cost estimate and works programme to take into account the possibility of localized diversion of uncharted utilities.

#### *4.7 Tunnel Reserve Zone*

The Tunnel Reserve Zone may prohibit the use of soil nails and limit the depth of excavation of the proposed

works. Consent for works from WSD should be obtained and all requirements imposed by WSD should be strictly followed.

#### 4.8 Water Gathering Grounds

The “Conditions for Working within Gathering Grounds and Conditions of Working in the Vicinity of Waterworks Installations” imposed by WSD should be abided at all time during construction of the slope upgrading works. All pro-active control measures to reduce pollution of the country park environment and water sources should be strictly enforced.

### 5 NATURAL TERRAIN HAZARDS AND MITIGATION WORKS

Study and mitigation of natural terrain landslide hazards affecting catchwater have been carried out in order to keep the natural terrain landslide risk to a level that is as low as practically achievable in the past. Nonetheless, it may not be realistic to deal with all natural terrain hazards and landslide problems affecting catchwater in the short run. In fact, stabilization works to large areas of natural terrain will be both impractical and environmentally damaging. It has been current practice to deal with natural terrain hazards based on the “react-to-know” principle as stipulated in GEO circular No. 28 – Study and Mitigation of Natural Terrain Hazards, i.e. detailed natural terrain hazard study and mitigation actions are required only when there are immediate and obvious hazards such as signs of distress, evidence of continuing hazardous movement or recipient instability that could affect the performance of the catchwater system.

Natural terrain hazards are to be identified and examined to determine the extent of risk from landslide, debris flow or boulder fall in accordance with GEO Report No. 138. Mitigation measures including in-situ stabilization and boulder fence are considered favourable options to protect the catchwater from blockage. However, they may create considerable visual and landscape impact and shall be properly engineered to blend with the surrounding natural slopes visually.

### 6 CONCLUSIONS

AECOM has successfully completed a number of slope upgrading works for WSD slopes adjoining catchwaters, access road or WSD’s facilities which generally have their own characteristics. Particular attention shall be paid to carry out detailed design to best suit with the site condition and facilitate the future operation and maintenance. Especially for the catchwater slopes which may fall within Country Park or ecologically sensitive area, it is essential to identify any adverse impacts on the study feature from the proposed works and to design to visually blend with the surrounding countryside. Site safety and environmental considerations are also the key issues for the upgrading works. Precautionary measures including provision of a 3m high safety fence with dust screen and noise barrier encompassed the works area, an effective temporary drainage system and suppression of dust emission during the drilling operation were implemented to prevent nuisance caused to the public and pollution of the water flowing along the catchwater during construction.

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# Science, Engineering Geology and the Landslip Preventive Measures Programme

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## ABSTRACT

This paper examines the core skills of engineering geologists and how their training experience, knowledge and, more importantly, their philosophy differs from, and is complementary to, geotechnical engineers. The paper considers the engineering geological input to the LPM programme, in particular the use of engineering geological models. Finally, the paper outlines areas where engineering geological input can improve the current approach to natural terrain hazard studies carried out under the LPM Programme.

## 1 INTRODUCTION

The relationship between engineering geology and geotechnical engineering is often misunderstood. The resulting confusion can have significant implications for engineering projects. This paper aims to address this misunderstanding, highlight areas where insufficient engineering geological involvement in the Landslip Preventive Measures (LPM) Programme could lead to problems, and describes how engineering geologists can contribute to the success of the programme. Science and the scientific method are first discussed, engineering geology is defined and then engineering geological inputs to the new Landslip Preventive and Mitigation Programme (LPMitP) are discussed. Finally, recommendations for improvement are suggested.

## 2 SCIENCE AND THE SCIENTIFIC METHOD

When science is undertaken with a practical objective, it is called applied science, the application of the science of geology to engineering problems is called engineering geology.

There are many definitions and descriptions of science and the scientific method. McClelland (2006) states that *'Science is a methodical approach to studying the natural world. Science asks basic questions, such as how does the world work? How did the world come to be? What was the world like in the past, what is it like now, and what will it be like in the future? These questions are answered using observation, testing, and interpretation through logic.'* McClelland goes on to state that the scientific method *'...is not a recipe: it requires intelligence, imagination, and creativity. In this sense, it is not a mindless set of standards and procedures to follow, but is rather an ongoing cycle, constantly developing more useful, accurate and comprehensive models and methods. The scientific method is a form of critical thinking that will be subjected to review and independent duplication in order to reduce the degree of uncertainty. The scientific method may include some or all of the following "steps" in one form or another: observation, defining a question or problem, research (planning, evaluating current evidence), forming a hypothesis, prediction from the hypothesis (deductive reasoning), experimentation (testing the hypothesis), evaluation and analysis, peer review and evaluation, and publication.'* As such the scientific method is not a check list. The natural world is too complex to have a standard process as every enquiry is unique. A key aspect of the scientific method is that multiple working hypotheses may be held simultaneously, with many tentative theories and the expectation that no single theory will provide all the answers.

As scientists, geologists use hypotheses and understand that there is generally no single ‘answer’. By their very nature hypotheses, which may be well supported by evidence, are never proven. So what geologists seek is a story, not just a conclusion. One way to develop and test hypotheses and to tell a “story” is by using models, as will be discussed later.

### **3 WHAT IS ENGINEERING GEOLOGY AND HOW DOES IT DIFFER FROM GEOTECHNICAL ENGINEERING?**

The IAEG Statutes (1992) provide the following definition ‘*Engineering Geology is the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of man as well as to the prediction and of the development of measures for prevention or remediation of geological hazards.*’

Therefore on the basis of the previous section and the IAEG’s definition, an engineering geologist can be defined quite specifically as someone who has been educated as a geologist, receives additional education and training in the application of geology to engineering and applies that knowledge as their profession. As such the engineering geologist is first and foremost a scientist. However, they must also have an understanding of their responsibilities and a commitment to professional ethics.

Baynes (2003) suggests that the engineering geologist has five generic responsibilities:

- Observation and investigation of the geology in engineering projects
- Engineering geological model development
- Establishing standards and scope for the engineering geological activities
- Engineering geological information management
- Communicating the geology to engineers

The observation and investigation, along with the development of the engineering geological model, is how the engineering geologist puts the scientific method into practice. The model selected as a basis for analysis and design should be as simple as required to explain the observations and should communicate the key information and uncertainties. This requires the engineering geologist to determine the appropriate level of simplicity, what information is critical to the success and safety of the project and what information can be omitted. The engineering geologist’s responsibility for the communication of information requires that they acquire sufficient education, training, knowledge and experience to understand engineering terminology and the requirements of geotechnical design. They must use this understanding to ensure that the key aspects of the geology are effectively communicated to the geotechnical engineer.

Whilst scientists explore and discover new knowledge about the natural world and its workings, engineers use their abilities to solve problems, with an eye toward optimising cost, efficiency and technical elegance. These aims often require that the engineer sets up clear and logical systematic approaches to problems.

There are many superficial similarities between engineering geology and geotechnical engineering. This often leads to the mistaken belief that the disciplines are almost synonymous. However, the difference between the two disciplines extends beyond simple knowledge of engineering or geology, it is philosophical - being how each thinks rather than what each does. The difference is exemplified by the scientific method used by engineering geologists versus the systems-based approach typically used by engineers, together with the geologist’s comfort with qualitative information contrasted with the engineer’s need for quantitative data.

Whilst engineers and geologists have a different approach, they should be ideally matched to bring their respective strengths to geo-engineering problems. Unfortunately, the relationship can be far from perfect. The reasons for this include:

- Some who describe themselves as engineering geologists have insufficient geological knowledge .
- Some who describe themselves as engineering geologists have insufficient engineering knowledge to communicate effectively with engineers.
- Some *geotechnical engineers* may believe they possess enough geological knowledge to dispense with the input of an engineering geologist. However, as noted by Baynes *et. al.* (2003), ‘*one of the fundamental problems with geotechnical engineers is the often huge gulf between the ground models they use for analysis and decision-making, and those that can be regarded as realistic models.*’

- *The potential for conflict to exist due to the fact that the engineering geologist recognises that the geological conditions of each project are unique and a standard process is not appropriate, whereas the geotechnical engineer requires clear systems to achieve their aims.*

We now consider the application of the scientific approach in engineering geology i.e. the use of models.

#### 4 ENGINEERING GEOLOGICAL MODELS

The starting point for the engineering geological model is not the geology but the engineering (IAEG, 2011). For the same geological setting, different engineering projects will require different questions to be asked, different models to be developed and different investigations to be carried out. Certain engineering geological parameters may be more critical than others and some projects are exposed to more geological risk.

The better the model reflects actual conditions, the lower the risk. Unfortunately, it is not possible to define every detail of the ground and so the objective of an engineering geological model is to provide appropriate detail and understanding of the ground.

As important as the known ground conditions, are the unknowns. The unknowns of the model should be recorded so that they can then be factored into further investigation or into the engineering for the project, for example, through contingency planning. Unknowns that are not identified are those of most concern, as these can result in the non-conformance or even failure of the engineered structure.

IAEG (2011) notes three types of engineering geological models:

- *The conceptual model:* this is the first model produced and provides input for conceptual design. It generally uses existing data such as geological maps and memoirs, topographical maps, aerial photographs and published information. However, engineering geological precedence and experience are critical to allow the evaluation and synthesis of such data.
- *The observational model:* this is usually developed on the basis of a site investigation, which should be targeted to address the potential unknowns identified in the conceptual model. As such, the unknowns associated with the model at this stage should be reasonably well defined and limited. The observational model typically provides information that can be used at the schematic design stage.
- *The analytical model:* this provides specific input to the detailed design. This model may be a simplification of the observational model or may be based on further specialist investigation including *in situ* and laboratory testing. The model will need to be in a simplified form suitable for engineering analysis and therefore considerable engineering geological judgment is required to ensure that a representative ground model is analysed.

As with the scientific method, the model approach is not a rigid process. Rather it is a framework for investigating engineering geological problems.

The model approach is an extremely powerful tool. As noted by Knill (2001) *‘the role of the geological modelling making process is seen as a way in which complexity, and the distribution of geotechnical properties can be resolved. In recognising that “risk must be managed to overcome limitation of site characterisation, knowledge of material properties, other unknowns and the vagaries of construction practice” the role of the engineering geologist is seen as being elevated to the role of risk manager through geological model-making.’*

#### 5 ENGINEERING GEOLOGICAL MODELS AND THE LPM PROGRAMME

The LPM programme requires the evaluation of engineering geological aspects and the incorporation of the pertinent findings. However, concerns were raised almost 10 years ago that the necessary competency in engineering geology was not being used (SSTRB, 2000). An initial review of LPM practice for *‘major geological deficiencies’* (which were considered a *‘non-compliance’*) was undertaken in 2002 which concluded that whilst no non-compliances existed *‘in all cases the geological model adopted for design was very simplistic’* and that *‘no account was taken of variations in lithology or structure of three-dimensional variations within the geological model’* (GEO, 2004).

Similarly a review of landslides between 1997 and 2001 noted that *‘the use of an over-simplified geological and/or hydrogeological model which does not adequately cater for safety-critical features in the ground is the most important cause of major failures of engineered cut slopes’* (GEO, 2003).

A more detailed review of 11 LPM sites was then undertaken (GEO, 2004). This comprised two approaches; a *Process Audit* and a *Model Audit*. The Process Audit was based on the GEO’s internal operation procedures and simply evaluated whether there was recorded evidence that a task had been undertaken. The checklist comprised 16 items, so a total of 192 checklist items were audited at 11 sites with only a single non-compliance.

However, such a check list approach clearly does not evaluate how well a task was undertaken. Consequently, a model audit approach was also adopted, whereby an engineering geological model of each site was developed and the audit undertaken on the basis of evaluating against best practice. This was undertaken in phases to reflect the different stages of the LPM. A conceptual model was generated based on published geological and existing ground investigation (GI) data. A site reconnaissance was then undertaken and this, combined with the conceptual model, was used to design a hypothetical GI for the site. This GI was evaluated and where possible inspections were undertaken during slope upgrading works. On this basis an observational model was then generated, which was compared with the Stage 3 Study Report for each slope. The advantages of this method over the Process Audit are that it is comprehensive, site specific and allows the quality of the work to be evaluated. With respect to the LPM, the audit indicated:

- The general lack of pertinent engineering geological observations and subsequent interpretation during the aerial photographic interpretation, and so common failure to take account of the geological and geomorphological setting of the site.
- The common lack of a clearly stated strategy for GI, which do not fully address geological uncertainties.
- The variable quality of GI data with respect to material and mass descriptions;
- The use of over simplified geological models, and therefore the potentially unrepresentative geotechnical models adopted for design.
- The limited information presented to demonstrate that the adopted design approach was verified by pertinent engineering geological observations during construction.

Table 1: Differences between man-made and natural slope investigations, after Parry & Hart (2009)

| Man-made Slope Assessment                                                             | Natural Slope Assessment                                                                                                                                       |
|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Site of limited extent                                                                | Sites have a large extent, often comprising multiple catchments                                                                                                |
| Ground investigation stations are closely spaced                                      | Limited scope for GI given large site and difficult access, means it is essential that GI is located in critical areas                                         |
| Exposures are available either before, during the GI, or during construction          | Exposures are limited to rock outcrop, landslide scars and drainage lines                                                                                      |
| Considerable amount of published data on geotechnical properties                      | Relatively limited data on the behaviour of natural landslides in Hong Kong                                                                                    |
| It may be appropriate to use simple classification of material types e.g. “colluvium” | Simple classifications are inappropriate. Classifying the superficial deposits requires an understanding of landscape evolution and geomorphological processes |
| Well developed software for slope stability analysis                                  | Software programmes are of limited use for catchment wide applications                                                                                         |

However, Hong Kong is fortunate that it has considerable funds available for slope safety and consequently *‘robust’* slope designs are undertaken (GEO, 2003). As such, many of the engineering geological uncertainties discussed above, arising due to a lack of engineering geological input, were apparently overcome by the use of robust designs. However, the LPM has moved into a new phase and is gradually switching its attention from man made slopes to natural terrain (Chan & Mak, 1997). As discussed

by Parry & Hart (2009) there are considerable differences between man made slopes and natural slopes (Table 1).

Given the above factors, the “robustness” available to minimise engineering geological uncertainty, and therefore engineering risk, with regards to natural slopes is considerably reduced. Engineering geological uncertainties can no longer be relegated or ignored.

## 6 KEY AREAS FOR IMPROVEMENT OF THE LPMitP

The importance of engineering geological models in the LPMitP has been discussed elsewhere (Parry & Ng, 2010; Parry & Hart, 2009). This paper considers best practice as well as areas of concern with regards to engineering geological models.

### 6.1 Conceptual Engineering Geological Models

The *design event approach* (Ng *et al.*, 2003) was developed to allow rapid evaluation of the likely magnitude and frequency of possible hazards a site faces and therefore allow cost implications and alternative layouts to be considered at an early stage (Parry & Ng, 2010). It is undertaken as part of the desk study and forms the framework of a conceptual model in Hong Kong. Ng *et al.* (2003) refer to the desk study stage as a Natural Terrain Hazard Review (NTHR). In the latest LPMitP briefs it is referred to as a Desk Study Working Paper (DSWP). This change followed feedback to GEO, the purpose being to emphasise the need to evaluate and synthesise the data and generate a conceptual model.

However, there still appears to be a misconception that the DSWP is simply a data gathering exercise and consequently it is commonly undertaken by junior staff, often with insufficient guidance. This can result in very large reports, containing exhaustive factual information, with limited synthesis and therefore inadequate models.

A DSWP should be, to all intents and purposes, a conceptual engineering geological model. It should discuss the data sets that have been used, but this should be in terms of the relevance to the project and the uncertainties associated with them. The main purpose of the DSWP should be the synthesis and evaluation of the data with respect to natural terrain hazards. Geological maps and memoirs should be used to establish the likely geological setting and likely variations that may affect the engineering geological conditions. Existing GI data should be evaluated and if necessary re-interpreted (Parry & Hart, 2009; Parry, 2010). A commonly used data set is the Enhanced Natural Terrain Landslide Inventory (ENTLI). However, the limitations of which are well documented (Parry & Ng, 2010) and therefore, in the authors’ opinion, the ENTLI is not a suitable landslide inventory for the development of a conceptual model.

A key component of the conceptual model is a detailed aerial photograph interpretation (API). This is not simply a site history as used for man made slopes, which is of limited value for natural terrain. Instead, the API should have three key purposes; the generation of a landslide inventory, initial engineering geological (incorporating geomorphological) mapping and evaluation of terrain evolution. The combination of these three components forms the corner stone of the conceptual model for NTHS projects in Hong Kong.

*Landslide inventory*, this should be used to supersede the ENTLI data. It should also interpret landslide source areas and, where possible, identify landslide debris. A detailed API also allows landslide source volumes to be estimated and a relative degree of certainty applied to each feature interpreted to be a landslide. The identification of debris lobes provides clear evidence of the occurrence of landslides within a catchment, as well as providing information on run out distances (Parry *et al.*, 2010). Territory wide LiDAR coverage of Hong Kong has now been obtained by GEO and this will prove an invaluable data set to assist API in areas of dense vegetation. However, LiDAR only complements API, it does not replace it.

*Initial engineering geological mapping* should aim to assess landforms, materials, ages and processes (GEO, 2004) and provide a rational basis for the initial GI design. This enables a realistic GI cost to be estimated at an early stage of the project. However, the final GI design will depend upon the results of the detailed field mapping. Therefore, it is essential that the investigation programme is flexible to ensure that the key uncertainties can be investigated.

*Terrain evolution* is the identification of terrain units based on land surface evaluation (Griffiths, 2001). Terrain units (Parry, 2010) reflect landscapes with different ages of development with different processes acting upon them, both in the past and now. These form ‘*areas within which certain predictable combinations*

*of surface forms and their associated soils and vegetations are likely to be found'* (Cooke & Doornkamp, 1990). As such, terrain units typically have unique landslide magnitude-frequency relationships, and therefore they provide the framework for evaluating the appropriate landslide source volumes from which the associated hazards can be assessed.

The evaluation of uncertainties, and their formal documentation, should be a key function of the DSWP. Geological uncertainty registers (Knill, 2001) should then be prepared and updated throughout the various stages of the study (e.g. DSWP, field mapping, GI). The identification of uncertainties and their investigation during the subsequent phases of the study provides a transparent and methodical approach to the management of geological uncertainties. It also allows any unresolved uncertainties to be transferred to geotechnical risk registers during the design and construction phase. Given the nature of geological uncertainties, some will generally remain and should be discussed and recorded in the final report.

The engineering geological model, the assumptions, the remaining uncertainties and their investigation should be the focus of a technical review at this stage. If this is undertaken the DSWP becomes a powerful tool, allowing the early assessment of potential hazards and the requirement for mitigation works. If this is not undertaken the DSWP merely becomes a repository of factual data which will be of limited value in the LPMitP process.

## 6.2 Observational Engineering Geological Models

Even the most carefully developed conceptual model will contain significant uncertainties in terms of landslide magnitude, age (frequency), potential entrainment and mobility. Observational models differ from conceptual models in that they are based on site specific field verified data, typically in the form of engineering geological field mapping and GI.

Given the limitations of API, landslide features should be field inspected to allow for their confirmation and a more accurate estimation of source volume, the evaluation of the failure mechanisms and assessment of the mobility. The field mapping also allows the identification of landslides which are not evident from API. In addition to landslide verification, the mapping should identify past and current geomorphological processes and evaluate the terrain units of the conceptual model and their associated engineering geological conditions.

The key uncertainty to be addressed as part of the observational model is what is the appropriate landslide volume and notional return period (i.e. magnitude and frequency) for design. As discussed, the design event approach was developed to enable a rapid evaluation at the planning stage. However, such an approach can be applied overly simplistically for design purposes. For example, what if the study area contains no landslides - does this imply that landslides do not occur, or do they have a relatively long return period? If landslides are present, but are of a limited volume, are these a sufficient basis for the design event or is there a larger, but less obvious, landslide failure mechanism that could occur? How is subsequent entrainment assessed? Specific problems include:

- (i) The aerial photographic record in Hong Kong typically covers the last 50 years, which is insufficient to allow a reliable estimate of an event with a return period of 100 years. To estimate the return period for 100 years with 95% reliability requires 115 years of records. The period of time necessary to determine of a 1000 year return period event has occurred with the similar probability is in the order of 6000 years (Lee & Jones, 2004).
- (ii) Many "relict" landslides are likely to be considerably older than 1000 years. Limited age dating undertaken on large landslides has returned ages as old as 30,000 years BP (Sewell & Campbell, 2005).

The Authors consider that while the design event approach is suitable for the conceptual model, a more complete evaluation of magnitude and frequency should be undertaken, such as the approach adopted in Australia (AGS, 2007) for the observational model and beyond. Such an approach will assist in bridging the gap between the Design Event approach and Quantitative Risk Assessment (QRA).

GI is required to complement detailed engineering geological mapping. Unfortunately, some practitioners consider that a NTHS can be undertaken without any GI. Whilst this may be the case for small and engineering geologically 'simple' sites, this is typically not the case with natural terrain studies. The cost of GI in areas of natural terrain is now relatively expensive with changes in health and safety regulations requiring access scaffolding to trial pit locations and remote drillhole locations often requiring helicopter

mobilizations. Consequently, each GI location must be carefully selected to maximize the information it will provide.

In order to obtain data to evaluate landslide hazards it is frequently the poorest ground which is the most relevant to investigate. Large diameter, triple tube barrel (4C-MLC) drillholes with air foam flush are required within the commonly boulder rich landslide debris and continuous Mazier sampling, with subsequent splitting and logging, should be employed within saprolite. Given the spatial and often subtle variations in superficial deposits, as well as problematic drilling conditions, trial pits and trenches should also be undertaken in order that detailed records and subsequent interpretation can be undertaken.

The standard GI approach adopted in Hong Kong, in which the GI contractor produces logs in accordance with Geoguide 2 (GCO, 1987), is not considered appropriate for NTHS. GI contractors are at a distinct disadvantage when preparing logs as they have no knowledge of the engineering geological model for the site. Nor will they be aware of the results of the detailed engineering geological mapping. Furthermore, they will not have the results of the detailed logging of split mazers and can only produce a log based on samples from the mazier cutting shoe. Finally, they have little experience or knowledge of the interpretation of geomorphological processes which are so critical to the interpretation of superficial deposits. Therefore, the authors recommend that the engineering geologist undertaking the assessment should log the material and these logs should be used as the basis for the NTHS.

It seems to be increasingly common that to meet project milestones, NTHS reports are submitted, and even the results presented to the Government checking panel on natural terrain, before the GI information is complete and the results reviewed. This practice results in a higher degree of uncertainty and may result in the design events adopted being superseded following GI. This is inefficient, potential confusing and is not best practice. Consequently, it is recommended that project programmes on future studies are modified to incorporate flexibility to avoid such situations.

### 6.3 Analytical Models

The key analytical model for NTHS is related to debris mobility modelling. The main contribution of engineering geology to debris mobility models includes:

- Providing site-specific data with respect to drainage line characteristics, in particular the most applicable channel geometry to adopt for channelised debris flows;
- Potential entrainability of the substrate;
- Determining the possibility of secondary failures, and
- Examining evidence from historical landslides, in particular recording field evidence of debris height and super elevation, for mobility back analyses.

All of these factors are dependent upon careful field observations. For example, the failure to distinguish between run-out distances of remoulded landslide debris and outwash material could result in significant errors in the back analysis of the landslide event.

Without site specific back analysis for landslides, generic mobility parameters must be adopted for analyses. In Hong Kong, the parameters recommended by Lo (2000) are most commonly used. However, the number of landslides these are derived from are small and are largely based on the work of Hungr (1998) who analysed 10 landslides of which only two were natural terrain landslides (one channelised one non-channelised) and the work of Ayotte and Hungr (1998) who analysed 20 landslides of which 16 were natural terrain and 6 were classified as channelised debris flows. As such, there is a limited amount of data with respect to the mobility of natural landslides, in particular channelised debris flows. Furthermore, many of the back analysed landslides have limited field data, with most landslides not being mapped in detail. Landslides are very complex processes and require a high level of mapping in order that all the pertinent data is recorded to enable the correct interpretation of geomorphological processes acting at a particular location. For example, high reflectance on aerial photographs is often used to determine the length of debris run out. However, detailed field mapping allows a landslide to be interpreted in far greater detail e.g. detailed field mapping following the June 2008 rainstorm indicated that an apparently very mobile landslide from API actually initiated as a debris slide, translated into a debris flow on entering a stream course and was subsequently transformed into a debris flood due to increasing surface water input. Simply assuming that such an event is a

channelised debris flow for the purpose of a back analysis can be potentially misleading. Furthermore, detailed mapping allows secondary events such as reworking of debris by subsequent storm events to be evaluated. Simply assuming that landslides are single process events results in over conservative parameters being derived from any subsequent back analysis, with the result that unnecessary mitigation works may be required if such parameters are adopted without consideration of the uncertainty associated with them.

## 7 CONCLUSIONS

It is the engineering geologist's responsibility to develop the engineering geological model and ensure that the significant findings are communicated to the geotechnical engineer. It is the geotechnical engineer's responsibility to ensure that their design takes it into account. It is a joint responsibility to ensure that the communication is effective.

The nature of LPMitP projects requires significant, high quality engineering geological input to ensure that an adequate engineering geological model is developed and natural terrain hazards are identified, appropriately quantified and assessed. Only once this has been done can the geotechnical engineer design the mitigation works.

The views of Baynes *et. al.* (2003) are worth noting, 'We believe that geotechnical engineering should have, at its root, scientific geo-thinking, and feel the poor decision-making we see within the geotechnical industry is largely the result of inadequacies in such thinking. In other words, we think the pendulum has swung too far towards narrow engineering thinking... and away from more holistic and scientific geo-thinking.'

Engineering geologists often do not have the correct training and skill to design the most appropriate mitigation solutions. It is suggested that geotechnical engineers do not have the correct philosophy and skills to develop engineering geological models and therefore may lack critical knowledge to evaluate the hazards posed by natural terrain. It is time for all members of the geo-engineering community to recognise their limitations.

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# Some Recent Technical Advances in Slope Engineering Practice in Hong Kong

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## ABSTRACT

The slope engineering practice in Hong Kong has been evolving in response to the challenges of the Government's Landslip Preventive Measures Programme. This has led to notable technological advances in various aspects of slope design and construction. This paper presents the key advances in slope engineering practice in the past decade in respect of man-made slopes. The state-of-the-art in soil nailing, prescriptive measures, surface drainage, landscaping and bio-engineering, etc. is highlighted.

## 1 INTRODUCTION

Hong Kong is renowned for its dense urban developments on steep terrain in close proximity to man-made slopes and natural terrain. There are approximately 60,000 sizeable man-made slopes in Hong Kong. To deal with the legacy of a large number of old man-made slopes, the Landslip Preventive Measures (LPM) Programme has been implemented since 1976 to progressively rectify substandard government and private man-made slopes. The LPM Programme has also led to significant advances in various aspects of slope design and construction in the past decades. This paper presents some recent key advances in respect of slope engineering practice, with particular emphasis on soil nailing, prescriptive measures, surface drainage, together with landscaping and bio-engineering.

## 2 SOIL NAILING

The soil nailing technique has gained its popularity in slope stabilisation in Hong Kong since the early 1990s. Experience gained over years of application, particularly through the LPM Programme, has led to further development of the technique in respect of design method, construction, quality control and use of new technology. In the last decade, the Geotechnical Engineering Office (GEO), in collaboration with geotechnical practitioners and research institutes, has carried out a series of soil nail-related studies and summarised the experience gained with a view to preparing improved guidelines on the design and construction of soil nails. The studies involved a range of subject areas including methods of stability analysis, nail-soil interaction, design of soil nail head, durability, pullout resistance, reinforcement materials, use of soil nails in loose fill, hole drilling techniques, potential damming effect of soil nail grouting and non-destructive testing. The Guide to Soil Nail Design and Construction (Geoguide 7) was published by the GEO in 2008, which consolidates the findings of the above studies and presents the standard of good practice for the design, construction, monitoring and maintenance of soil-nailed systems. Some of the notable advances made are highlighted below.

### Method of stability analysis

Analytical methods involving trial wedges (single-wedge or double-wedge) and limit equilibrium methods (LEM) of slices on circular, spiral or other non-circular slip surfaces are commonly used. It is essential to have a good understanding of the principles behind the calculation methods so that the appropriate method is

used and the results are interpreted correctly. In light of this, a review of the limit equilibrium methods for soil nail design was conducted by the GEO (Shiu et al, 2007), which recommends only those analysis methods that satisfy both moment and force equilibrium should be used for soil-nailed slopes.

While LEM are good enough for design purpose, none of them can account for the actual behaviour of a soil-nailed system, which involves a strain compatibility problem. It is possible to define a wide variety of nail length patterns that satisfy stability requirements but that may not satisfy serviceability requirements. Hence, under special circumstances, a stress-strain analysis (Figure 1a) may be required for assessing the design capacity of soil nails or ground deformation (Shiu & Chang, 2005).

Furthermore, the nail inclination can significantly affect the load mobilisation and hence reinforcing action of the soil nails. An increase in nail inclination would reduce the efficiency of the reinforcing action of the soil nails in cut slopes. For steeply inclined soil nails, axial compressive forces could be mobilized in the soil nails for typical sliding failures, which would be detrimental to slope stability (Pun & Urciuoli, 2008). The mechanism of nail-soil interaction and load mobilisation cannot be addressed in the LEM.

Physical modelling using centrifuge tests has also been conducted to study the reinforcing effect of soil nails with different nail head size and nail inclination (HKUST, 2008). The results of the centrifuge tests support the results of the numerical modelling (Shiu & Chang, 2005).

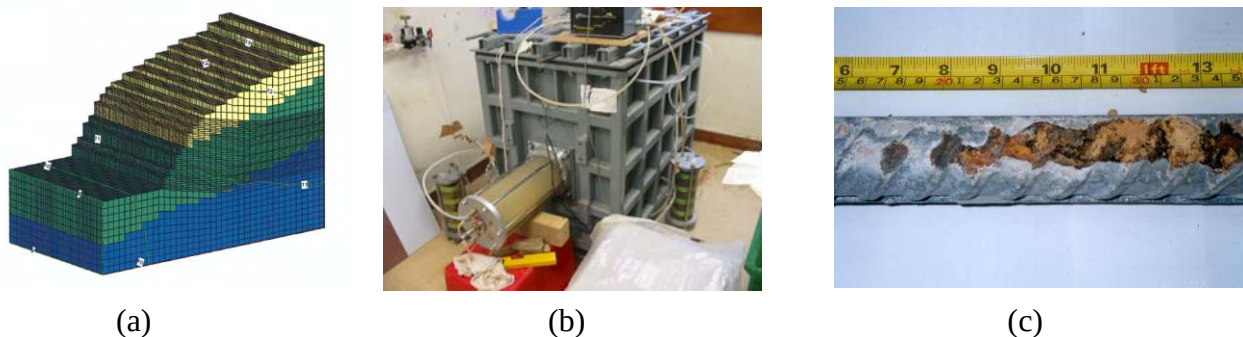


Figure 1: Soil nail studies: (a) method of stability analysis, (b) laboratory pullout test, and (c) durability

### Pullout Resistance

Pullout resistance is one of the key parameters for the design of soil nails. At present, the methods for estimating pullout resistance are not unified, as reflected by the many approaches used in different technical standards and codes of practice. GEO has conducted a review of the design methods and factors of safety adopted by Hong Kong and overseas, including the US, Japan and some European countries (UK, France, and Nordic countries), for estimation of pullout resistance of soil nails (Cheung et al, 2008). The review also included carrying out of laboratory and field pullout tests (Figure 1b).

Some 900 field pullout test data have also been collected from local construction sites for analysis. The values of the field pullout resistance were generally several times higher than those estimated using the effective stress method, but the safety margin gradually decreases when overburden pressure increases. The difference between the measured and the estimated pullout resistance is likely to be due to many factors including soil arching, restrained soil dilatancy, soil suction, roughness of drillhole surface and over-break, which are difficult to isolate and quantify in design. All these factors except soil arching tend to result in higher pullout resistance than the design value. The finding of the review gives assurance on the adequacy of the effective stress method, which is being adopted in Hong Kong. Nevertheless, as a precaution against the possibility that the positive contribution to the pullout resistance from soil dilatancy, drillhole irregularities, etc. being less than the negative effect due to soil arching in the case of high overburden pressure, Geoguide 7 recommends to limit the maximum overburden pressure to 300 kPa in the estimation of pullout resistance in conjunction with a reduced factor of safety of 1.5 (previously taken to be 2).

### Durability

Durability is an important aspect of soil nailing system. The long-term performance of soil nails depends on their ability to withstand corrosion attack from the surrounding ground (Figure 1c). To enhance the

understanding of the subject, a review of the current state of practice of corrosion protection in different parts of the world has been carried out (Shiu & Cheung, 2008). The review included a survey of the chemical properties of common Hong Kong soils and an assessment of their corrosion potential. In addition, soil nails of different ages were exhumed from the ground, which revealed that localized corrosion could occur even where hot dip galvanization had been provided, particularly in areas where voids existed in the cement grout.

The review has resulted in the development of an improved corrosion protection framework (GEO, 2008). Three levels of corrosion protection are defined, namely (i) Class 1 - Hot-dip galvanising with a minimum zinc coating of  $610 \text{ g/m}^2$  plus corrugated plastic sheathing, (ii) Class 2 - Hot-dip galvanising with a minimum zinc coating of  $610 \text{ g/m}^2$  plus a 2 mm sacrificial thickness on the radius of the steel reinforcement, and (iii) Class 3 - Hot-dip galvanising with a minimum zinc coating of  $610 \text{ g/m}^2$ . The provision of corrosion protection measures to steel reinforcement should be based on aggressivity of the ground. A scoring system, which is based primarily on the physical properties and chemical characteristics of the soils, is used to categorize the ground into four different levels of aggressiveness: “non-aggressive”, “mildly aggressive”, “aggressive” and “highly aggressive”.

### Nail reinforcement

To overcome the problem of corrosion of metallic reinforcement and limited working space, the feasibility of using innovative non-metallic materials, stainless steel and high tensile steel strand in soil nailing works has been examined. Field installation trials have demonstrated that these reinforcement materials could be a potential alternative to steel bars in soil nailing works.

Carbon fibre reinforced polymer (CFRP) is highly corrosion resistant (Figure 2a). The fibres in CFRP composites are carbon in nature and the matrix is a resin. The CFRP reinforcement is lightweight and as such it greatly eases the installation works, especially at cramped sites behind buildings or more remote sites in terms of access. It has high tensile strength when compared with high yield steel reinforcement. The brittle behaviour and low bending capacity of CFRP are concerns that need to be carefully considered. A set of interim design and construction guidelines has been developed to facilitate trial use of CFRP to gain more insights and experience (Cheung & Lo, 2005).

A range of stainless alloy types is available for the selection of soil nail reinforcement. An advantage of stainless steel reinforcement is its high corrosion resistance while the ductile behavior of steel is retained. Apart from solid stainless steel bars, a hybrid of high yield deformed steel and stainless steel bars is also available in which the deformed steel bars are fused by a stainless steel cladding (Figure 2b). The cost of this material is, however, high and there is little experience in the use of this stainless steel cladding bars in soil nailing works. Nevertheless, it was established that solid stainless steel and stainless steel cladding bars of grade 304 or above are technically suitable for use in soil nailing works (AECOM, 2009).

High tensile steel strand reinforcement is commonly used in prestressed ground anchors (Figure 2c). Because of its flexibility, it is most suitable for use at sites with limited working space. In order to assess the suitability of using this material as soil nails, numerical analysis and field tests were carried out to examine the slacking effect of steel strands. Although the review suggests that the material may be suitable for use in soil nailing, it is susceptible to corrosion and suitable corrosion protection measures have to be provided. Details of the review can be found in CMW (2008).



(a)



(b)



(c)

Figure 2: Nail reinforcement: (a) CFRP reinforcement, (b) solid stainless steel/stainless steel cladding bars, and (c) steel strand steel bar

### Non-destructive testing

As part of the quality control of soil nailing works under the LPM Programme, the GEO has begun since 2001 to identify and try out various non-destructive testing (NDT) methods that could be used to help assess the quality of installed soil nails. The NDT methods are to provide additional quality assurance and serve as a deterrent against malpractices. Among the potential NDT methods examined, which include sonic echo method, mise-a-la-masse method, electro-magnetic induction method, electrical resistance method, magnetometry and time domain reflectometry (TDR), TDR was found to be the simplest, relatively quick and least expensive (Cheung, 2003). In 2004, the GEO introduced TDR to its soil nailing works under the LPM Programme for pilot use during independent site audits. Upon completion of the pilot programme in 2007, an independent review of TDR and other NDT methods (Lee & OAP, 2007) was conducted, which supported the continued use of TDR as an audit tool and suggested enhancement to the sampling strategy for testing.

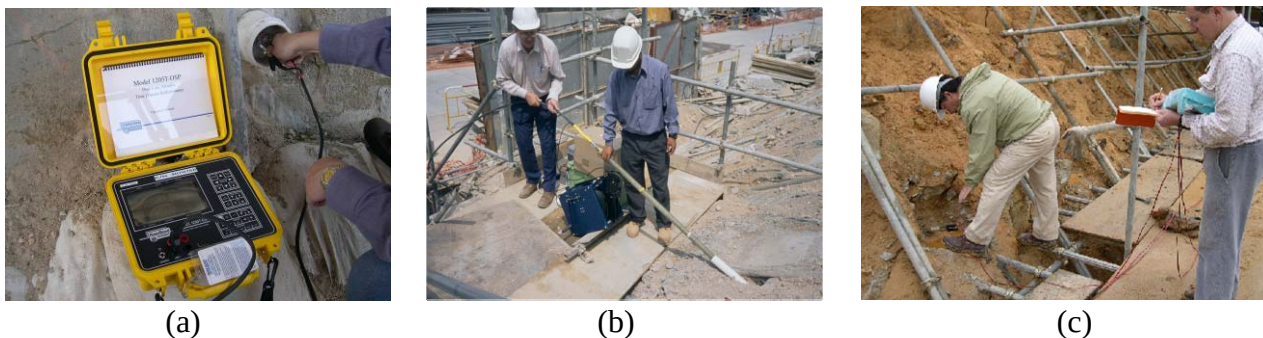


Figure 3: Non-destructive testing: (a) TDR, (b) magnetometry, and (c) electrical resistance method

## 3 PRESCRIPTIVE MEASURES

Many of the engineered man-made slopes in Hong Kong were designed using the conventional analytical approach based on detailed ground investigations and design analyses. As an alternative to the conventional analytical approach, the prescriptive approach provides an experience-based and expedient method for the design of slope improvement works. Since the mid-1990s, the GEO has carried out a series of studies that were aimed at developing a prescriptive design framework and suitable prescriptive measures for use in man-made slopes. These include prescriptive measures for soil cuts (Wong & Pang, 1996; Pun et al, 2000), use of reinforced concrete skin walls for existing masonry retaining walls (Wong & Pun, 1999), use of prescriptive measures for rock cuts (Yu et al, 2005), and the extension of application of prescriptive soil nails to concrete retaining walls, masonry retaining walls and soil cuts with toe walls (Lui & Shiu, 2005). In 2007, prescriptive measures involving surface protection, surface drainage and subsurface drainage were also rationalised for use on fill slopes and retaining walls, with due regard to the findings of the systematic landslide studies undertaken by the GEO since 1997.

Before 2009, the various types of prescriptive measures for man-made slopes were promulgated through a series of technical reports and guidance documents. In 2009, the GEO integrated and rationalised all the recommendations from various documents and published a comprehensive guidance document on the application of prescriptive measures to existing man-made slopes and retaining walls (GEO, 2009).

## 4 SURFACE DRAINAGE

There have been concerns regarding the observed overflow from stepped drainage channels during heavy rainfall and hence their design capacity. In 2006 the GEO carried out a study with a view to improving the hydraulic design of stepped drainage channels. The study included a review of local and overseas literature on the design methodology, and field tests for verification of improved design method (MCL, 2006). Among the design methods adopted by various countries, the one proposed by Chanson (1994) is considered the most comprehensive and suitable for Hong Kong's conditions. As the stepped drainage channels in Hong Kong are usually steeply inclined, it is anticipated that the flow with relatively high kinetic energy would require a

channel with high energy-dissipating capability. In the improved design method, a skimming flow condition is assumed since skimming flows would dissipate energy more efficiently. The field tests showed good agreement between the observed and design capacity using the improved design method (Figure 4a). The improved design method was promulgated through GEO Technical Guidance Note No. 27 (TGN 27) (GEO, 2006). In addition, GEO has completed an updated frequency analysis of extreme rainfall intensities based on 26 years of rainfall data (i.e. between 1984 and 2009). A set of new intensity-duration-frequency (IDF) curves was derived for the design of surface drainage provisions (Tang & Cheung, 2011). Currently, the GEO is conducting a review of the methods for estimating surface runoff for slope surface drainage systems. These methods include the Rational Method, time-area method, unit-hydrograph method, reservoir routing methods, flow gauging methods and statistical methods.

Notwithstanding the above studies, inadequate implementation of the recommended good practice in some instances has led to poor practice and detailing. Systematic landslide investigations undertaken by the GEO have shown that inadequate surface drainage provisions (e.g. uncontrolled overland flow, poor detailing or inadequate construction of surface drainage provisions) could be a key contributory factor in causing landslides and washout incidents in Hong Kong (Hui et al, 2007).

In essence, a holistic assessment of the overall site setting and the associated environmental conditions should be made, including the characteristics of the catchment, information on land drainage in the uphill area, likely consequences in the event of surface water overflow, etc. Also, the sizing of drainage channels should not be dictated only by hydraulic considerations; due allowance should be made for possible blockages and the relevant site-specific environmental setting so as to enhance the redundancy of the drainage system.

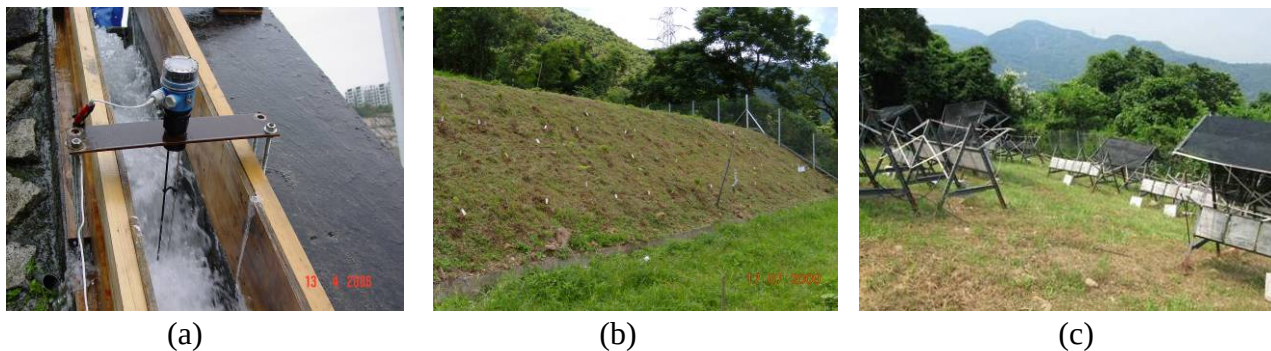


Figure 4: (a) Field test of stepped drainage channel, (b) trial sites using native plant species, and (c) shotcrete panels with microalgae at the Kadoorie Institute

## 5 GREENING AND BIO-ENGINEERING

There has been an increase in the public awareness of and concerns about the environment in the last decade, which has led to the integration of the concept of greening and landscaping in the design of slope works. One of the notable milestones to address this trend was the promulgation of GEO Publication No. 1/2000 – Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2000). This is a pioneer document of its kind in the world, which provides comprehensive technical guidance for use by geotechnical and landscaping practitioners. Since then, a series of studies have been carried out by the GEO in collaboration with the geotechnical practitioners, together with Kadoorie Farm and Botanic Garden on various aspects of landscape treatment, bio-diversity and bio-engineering of slopes. The recent completed and on-going research initiatives include (a) review of the performance of different slope greening techniques (Lui & Shiu, 2006), (b) assessment of the suitability of soil cement as a planting medium for slope vegetation (FHKL, 2009), (c) study of masonry walls with trees (CMW, 2011), (d) study of soil bio-engineering measures for the repair of natural terrain landslide scars (Campbell et al, 2008), (e) study of the application of soil bio-engineering measures to control surface erosion on man-made slopes (JCL, 2010), and (f) landscape treatment for debris-resisting barriers (AECOM, 2011).

In recent years, the GEO has invested significant efforts to enhance the ecological values of man-made slopes. Through extensive planting trials, a wide range of native tree and shrub species have been identified as being suitable for use on steep slopes, including slopes with a poor soil nutrition condition (Choi et al,

2009). Guidelines on the selection and application of vegetation species can be found in GEO (2007) and HCL (2011) respectively.

The GEO, in collaboration with the University of Hong Kong, is currently investigating the feasibility of using microalgae for greening slopes with hard surface facing. Some shotcrete panels with colonization of microalgae were constructed at the Kadoorie Institute in Shek Kong in 2009 (Figure 4c). The growth and colonization of the microalgae in respect of various parameters such as shading, amount of sunlight, irrigation, inoculation, etc. are being monitored with a view to identifying those factors that would favour or retard the growth and colonization of microalgae on hard slope facing.

As there has been continuous development in this subject since 2000, the GEO has initiated a study to update GEO Publication No. 1/2000 in order to incorporate the findings of relevant recent studies, field trials and experience gained over the past decade. In addition, the scope of the guidance document will be expanded to cover natural terrain mitigation works in order to cope with the demand of the newly launched Landslip Prevention and Mitigation (LPMit) Programme, which dovetailed the LPM Programme.

## 6 CONCLUSIONS

The slope engineering practice in Hong Kong has been evolving in response to the challenges of the Government's Landslip Preventive Measures Programme. Systematic research and development work in slope engineering in the past decades have led to advances in knowledge and technology for reducing the likelihood of landslides on man-made slopes, as well as improving the aesthetics of slopes and the sustainability of slope greening measures. Further development and advances in slope engineering know-how and technology will continue, which can open up more opportunities for practical applications in geotechnical engineering.

## ACKNOWLEDGEMENTS

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# Evolution of Soil Nailing Construction Practice in the Past Decades

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## ABSTRACT

Since the introduction of the use of soil nails in stabilizing soil slopes in the 1980's in Hong Kong, many improvements have been made to the design and construction of soil nails, leading to the publication of Geoguide 7 "Guide to Soil Nail Design and Construction" by Geotechnical Engineering Office in 2008 (GEO, 2008). Given that the subject of design and construction of soil nails in stabilizing soil slopes is of relevance to many practitioners, this paper will present the continual construction technology and system improvement made throughout the years. Evolution of soil nailing construction practices comes in many forms. These include the use of various kinds of drilling, grouting and concreting techniques, the use of proprietary products to cope with different site situations and constraints, e.g. use of concentric drill for loose fill slopes adjacent to structures and roads, etc. The improved contractual provisions in ensuring proper installation of steel bars and grouting, the use of non-destructive testing for the quality control of soil nails, and the improvement in corrosion protection, will be discussed. The possible areas for further improvement to current guidelines and construction practices will also be explored.

## 1 INTRODUCTION

In the old days, the rules of thumb for slope design and construction were about 60° for cut slopes and about 35° for fill embankments. Collapses of man-made slopes were not uncommon and had resulted in a number of fatalities since the late 1940's when major urban development on marginally stable hillsides took place in Hong Kong. Since focused slope safety effort by the Government in 1977, a large number of sub-standard slopes have been upgraded. The increasing use of soil nails as an in-situ soil reinforcement technique since the late 1980's is also one of the key factors that have contributed to reducing large-scale man-made slope failures.

Soil nails were first used in France in 1961, as permanent support for retaining walls in soft rock (Bonazzi and Colombet, 1984). Since its introduction to Hong Kong in the 1980's, it soon became the standard practice in slope works due to its robustness among various design options (Wong and Ho, 1999). Since there are time savings and enhanced robustness in using soil nails for the stabilization of slopes as compared with the conventional technology of cutting back, its use has become popular after the launch of the 5-year accelerated Landslip Preventive Measures (LPM) Programme in 1995 when the Geotechnical Engineering Office (GEO) committed to upgrade a large number of slopes within a short period of time.

Soil nail construction in Hong Kong was relatively primitive in the 1990's. Shortcomings such as water and debris not fully displaced from the drillhole during grouting, cuts made along the side of grout pipes, use of broken centralizers, rust on the threads of steel bars and couplers, etc, were sometimes found in site audits. Improvement of the soil nailing practices has been implemented over the years to overcome these shortfalls. This paper will review the evolution of soil nailing construction practices, from drilling, grouting, fabrication and construction of soil nail components, nail heads, and the system improvement involved.

## 2 DRILLING

Soil nails were initially constructed by crawler type mini-pile drilling rigs which were pneumatic percussive drilling rigs powered by air compressors (Plate 1). Due to the large-size of the machine, it could only be used in site formation projects with the ground in front being lowered in stages, or in roadside slopes with only one to two rows of soil nails. For large and steep slopes, construction of soil nails at height by mini-pile drilling rigs requires the construction of heavy duty access and working platforms. Bamboo or wooden scaffoldings (Plate 2) were the common practice but sometimes these scaffoldings may not be strong enough to support the weight of the machine. For obvious operational reasons, a simplified light-weight drilling rig with only a rotary motor mounted onto a fixed leader, powered by an air compressor placed at a convenient location, was devised subsequently (Plate 3). Air flush is used in all cases and the holes are drilled without casing. Because of its light weight, this drilling machine could be mobilised and handled by two workers only. The drilling machine can be supported by standard tubular steel scaffoldings (Plate 4) without the need of substantial access and working platform.

Many slopes affecting village houses, with very restrictive access and limited working space, are required to be upgraded. To cope with such conditions, an even shorter and tailor-made soil nail drilling machine was devised (Plate 5). Though continuous improvement in machinery has helped to overcome the difficult situation and site constraints, additional manpower is required to connect and fix drill rods of 500 mm long during the drilling operation. The effect is that as much as four times more working hours was needed for the drilling, fixing and installation of shorter soil nail bars, plus the additional materials cost (i.e. couplers and associated fixing accessories). Likewise, hand-held coring machines can be used for these kinds of slope works with limited space. Coring machines generate less noise and dust than their percussive counterparts, but the speed of coring is very slow and the maximum depth of coring is about 6 m only. The use of water as the flushing medium during drilling may also have adverse effect on slope stability.



Plate 1: Use of mini-pile drilling rig for soil nail construction



Plate 2: Bamboo scaffolding for mini-pile drilling rig



Plate 3 – Typical soil nail drilling rig with 1.5 m long leader



Plate 4: Steel tubular scaffolding for soil nail construction



Plate 5: Special soil nail drilling rig with leader less than 1 m long

The upgrading of some roadside slopes using soil nails posed another problem. For busy roads, application for lane closures for an extended period of time is often rejected by the relevant authorities. Permission for lane closure is restricted to a few hours each day, normally from 10:00 am to 3:00 pm. Since the drilling machine has to be demobilized for road opening on a daily basis, it is not possible to erect scaffoldings and working platforms for the set up of drilling machines in the usual manner. Under such circumstances, a tailor-made movable drilling system, by mounting of a drilling rig onto a lorry (Plate 6), has been developed to overcome this constraint.

Since the issue of the guideline for design of soil nails in loose fill slopes by the Geotechnical Division of the Hong Kong Institution of Engineers in 2003 (HKIE, 2003), more fill slopes have been upgraded with soil nails instead of recompaction. Gaps or cavities in loose fill slopes, often encountered during the drilling process, are easily detected because there will be a sudden drop in pressure as shown in the pressure-meter of the air compressor. Under such circumstances, the drilled materials cannot be blown out as air pressure cannot be sustained. To overcome this and hole collapses during drilling, eccentric overburden drilling system (ODS) (e.g. ODEX) may be used (Figure 1). Under the eccentric ODS, the reamer bit swings out and drill a hole slightly larger than the outside diameter of the casing, thus facilitating its advancement. The casing helps supporting the ground and return of flushing air. However, some cuttings would be flushed up between the casing and the ground as the drillhole is made slightly larger than the casing. This could cause disturbance to the surrounding ground. Before the adoption of a particular drilling system, due consideration should be given to the geology and ground condition of the feature, as well as the utilities and structures in its vicinity.

Recently, a concentric drilling system (Wong et al 2011) has been made available on the market (Figure 2



Plate 6: Drill rig on Lorry

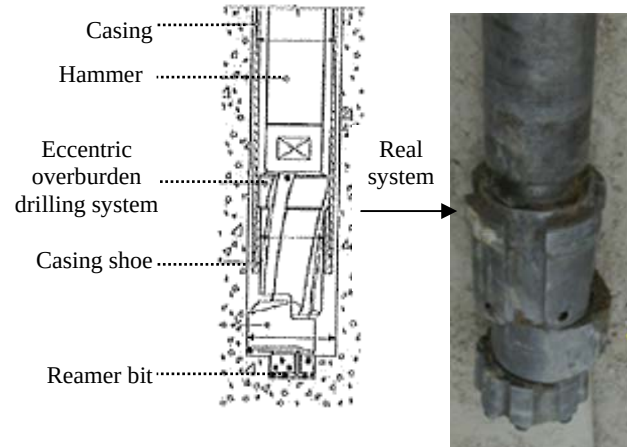


Figure 1: Eccentric overburden drilling system

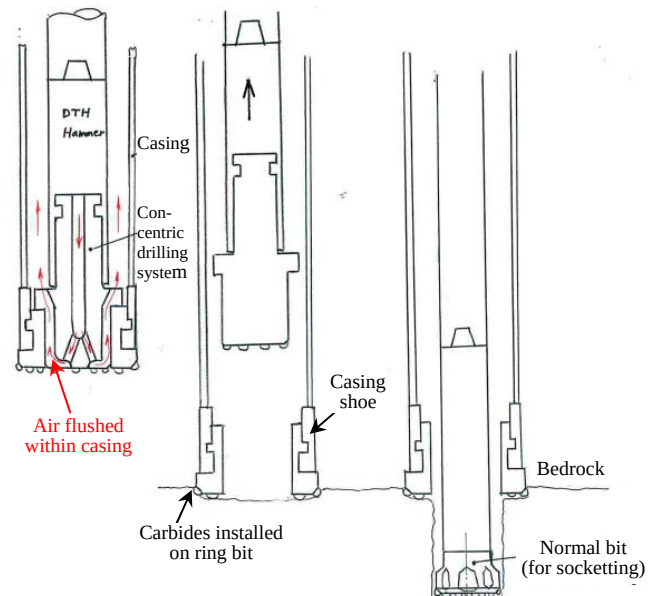


Figure 2: Concentric drilling system



Plate 7: Ring bit and pilot bit of the concentric drilling system

and Plate 7). It does not have any eccentric parts and works with a pilot bit system together with a crown/ring bit. With the ring bit fully covering the pilot bit and guiding the air to return inside the casing, disturbance of the surrounding ground is minimized. Without the excessive torque on other parts of the drilling rig as compared to the ODS, the concentric drilling system has proved to work well in difficult grounds (e.g. very loose/boulder field/debris-fill slopes, etc). The main drawback is that the ring bit together with the casing shoe is welded to the permanent casing, which has to be left underground when the pilot bit and down-the-hole hammer are retrieved. A longer leader of about 2.5 m length has to be used to accommodate the pilot bit system and a higher air pressure, up to about 17 bars, is also required.

As discussed above, there have been improvements in the hardware part of the drilling system over the years that have helped the construction of soil nails in difficult ground and restrictive sites. Further advances in technology in the soil nailing operating system are anticipated to deal with specific operational difficulties and problems. Nevertheless, the use of a light-weight drilling rig with only a rotary motor mounted onto a fixed 1.5 m long leader, powered by an air compressor of about 12 bars placed at a separate location, is still the common practice for the construction of soil nails in Hong Kong nowadays.

Another area of improvement that has been recently implemented to address the conventional problem of dust generated by soil nailing works is the promulgation of air blower. Conventionally, dust suppression was done by spraying water and covering the surrounding area of the drilling rig by tarpaulin sheets. However, this may not be effective especially during drilling in rock (Plate 8) and spraying water constantly onto a slope might have adverse effect on slope stability. Recently, a new system comprising a portable air blower connected to a duct has been used. One end of the duct sucks the dust generated from the drilling rig while the other end discharges the dust into a bucket of water. The driving force of the suction/blowing action comes from the air blower connected in the middle of the duct (Plate 9). The whole system can be reused and hence is environmentally friendly. This is also a cost-effective solution and reduces complaints regarding dust generated by soil nailing works. This preferred means to reduce dust generation would be adopted in all future LPM works.



Plate 8: Dust coming out even with the use of tarpaulin sheet and water spraying

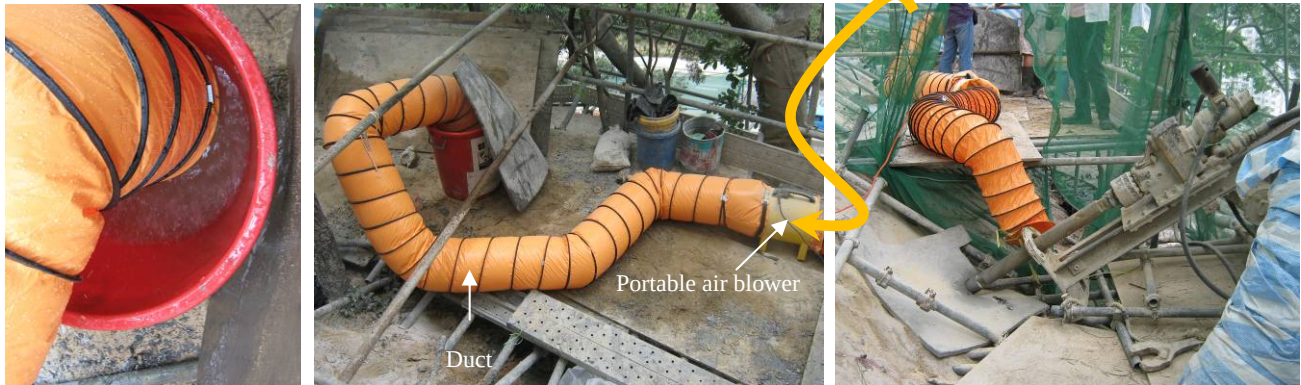


Plate 9: Use of air blower to suck dust generated during drilling to a bucket of water

### 3 GROUTING

The cement grout sleeve is an integral part of the soil nail system and its primary function is to transfer stresses between the ground and the soil nail reinforcement. In essence, grouting of a soil nail involves filling some well-mixed prescribed water-cement grout into a drillhole by a grout tube filling from bottom upward. While grouting appears to be a simple operation, serious defective workmanship could happen in the absence of proper control and adequate supervision.

Once a drillhole is filled with grout, it will not be possible to extract the grout even if the grout quality is found to be below the required standard. The soil nail installed has to be abandoned and replaced by a new

nail. To ensure a successful grouting operation, proper control of the workability and quality of the grout is a must. Hence, flow cone and grout bleeding tests have to be conducted on site at the day of grouting, to ensure that the grout mix is workable, but at the same time, an appropriate amount of water is mixed with the cement. Conventional grout cube strength test will then be carried out at the laboratory to verify the grout strength. To ensure the production of a colloidal grout mix, there are also specification provisions that require a minimum rotor speed for the grout mixer as well as the agitation tank.

In the old days, the specifications required the contractor to grout the hole until full, regardless of how many bags of cement used to achieve that. There have been cases where the contractor has had to use over 100 bags of cement to grout a single hole and was not eligible for any additional costs. One extreme case was over 900 bags of cement used. This problem was particularly significant when strengthening existing retaining walls that had rock or debris as backfill. The GEO subsequently revised the specifications to require the contractor to inform the Engineer if the grout intake increased suddenly by a significant amount. The Engineer would then decide what follow-up action to take. Any grout over 10 times the calculated volume of grout intake would be reimbursed to the contractor. Reported cases of grout loss have also been reduced in the past ten years due to the use of permanent casing to sleeve over the potential location of grout leakage in loose fill/boulder field/debris-fill slopes and slopes with cavities.

Before the introduction of the “L-shaped” upstand pipe, a sub-horizontal soil nail could never be fully filled with cement grout in liquid state without something plugged at the top of a drillhole. It was therefore a common practice to use empty cement bags to plug the top of a drillhole as the hole was deemed to be fully filled in the first instance, and then poured grout back to the empty space on the next day (Plates 10 and 11). In order to ensure full grouting of the drillhole, a slight pressure grouting method using a 300 mm long “L-shaped” upstand pipe was introduced in early 2004 (Plate 12). This upstand pipe also serves as a monitoring device to check the quality of overflow grout. Grouting operation shall only stop when the overflow grout is consistent and free of undesirable substances. As an additional control measure, samples of overflow grout may be taken for examination of its consistency and quality and reconfirmation of its workability as necessary. When grout injection stops, the grout level in the upstand pipe may drop as some grout in the hole is lost to the surrounding ground. The upstand pipe would be refilled with grout to keep up the pressure whenever the grout level in the upstand pipe drops to the bottom of the bend.



Plate 10: Top of drillhole plugged with cement package bags



Plate 11: Absence of grout on the upper part of drillhole



Plate 12: Use of “L-shaped” upstand pipe for maintaining grout level



Plate 13: Smaller grouting equipment used for LPM site

In addition to the system improvements and control measures introduced to the grouting process over the years, the grouting equipment has become smaller and more compact (Plate 13). Traditionally, the mixer (1.2 m diameter), the grout storage tank (1.2 m diameter) and hydraulic pump (1.5 m x 0.5 m) are separate items and require a much larger area (3 m x 3 m) for their accommodation. The newer all-in-one grouting equipment, with mixer, agitation tank and grout pump, can be lifted and placed easily within a small area of about 1 m x 2 m.

#### 4 SOIL NAIL REINFORCEMENT

Steel reinforcement is the main element of a soil nail and its primary function is to provide tensile resistance. The reinforcement commonly used is a solid high yield deformed steel bar. The durability of a steel soil nail system is governed primarily by its resistance to corrosion under different soil conditions. The problems with corrosion were first discovered in installed anchors, which were adopted in the early days of slope stabilization works. There was serious concern when some pull-out tests failed and the anchor strands were found to be badly corroded (Bruce and Wolfhope, 2005). Although soil nails, being not prestressed, are not liable to stress accelerated corrosion, the need for appropriate and adequate corrosion protection measures to the soil nails has still been given serious consideration in the development of the soil nail system.

In the old days, corrosion protection measures for soil nails were mainly prescriptive, by relying on the grout cover and the 2 mm sacrificial thickness allowed on the design of the soil nail steel bar. However, studies of corrosion rate of steel in soil revealed that the use of 2 mm sacrificial thickness on bar radius for a design life of 120 years was insufficient, and grout cover was known to have contained voids of various sizes (Shiu and Cheung, 2009). There was an obvious need for alternative measures. Galvanization of the steel bar was introduced in the mid 1990's, which is now a standard provision for corrosion protection. The galvanization process is carried out in a factory and the required numbers of galvanized steel bars will be delivered to site as and when required. Hence, the galvanization process has little effect on the progress of site works.

An improved approach, classifying the soil into four categories, namely 'Non-aggressive', 'Mildly aggressive', 'Aggressive' and 'Highly Aggressive', was introduced in 2002. The improved approach was put on trial in LPM works till the end of 2004, and fully implemented since early 2005 (Shiu and Cheung, 2009). For the 'Aggressive' and 'Highly Aggressive' soil condition, an outer corrugated plastic sheathing was adopted (Plate 14) in addition to the hot-dip galvanization of nail bars.

For those sites with limited space, steel bars will be cut into shorter pieces and connected by couplers to facilitate installation of soil nails. The threaded ends of these steel bars and the couplers are more vulnerable to corrosion as threading is carried out after hot dip galvanization of the steel bars. As a standard practice, zinc rich paint is applied directly to the threaded portion of steel bars and couplers. However, the level of protection provided by the paint is less than that of hot dip galvanization, as rusts were often found at the threads on the steel bars and couplers during site inspections (Plate 15). It is

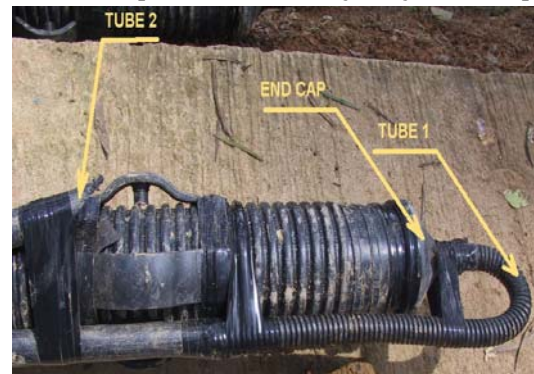


Plate 14: Corrugated plastic sheath for aggressive sites



Plate 15: Rust formed in coupler



Plate 16: Use of hand-held blower to apply the heat-shrinkable mastic material onto the soil nail steel bar

therefore necessary that any rust on steel bars and couplers be removed by steel brush, and the rusted area painted with zinc rich protective coating before use.

As an additional precautionary measure, heat-shrinkable mastic sleeve was introduced in 2003 to further reduce the possibility of rust development in the coupler portion, the weakest link in the system against corrosion. Heat-shrinkable mastic material can be applied easily on the coupler portion on site by heating with portable gas equipment (Plate 16). The inner mastic sealant material will then tightly encase the steel bar and inhibit corrosion by preventing air and water from getting inside.

## 5 NAIL HEAD

A soil nail head typically comprises a reinforced concrete pad, steel bearing plate and nuts. Its primary function is to provide a reaction for individual soil nails to mobilize tensile force. It also promotes local stability of the ground near the slope surface between soil nails. There has not been any major<sup>1</sup> failure in soil nailed (including nail heads) slopes. However, large-scale failures in temporary soil-nailed slopes in the absence of nail heads had occurred (Sun and Tsui 2003).

In the early 1990's, nail heads were constructed by means of ready mix concrete. However, there are more restrictions in the use of ready mixed concrete as compared to shotcreting. Normally, the volume of concrete required for the construction of nail heads is relatively small and does not facilitate the optimal and timely use of the concrete trucks delivery. Concreting operation would become even more difficult for slopes with no vehicular access. Under such circumstances, manual transportation, i.e. bucket by bucket would be the only means to concrete the nail heads, and it would be very difficult to control the built quality and workmanship.

Nail heads are commonly constructed by shotcreting nowadays. Dry-mix is adopted in shotcreting since it is readily available in all concrete plants. Quality assurance of nail head shotcreting is further enhanced by tightening the qualification and experience of the nozzleman. Control testing on the compressive strength of the cores recovered from a test panel constructed at the same time as shotcreting is also specified. An advantage of Dry-mix process is that it can be applied to sites with no vehicular access as its operation relies on the pressure provided by an air compressor placed at a convenient location away from the point of work.

Particular attention should be paid to ensuring the integrity of soil nail heads, especially at the location beneath the bearing plate where honeycombing is not uncommon. For nail heads to be constructed using shotcrete, it is a good practice to construct the nail head in two stages. In the first stage, shotcrete should be applied to a specified thickness above the intended base level of the steel bearing plate. The bearing plate should then be hammered into place to ensure that no void is left behind, and the nut tightened onto the soil nail reinforcement before application of the second stage shotcreting. Despite the common knowledge of this good practice, there are findings of honeycombing and/or voids underneath the bearing plate in audits from time to time (Plate 17). This reflects the fact that proper construction practice on site and adequate supervision should never be overlooked.



Plate 17: Voids observed below the bearing plate

## 6 PULLOUT TEST

The primary objective of a field pullout test is to verify the design assumptions on the bond strength at the interface between the ground and the cement grout sleeve, except for slopes designed by prescriptive approach (Wong et al 1999). The test also gives an indication of the contractor's workmanship, construction method, and potential construction difficulties. Pullout tests should be carried out prior to the construction of working nails so that information gathered from the tests can be reviewed for making design changes as needed.

Test nails are installed using the same procedures as working soil nails except that only the bottom 2 m of the test nail, the bonded section, is grouted. Packers are used to seal off the grouted section and the entire free length of the steel bar shall be debonded to ensure that the test load is only applied to the bonded section.

<sup>1</sup> A 'major' landslide is defined as a failure in which the estimated volume of the detached/displaced mass is  $\geq 50 \text{ m}^3$ , or where a fatality has occurred.

Grouting should then be carried out slowly and carefully to prevent over-grouting. Checks can be made by blowing air into the two return pipes, with one terminated inside and the other outside the packers respectively. Grouting shall immediately be stopped when the inner return pipe has been blocked by the grout.

Failure of a pullout test is uncommon, except that bearing failures sometimes occur on slope surface due to insufficient load spreading. To overcome this problem, a concrete pad (Figure 4) is constructed on the slope surface, in addition to the steel seating plate required by the General Specification for Civil Engineering Works (2006) (GS). An additional dial gauge is added to measure the movement of the steel seating plate. This serves as a countercheck to ensure that the observed extension of soil nail steel bar is induced by the hydraulic jack instead of displacement of the seating plate. A frictionless support to the hydraulic jack has also been introduced in the test apparatus since 2008 to minimize the friction loss due to the jacking motion.

Under the traditional LPM contracts, pullout tests would be carried out for a minimum of three nails or 6% of the total number of working nails, whichever is the greater. After a special task carried out by MGSL (2003), the requirement was revised to a minimum of two nails or 2% of the total number of working nails, whichever is the greater. The study also recommended the simplification of testing cycles from five phases to three phases, using a larger size steel bar than the working soil nails for the development of the ultimate soil-grout bond load in the pullout test, as well as limiting the maximum test load to 90% of the yield load of the steel bar. These recommendations were subsequently implemented by the issue of the first version of Design Technical Guideline No. 11 (Chan, 2008) in 2004 and updating of the GS.

## 7 SYSTEM IMPROVEMENT

A soil nail, when constructed, is buried under ground, and its built quality is not readily visible. There is a need to put in place reliable procedures for the supervision, testing and certification for acceptance of the soil nailing works during construction in order to ensure that the quality of works is up to standard. In particular, full time supervision is required during all critical stages of soil nailing works, especially those aspects of the works that are difficult to be verified afterwards, e.g. length of installed soil nail, integrity of corrosion protection measures and volume of grout consumed.

Since a reported suspected case of short nail in January 2001 (Singtao, 2001), quality supervision of soil nail has received much attention in both public and private works projects. Additional requirements have been specified in the contract specifications. Practice Note for Authorized Persons and Registered Structural Engineers (PNAP) 284 entitled “Quality Supervision of Soil Nailing Works” was issued in October 2003 (reissued as APP-135 in 2009) stipulating the requirements in supervision, testing and certification of soil nailing works. In addition, the qualification, experience and the role of the contractor’s site representatives for soil nail works have been specified.

A non-destructive test, the Time Domain Reflectometry (TDR), was introduced in 2004. TDR was first devised to check the length of a soil nail bar installed. It does not offer measurement of the exact dimension of the bar length, but rather an estimated length of the nail bar within reasonable range (Cheung, 2006). As an added advantage, it also helps to assess quality of the grout in the cement grout sleeve. TDR test has

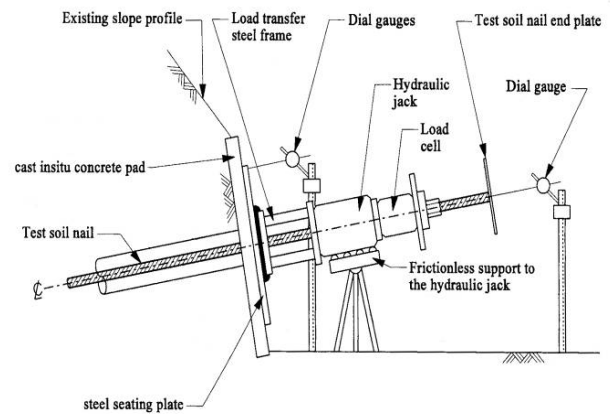


Figure 4: Standard Pull out test set up



Plate 18: Doubtful grout integrity detected in completed nail

successfully detected some cases where grout integrity was in doubt. Subsequent investigation revealed that the cement grout sleeve was damaged by the drilling of a nearby raking drain (Plate 18). The use of TDR to spot check the length of soil nails installed and grout integrity has become a standard practice for LPM sites.

A course on the quality supervision of soil nail construction, organized jointly by the Hong Kong Polytechnic University and GEO, is held every six months. It is intended to allow professionals, site supervisory staff and contractor's staff to obtain the necessary knowledge and experience in soil nail construction. The course provides a comprehensive technical training on soil nail construction. It also highlights common non-compliances identified and the critical areas to check during construction to ensure the quality of soil nails installed.

The relevant provisions on soil nail construction are given in Chapter 7 of the GS. The detailed requirements on materials, procedures and testing for the construction of soil nails are clearly stated. In addition, the GEO published Geoguide 7 "Guide to Soil Nail Design and Construction" in 2008 to recommend the standard of good practice to practitioners for the design, construction, monitoring and maintenance of soil-nailed systems in Hong Kong.

## 8 NEW CHALLENGES AND POSSIBLE AREAS FOR FURTHER IMPROVEMENT

Many improvements have been made in the design and construction of soil nails in Hong Kong since its introduction in the 1980's. Nevertheless, there is room for further improvement in the construction practice of the soil nailing system. Some suggested items, which are not exhaustive, that deserve further thoughts and work, are discussed as follows:

- i) The construction of long nails, typically over 20 m, often poses difficulties in drilling of holes and the grouting process. More comprehensive site trials should be conducted to evaluate the optimal mode of drilling and grouting. It is desirable to develop a more powerful and efficient drilling system for the drilling of long holes through adverse ground conditions.
- ii) The construction of soil nails for slopes located in remote areas with restricted access is quite common nowadays. For operational reasons, it is beneficial to devise a lighter drilling machine to facilitate its transportation, most likely by manual labour. There is also a need to develop an efficient and effective transport system, aided by winches, conveyor belts and/or other means, for the delivery of materials for the soil nailing works. Some of these soil nailed slopes may involve the construction of extensive grillage beams, which is a labour-intensive activity. Under those scenarios, designers are encouraged to consider the use of smaller diameter bars (Y16 and below) or wire meshes for the construction of grillage beams. Since the bending of small diameter bars can be carried out by labour on the spot instead of the bending machine located at the works area at a distance from the works, its adoption would help to achieve a smoother and faster work progress and to reduce the hardship to contractors.
- iii) The natural terrain landslide mitigation works under the post-2010 Landslip Prevention and Mitigation Programme involve sites with difficult access or on steep terrain. In other words, soil nails will likely be constructed at high elevation on inaccessible hillside. This new challenge demands a critical review of the current construction practices of soil nailing work. There is an obvious need for an enhanced or new soil nailing system and construction practice, probably with lighter but more powerful drilling machines, a more compact and efficient grouting system, while maintaining or improving the safety measures for personnel involved in the works at height. In addition, the use of light weight, high tensile carbon fibre reinforced polymer strip (CFRP) and epoxy-coated high tensile multi-strain cables to replace traditional heavy reinforcing bar can be explored further.
- iv) In recent years, public awareness of LPM works has increased significantly. The increasing attention of the public, especially during the construction phase of slope upgrading works in the vicinity of densely populated urban areas, has a profound effect on the construction programme and practice, including that of soil nails. The public not only demands a safe slope upon its completion, but also a proper control on noise, dust and waste water generated during the soil nails construction. To be proactive and to minimize possible complaints, further work should be carried out to identify and implement more effective precautionary and control measures on undesirable nuisances in the drilling and installation of soil nails, especially for noise reduction at connections amongst different parts of machinery involved in soil nailing works.

## 9 CONCLUSION

In the past few decades, many improvements have been made to the design and construction of soil nails. The critical components of the soil nailing practice, including drilling, grouting, corrosion protection of the bar reinforcement, nail head construction, as well as quality supervision of the construction process, have evolved and improved significantly. The soil nailing system has proven itself to be a flexible and economical means that provides a robust solution for slope improvement works. As is always, there is room for further improvement as discussed above.

A partnering approach is being adopted by the GEO in closely liaising with the geotechnical consultants and LPM contractors with a view to further enhance the existing Slope Safety System in Hong Kong. With the committed and devoted efforts by all stakeholders, further improvement in the soil nailing system would be realized progressively.

## ACKNOWLEDGEMENTS

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# Application of Native Plant Species in the Landslip Preventive Measures Programme

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## ABSTRACT

Public awareness of the environment has significantly increased in the last decade, and this has led to the integration of landscape and ecological elements in the design of slope works. There has been a demand from the society for a greener and more sustainable approach to the Landslip Preventive Measures (LPM) works without compromising on public safety. A holistic approach is therefore evolved in the LPM Programme where the existing environmental settings, landscape opportunities and ecological factors are considered in the early stage of the LPM design process.

As part of the holistic approach, trials have been carried out on several LPM sites aiming at identifying suitable plant species in particular those native species for ecological greening on slopes with different environmental settings.

This paper describes one of the site trials in which native tree and shrub species have been applied on the LPM works. The initial (1 year) and longer term (5 years) survival and growth of the 10 selected native tree and shrub seedlings are reported. Contributing factors to vegetation establishment of the LPM works are also discussed.

## 1 INTRODUCTION

The Government embarked on the Landslip Preventive Measures (LPM) Programme in the late 1970s to address public concerns on safety of man-made slopes and retaining walls, particularly those formed before the establishment of the geotechnical control authority, i.e. the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department. In the early years of the LPM Programme, major focus was on slope safety with lesser emphasis on landscaping.

With the technological advancement, new techniques for slope upgrading were introduced. At the same time, with the increase in environmental awareness, the public is more concerned on the visual impact of man-made slopes. Landscaping has therefore become an integral part of the slope design for LPM works with the purpose of blending the landscape design to the surrounding environment (Martin, 2001).

Apart from landscaping, the concepts of ecological value and sustainability have also been gradually introduced into slope upgrading works such that they can be considered in the early stage of the design process. Native species have been promoted for the LPM works as far as practicable to enhance the ecological value of the slope sites and to achieve sustainability. A number of studies have indeed been carried out to investigate vegetation application on man-made slopes (Hau *et al.* 2005; Lui *et al.* 2005).

This paper summarizes the findings of a special task study on the application of vegetation on man-made slopes under an LPM consultancy. The study included site trials on some LPM slopes using various vegetation species and application methods under different environmental settings. The purpose of these site trials is to identify more native woody plant species suitable for planting on LPM slopes. The outcome of the site trials on pit-planting seedlings of the potentially suitable native species on three LPM slopes are reported.

## 2 METHODOLOGY

### 2.1 Study sites

Three slope sites were selected for the trial based on site availability and the variations of environmental conditions. Slope 10NE-B/C77 is located behind the Tsing Nam Street Service Reservoir. The slope surface was almost entirely covered by mature *Acacia confusa* (台灣相思) trees. The hillside was rather degraded and covered by mixed patches of exotic trees and natural hillside shrubland. Slope 11NE-B/C824 is located along Clear Water Bay Road. Though situated along a busy road, the slope was embedded in an extensive mature secondary forest. The mature native trees on the slope crest have provided appropriate shade for the plant growth. Slope 12SW-A/C129 is located along Tai Au Mun Road which was very exposed to wind and sun. The hillside was covered by mixed grass-shrubland and there were neither existing tall trees on the slope surface nor the slope crest (Figure 1). The planted seedlings were therefore expected to grow in very harsh environmental conditions.

The safety of the three slopes was found substandard and therefore LPM works have to be carried out. The works including installation of soil nails and provision of drainage system were implemented in 2005. The slope surfaces were covered by geo-textile and wire mesh. The landscape design of these slopes was primarily aimed for alleviating visual impact through green slope cover. At each of the three sites, designated area was identified for the site trials.

| Slope 10NE-B/C77<br>Tsing Nam Street, Tsing Yi                                                                                                                                                                                                                                                                      | Slope 11NE-B/C824<br>Clear Water Bay Road                                                                                                                                                                                                                                                                                                           | Slope 12SW-A/C129<br>Tai Au Mun Road                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                            |
| <ul style="list-style-type: none"> <li>• Slope gradient 40 deg</li> <li>• South facing</li> <li>• The slope surface is almost entirely covered by &gt;7m tall mature <i>Acacia confusa</i> trees</li> <li>• This is not a roadside slope</li> <li>• Low sunlight illumination because of the tree canopy</li> </ul> | <ul style="list-style-type: none"> <li>• Slope gradient 50 deg</li> <li>• Northwest facing</li> <li>• Hard surface cover before LPM works</li> <li>• No existing trees on slope surface</li> <li>• Mature trees on the slope crest provided appropriate shade for the slope surface</li> <li>• Relatively high traffic flow at slope toe</li> </ul> | <ul style="list-style-type: none"> <li>• Slope gradient 55 deg</li> <li>• East facing</li> <li>• Hard surface cover before LPM works</li> <li>• No existing trees on slope surface</li> <li>• Directly exposed to the sea, therefore receive strong wind and sun light illumination</li> </ul> |

Figure 1: Characteristics of the three slopes in the trial

### 2.2 Selection of plant species

A list of 198 potentially suitable species for application on man-made slopes was compiled based on past experience and recommendations from practitioners. From this list, nine small native tree and shrub species that had not been used on LPM slopes before were selected for the site trial and one additional native species which was known to grow well on man-made slopes was selected as a control to compare the performance of the less well known species (see Table 1). Three planting plots, each with approximately 100 m<sup>2</sup> in area, were established at each site. In each planting plot, 20 seedlings of each of the 10 selected species were planted randomly at a spacing of 1m in staggered pattern but the soil nail heads were avoided.

### 2.3 Planting and monitoring

The planting works in the site trial were carried out between September and November 2005. All the seedlings were supplied by the Native Tree Nursery of the Kadoorie Farm and Botanic Garden, and they complied with the General Specification for Civil Engineering Works (CEDD, 1992). The seedling height was between 500 and 1000 mm. Field checking for transplantation loss was conducted approximately one month after the planting work was completed. The seedlings that had died in the first month would be regarded as having perished due to stress during the transplant process. Replacement planting of the dead seedlings was then conducted.

The survival condition of each seedling, including the replacement seedlings, was recorded in May 2006, at the beginning of the first wet season after planting. The survival condition was examined again in September 2006 and December 2006 to determine the survival rate over the wet and dry seasons. Although the site trial under the LPM Agreement was completed in November 2007, monitoring was conducted again in October and November 2010 at the three slopes in order to determine the longer term growth of these planted seedlings (i.e. 5 years after the initial planting). The height of the planted seedlings was also measured.

Upon collecting field data, One-way Analysis of Variance (ANOVA) was conducted to compare the mean seedling survival rate among plots and among sites. The sites selected were very different in environmental conditions for plant growth, it was hypothesized that seedling survival would be significantly different between sites. Since the species used was regarded as a random factor, no statistical comparison was made between the survivals of difference species.

## 3 RESULTS

### 3.1 Differences in seedling survival between sites

Statistical analysis showed that the mean seedling survival rate after one year at slope 12SW-A/C129 ( $48 \pm 16\%$ ) was significantly lower than that at slopes 11NE-B/C824 ( $90 \pm 8\%$ ) and 10NE-B/C77 ( $85 \pm 9\%$ ) ( $p < 0.01$ ) (Table 1). The difference in survival rate between slopes 11NE-B/C824 and 10NE-B/C77 was not statistically significant ( $p > 0.05$ ). However, after 5 years, the mean survival rates at slope 12SW-A/C129 have slightly increased from 48 to 54% due to re-sprouting of some seedlings that were regarded as dead previously (Table 1). On the other hand, the mean survival rates at the other two sites have decreased. The results of ANOVA suggested that mean seedling survival rate after five years was significantly lower in slope 10NE-B/C77 ( $p < 0.05$ ) than those in the other two slopes while there was no significant difference in the mean survival rates between slopes 12SW-A/C129 and 11NE-B/C824 ( $p > 0.05$ ).

### 3.2 Differences in seedling survival within sites

Significant differences in mean seedling survival rate after one year were detected between planting plots in each of the three slopes (Table 1). In slope 12SW-A/C129, the seedling survival rate in Plot 1 ( $72 \pm 17\%$ ) and Plot 2 ( $53 \pm 24\%$ ) were significantly higher than that in Plot 3 ( $19 \pm 16\%$ ) respectively ( $p < 0.05$ ). However, there are no significant differences between Plot 1 and Plot 2 ( $p > 0.05$ ). In slope 11NE-B/C824, the seedling survival rate in Plot 1 ( $96 \pm 5\%$ ) was significantly higher than that in Plot 3 ( $85 \pm 12\%$ ) ( $p < 0.05$ ). However, there are no significant differences between Plot 1 and Plot 2 ( $90 \pm 14\%$ ), and Plot 2 and Plot 3. Lastly, in slope 10NE-B/C77, Plot 1 ( $100 \pm 2\%$ ) had significantly higher seedling survival rate than Plot 3 ( $90 \pm 13\%$ ) and Plot 3 had significantly higher seedling survival rate than Plot 2 ( $66 \pm 20\%$ ) ( $p < 0.05$ ).

Significant differences in the mean seedling survival rate after five years were also noticed between planting plots in slopes 12SW-A/C129 and 10NE-B/C77 but not in slope 11NE-B/C824 (Table 1). In slope 12SW-A/C129, Plot 3 ( $37 \pm 22\%$ ) had significantly lower survival rate than Plot 1 ( $60 \pm 29\%$ ) and Plot 2 ( $64 \pm 20\%$ ) ( $p < 0.05$ ). In slope 10NE-B/C77, Plot 3 ( $50 \pm 31\%$ ) had significantly higher survival rate than Plot 1 ( $7 \pm 8\%$ ) and Plot 2 ( $5 \pm 4\%$ ) ( $p < 0.05$ ). There were no significant difference in seedling survival between Plot 1 and Plot 2 ( $p > 0.05$ ).

Table 1: The survival rates of the planted seedlings in each plot one and five years after planting and seedling heights in 5 years

| Slope 12SW-A/C129                 |              | % survival |      |        |      |        |      |      |      | Stem Heights (cm) after 5 years |      |      |       |       |
|-----------------------------------|--------------|------------|------|--------|------|--------|------|------|------|---------------------------------|------|------|-------|-------|
| Species name                      | Chinese name | Plot 1     |      | Plot 2 |      | Plot 3 |      | Mean |      | Stem Heights (cm) after 5 years |      |      |       |       |
|                                   |              | Yr 1       | Yr 5 | Yr 1   | Yr 5 | Yr 1   | Yr 5 | Yr 1 | Yr 5 |                                 |      |      |       |       |
| <i>Cyclobalanopsis championii</i> | 嶺南青岡         | 95         | 95   | 40     | 55   | 10     | 40   | 48   | 63   | Nos.                            | Min. | Max. | Mean  | s.d.  |
| <i>Diplospora dubia</i>           | 狗骨柴          | 70         | 10   | 75     | 50   | 15     | 25   | 53   | 28   | 37                              | 50   | 110  | 97.8  | 38.4  |
| <i>Garcinia oblongifolia</i>      | 嶺南山竹子        | 60         | 50   | 40     | 75   | 5      | 50   | 35   | 58   | 17                              | 30   | 86   | 37.3  | 16.7  |
| <i>Gardenia jasminoides</i>       | 梔子           | 55         | 25   | 35     | 20   | 5      | 0    | 32   | 15   | 32                              | 19   | 85   | 42.8  | 22.4  |
| <i>Ilex viridis</i>               | 綠冬青          | 55         | 65   | 10     | 70   | 5      | 55   | 23   | 63   | 8                               | 20   | 33   | 30.8  | 11.5  |
| <i>Phyllanthus emblica</i>        | 餘甘子          | 85         | 80   | 60     | 75   | 50     | 60   | 65   | 72   | 37                              | 23   | 87   | 50.1  | 18.0  |
| <i>Reevesia thyrsoidea</i>        | 梭羅樹          | 55         | 45   | 75     | 80   | 30     | 45   | 53   | 57   | 43                              | 30   | 142  | 122.0 | 58.9  |
| <i>*Rhodomyrtus tomentosa</i>     | 桃金娘          | 100        | 100  | 80     | 80   | 40     | 60   | 73   | 80   | 34                              | 20   | 110  | 67.4  | 40.4  |
| <i>Rhus succedanea</i>            | 木蠟樹          | 80         | 70   | 80     | 80   | 20     | 5    | 60   | 52   | 48                              | 40   | 80   | 60.1  | 19.3  |
| <i>Ternstroemia gymnanthera</i>   | 厚皮香          | 60         | 60   | 35     | 50   | 5      | 30   | 33   | 47   | 31                              | 20   | 78   | 110.4 | 69.5  |
| Mean                              |              | 72         | 60   | 53     | 64   | 19     | 37   | 48   | 54   | 27                              | 17   | 150  | 68.0  | 52.9  |
| s.d.                              |              | 17         | 29   | 24     | 20   | 16     | 22   | 16   | 20   |                                 |      |      |       |       |
| Slope 11NE-B/C824                 |              | % survival |      |        |      |        |      |      |      | Stem Heights (cm) after 5 years |      |      |       |       |
| Species name                      | Chinese name | Plot 1     |      | Plot 2 |      | Plot 3 |      | Mean |      | Stem Heights (cm) after 5 years |      |      |       |       |
|                                   |              | Yr 1       | Yr 5 | Yr 1   | Yr 5 | Yr 1   | Yr 5 | Yr 1 | Yr 5 |                                 |      |      |       |       |
| <i>Cyclobalanopsis championii</i> | 嶺南青岡         | 100        | 75   | 100    | 90   | 100    | 80   | 100  | 82   | Nos.                            | Min. | Max. | Mean  | s.d.  |
| <i>Diplospora dubia</i>           | 狗骨柴          | 100        | 10   | 90     | 45   | 70     | 35   | 87   | 30   | 42                              | 73   | 300  | 172.5 | 55.1  |
| <i>Garcinia oblongifolia</i>      | 嶺南山竹子        | 100        | 60   | 95     | 85   | 85     | 50   | 93   | 65   | 11                              | 21   | 160  | 87.5  | 43.2  |
| <i>Gardenia jasminoides</i>       | 梔子           | 90         | 10   | 55     | 30   | 70     | 25   | 72   | 22   | 32                              | 120  | 265  | 184.8 | 38.2  |
| <i>Ilex viridis</i>               | 綠冬青          | 90         | 55   | 95     | 70   | 95     | 50   | 93   | 58   | 11                              | 15   | 200  | 126.5 | 62.6  |
| <i>Phyllanthus emblica</i>        | 餘甘子          | 90         | 55   | 90     | 65   | 80     | 80   | 87   | 67   | 25                              | 76   | 350  | 189.8 | 63.7  |
| <i>Reevesia thyrsoidea</i>        | 梭羅樹          | 95         | 70   | 100    | 90   | 90     | 80   | 95   | 80   | 16                              | 70   | 600  | 261.6 | 152.7 |
| <i>*Rhodomyrtus tomentosa</i>     | 桃金娘          | 100        | 5    | 100    | 25   | 100    | 25   | 100  | 18   | 40                              | 106  | 500  | 246.7 | 104.1 |
| <i>Rhus succedanea</i>            | 木蠟樹          | 100        | 50   | 80     | 50   | 90     | 85   | 90   | 62   | 8                               | 40   | 400  | 187.5 | 105.1 |
| <i>Ternstroemia gymnanthera</i>   | 厚皮香          | 95         | 50   | 90     | 45   | 70     | 20   | 85   | 38   | 21                              | 50   | 500  | 249.0 | 154.3 |
| Mean                              |              | 96         | 44   | 90     | 60   | 85     | 53   | 90   | 52   | 16                              | 106  | 250  | 190.1 | 47.6  |
| s.d.                              |              | 5          | 26   | 14     | 24   | 12     | 26   | 8    | 23   |                                 |      |      |       |       |
| Slope 10NE-B/C77                  |              | % survival |      |        |      |        |      |      |      | Stem Heights (cm) after 5 years |      |      |       |       |
| Species name                      | Chinese name | Plot 1     |      | Plot 2 |      | Plot 3 |      | Mean |      | Stem Heights (cm) after 5 years |      |      |       |       |
|                                   |              | Yr 1       | Yr 5 | Yr 1   | Yr 5 | Yr 1   | Yr 5 | Yr 1 | Yr 5 |                                 |      |      |       |       |
| <i>Cyclobalanopsis championii</i> | 嶺南青岡         | 100        | 0    | 90     | 10   | 95     | 70   | 95   | 27   | Nos.                            | Min. | Max. | Mean  | s.d.  |
| <i>Diplospora dubia</i>           | 狗骨柴          | 100        | 15   | 55     | 5    | 65     | 15   | 73   | 12   | 16                              | 48   | 220  | 118.2 | 44.9  |
| <i>Garcinia oblongifolia</i>      | 嶺南山竹子        | 100        | 15   | 75     | 10   | 95     | 100  | 90   | 42   | 7                               | 37   | 117  | 61.6  | 32.8  |
| <i>Gardenia jasminoides</i>       | 梔子           | 100        | 10   | 45     | 0    | 70     | 15   | 72   | 8    | 25                              | 50   | 198  | 129.2 | 42.4  |
| <i>Ilex viridis</i>               | 綠冬青          | 100        | 0    | 35     | 5    | 100    | 15   | 78   | 7    | 5                               | 72   | 160  | 117.8 | 37.1  |
| <i>Phyllanthus emblica</i>        | 餘甘子          | 100        | 0    | 95     | 0    | 100    | 35   | 98   | 12   | 4                               | 86   | 146  | 109.0 | 27.9  |
| <i>Reevesia thyrsoidea</i>        | 梭羅樹          | 95         | 15   | 85     | 10   | 100    | 85   | 93   | 37   | 7                               | 32   | 194  | 84.6  | 55.2  |
| <i>*Rhodomyrtus tomentosa</i>     | 桃金娘          | 100        | 0    | 60     | 0    | 95     | 35   | 85   | 12   | 22                              | 30   | 240  | 130.1 | 60.9  |
| <i>Rhus succedanea</i>            | 木蠟樹          | 100        | 15   | 70     | 5    | 95     | 50   | 88   | 23   | 7                               | 36   | 159  | 79.0  | 41.3  |
| <i>Ternstroemia gymnanthera</i>   | 厚皮香          | 100        | 0    | 50     | 5    | 85     | 75   | 78   | 27   | 14                              | 70   | 275  | 144.7 | 63.0  |
| Mean                              |              | 100        | 7    | 66     | 5    | 90     | 50   | 85   | 21   | 16                              | 22   | 164  | 77.2  | 44.0  |
| s.d.                              |              | 2          | 8    | 20     | 4    | 13     | 31   | 9    | 12   |                                 |      |      |       |       |

Note: \* denotes control species

### 3.3 Differences in seedling survival and growth rates between species and sites

The one-year seedling survival data (Table 1) indicated that within each site, the difference between species was not high especially in slopes 11NE-B/C824 and 10NE-B/C77. However, 5 years later, there appeared to be more differences in survival rate between species. Firstly, the mean survival rates of all species in slope 10NE-B/C77 were lower than 50% (Table 1). This was attributable to very low survival rates of all species in Plot 1 and Plot 2. The mean survival rates in Plot 3 were more similar to the mean survival rates in the other slopes. Considering only slopes 11NE-B/C824 and 12SW-A/C129, *Diplospora dubia* (狗骨柴),

*Gardenia jasminoides* (梔子) and *Ternstroemia gymnanthera* (厚皮香) had lower than 50% survival at both sites. The control species *Rhodomyrtus tomentosa* (桃金娘) had very low mean survival rate at slope 11NE-B/C824 (18%) but high mean survival rate at slope 12SW-A/C129. The rest of the 6 species had more than 50% survival at these 2 slopes.

In terms of seedling heights after 5 years, all species planted in slope 11NE-B/C824 had the highest mean height in comparison with those in the other two slopes (Table 1). In fact, a 3 to 4m tall canopy was formed on this slope (Figure 1). All species in slope 10NE-B/C77 except *Phyllanthus emblica* (餘甘子) had a mean height higher than that in slope 12SW-A/C129. At slope 10NE-B/C77, Plots 1 and 2 were severely invaded by weeds, in particular, *Ageratum conyzoides* (勝紅薊) and due to high seedling mortality, no canopy by the planted seedlings were formed (Figure 2). However, in Plot 3, a 2m canopy was formed by the planted seedlings (Figure 2). In slope 12SW-A/C129, seedling growth was slow and no canopy was formed on all plots (Figure 2).

Between species, tree species were generally taller than shrub species in most cases. *Cyclobalanopsis championii* (嶺南青岡) and *Rhus succedanea* (木蠟樹) had mean height at or higher than 1m at all sites (Table 1). *Garcinia oblongifolia* (嶺南山竹子), *Gardenia jasminoides* (梔子), *Ilex viridis* (綠冬青) and *Reevesia thyrsoidea* (梭羅樹) had a mean height higher than 1m at slopes 11NE-B/C824 and 10NE-B/C77 (Table 1).

| Slope 10NE-B/C77<br>Tsing Nam Street, Tsing Yi                                     | Slope 11NE-B/C824<br>Clear Water Bay Road                                           | Slope 12SW-A/C129<br>Tai Au Mun Road                                                 |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|  |  |  |
| Plot 1 and Plot 2 was invaded by weeds and had low seedling survival.              | A 3-4m canopy was formed                                                            | Seedling growth was slow and no canopy was formed on all three plots.                |

Figure 2: Plant establishment on the three slopes 5 years after planting

## 4 DISCUSSION

### 4.1 Differences in seedling survival rate between sites

A review of the initial field performance (2 years) of native tree and shrub species planted on man-made slopes in Hong Kong carried out by Hau and So (2005) shows that most of the native tree and shrub species are able to establish and grow well on slopes except on those very exposed slopes. The results of the site trial agree well with the findings in Hau and So (2005). All the planted species survive well on slopes 10NE-B/C77 and 11NE-B/C824 in the first year. As for slope 12SW-A/C129 where the site quality is relatively low for vegetation establishment, the mean survival rate is relatively low.

It is, however, worthwhile to note some interesting findings from the 5<sup>th</sup> year data. Whilst the mean survival rates in the 1<sup>st</sup> and 5<sup>th</sup> years of slope 12SW-A/C129 remained similar, the mean survival rate at slope 11NE-B/C824 had declined to a level similar to that of slope 12SW-A/C129. The mean survival rates at slope 10NE-B/C77 have dropped to very low levels. This suggests that long term monitoring of the planted vegetation is important in tracking the changes in seedling species performance over time.

The results are logical. The higher initial mortality on the very exposed slope 12SW-A/C129 can be explained by poor seedling establishment. However, those seedlings that could survive the first year could persist on this slope although the growth rates are slow (see section 3.3 above). The eventual high seedling mortality on slope 10NE-B/C77 was due to the mature *Acacia confusa* (台灣相思) tree cover on the slope

surface. *Acacia confusa* (台灣相思) is known to be allelopathic, which means that it will chemically suppress other plant species growing underneath them (Chou *et al.* 1998).

#### 4.2 Differences in seedling survival within sites

Significant differences in seedling survival after 1 and 5 years respectively between planting plots in each of the three slopes suggest that micro-site difference does affect the performance of planted seedlings both in short and long term.

#### 4.3 Differences in seedling survival and growth between species and sites

After five year of planting, the situation of seedling survival and growth becomes more apparent. Slope 11NE-B/C824 had acceptable seedling survival rate and very good growth rate (Hau & So 2005; Hau & Corlett 2003). The fact that this slope being embedded in mature secondary forests means that the environmental conditions are more beneficial to vegetation establishment. The low eventual survival rate of the control species *Rhodomirtus tomentosa* (桃金娘) at slope 11NE-B/C824 was due to the canopy shade formed by the planted seedlings as this species is light demanding.

The acceptable survival rate but slow growth rate of the seedlings planted on slope 12SW-A/C129 showed that vegetation on exposed slope would grow slowly. Species selection becomes more important in exposed slopes in order to achieve high survival rates. The good performance of the native Fagaceae *Cyclobalanopsis championii* (嶺南青岡) both in survival and growth especially in this exposed slope shows that other Fagaceae species such as *Cyclobalanopsis myrsinifolia* (小葉青岡) and *Cyclobalanopsis neglecta* (竹葉青岡) that are found naturally on exposed and steep hillside slopes should be tried on LPM slopes.

#### 4.4 Summary

Sites with favourable environmental conditions for plant growth, such as those surrounded by mature secondary forest, species selection, are more flexible in allowing the establishment and growth of different species. However, it is recommended to avoid those very light demanding species such as *Rhodomirtus tomentosa* (桃金娘) which could not survive even in slopes with little shading. For more exposed slopes, species selection is important. This study shows that *Diplospora dubia* (狗骨柴), *Gardenia jasminoides* (梔子) and *Ternstroemia gymnanthera* (厚皮香) have a low survival rate at exposed slopes. The rest of the 7 species planted are acceptable. Lastly, species selection on slopes covered by exotic tree stands is even more demanding. Since there is already a tree cover, the planting goal should focus on establishing a shade tolerant ground cover vegetation and site trials are needed.

Apart from plant species selection, planting quality and maintenance are also important factors to the survival of the seedlings and the long term vegetation growth. Quality seedlings should be used as far as possible. Planting works should also be supervised in respect of workmanship and appropriate handling of the seedlings. Planting works should ideally be carried out during the onset of wet season, in order to provide a favourable environment for their establishment.

### ACKNOWLEDGEMENTS

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# Application of Soil Bioengineering Measures to Man-made Slopes – A Pilot Study under the Landslip Preventive Measures (LPM) Programme

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## ABSTRACT

The public is now much more concerned than previously with the appearance of man-made slopes and demands better blending in of slopes with the surrounding environment. For many years guidelines on the landscaping of man-made slopes have been in place to address visual and environmental impact. Hydroseeding and planting of shrubs and whips in conjunction with erosion control mat/wire mesh and the preservation of existing vegetation are commonly used as slope surface cover under the Landslip Preventive Measures (LPM)/Landslip Preventive and Mitigation (LPMit) Programme. An alternative method, soil bioengineering has previously been used to repair and reduce erosion of natural terrain landslide scars. However, there is little experience available in Hong Kong for the application of soil bioengineering measures to control surface erosion and as landscaping measures for man-made slopes. As such, a study is being undertaken to review the application of soil bioengineering measures on man-made slopes. This paper provides an overview of soil bioengineering measures potentially applicable to Hong Kong slopes, details of field trials that have been undertaken and the interim results of the field trials.

## 1 INTRODUCTION

With regard to public safety, the Hong Kong Government is committed to maintaining the highest standards of slope safety and this necessitates upgrading works on man-made slopes. The public is much more concerned than previously with the appearance of man-made slopes, especially that they are not visually intrusive. As such, government guidelines on the landscaping of man-made slopes have been updated a number of times to address concerns on aesthetics and environment. Currently, experience with landscape mitigation measures on man-made slopes in Hong Kong typically includes hydroseeding and pit planting. The current policy for upgrading of existing man-made slopes under the LPM/LPMit Programme is also to preserve existing vegetation as far as possible, and to use vegetation as a surface cover on the slopes.

In April 2003, the Geotechnical Engineering Office (GEO) of Civil Engineering and Development Department (CEDD) began a pilot project to assess the suitability of soil bioengineering measures for minimizing the deterioration of natural slopes in areas of natural terrain landslide scars. A range of potentially suitable measures was reviewed and implemented on several natural slopes across Hong Kong. This is reported in Campbell et al. (2008). Although soil bioengineering is now widely practiced throughout the world for the treatment of erosion and unstable slopes, soil bioengineering techniques for man-made slopes had not previously been applied in Hong Kong (GEO, 2008).

In 2007, a new study of the application of soil bioengineering measures to control surface erosion on man-made soil slopes commenced as part of an LPM agreement. The main objectives for this study are: i) to review the contents of Campbell et al. (2008) and international literature with respect to their application on man-made soil slopes; ii) to select appropriate soil bioengineering measures for man-made soil slopes; iii) to identify suitable man-made slopes for carrying out field trials; and iv) to report the results of the study and field trials.

This paper presents an overview of soil bioengineering measures potentially applicable to Hong Kong and the interim results of the field trials that have been undertaken.

## 2 OVERVIEW OF SOIL BIOENGINEERING

### 2.1 Definition

Soil bioengineering has been defined as ‘the use of living vegetation, either alone or in conjunction with non-living plant material and civil engineering structures, to stabilize 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 behavior)’ (Morgan & Rickson, 1995).

### 2.2 Literature Review

Overseas soil bioengineering publications including Gray & Sotir (1996), US Department of Agriculture (1992) and (2000) were reviewed. Gray & Sotir (1996) covers various types of soil bioengineering measures including Live Stakes, Live Fascines, Bender Fences, Brushlayers, Hedgelayers, Branchpacking, Live Gully Repair, Live Cribwalls and Vegetated Gabions. US Department of Agriculture (1992) and (2000) both relate to upland slopes but include good details of the principles and design and construction guidelines for a large range of soil bioengineering measures. The limitations referred to in the two publications include the need for periodic monitoring and special management measures for the success of certain measures. The slopes referred to are on a large scale, typically much larger than the Hong Kong man-made slopes.

Locally GEO publication (GEO, 2000) lists common soil bioengineering measures including Coir/Jute Blankets, Hydro-mulching, Natural Fibre Geotextiles, Vetiver Grass and Soil Filled Panels. Campbell et al. (2008) only discusses the application of soil bioengineering to natural terrain and largely relates to volcanic geology.

### 2.3 Soil Bioengineering Measures

Soil bioengineering involves the installation of plants and materials in specific configurations to provide effective erosion control. After installation of the planting materials and subsequent growth of their foliage and roots combined with the invasive vegetation species growth, a soil bioengineering system is formed. Ideally this soil bioengineering system will encourage colonization by the surrounding plants, with the objective of producing a sustainable vegetation cover.

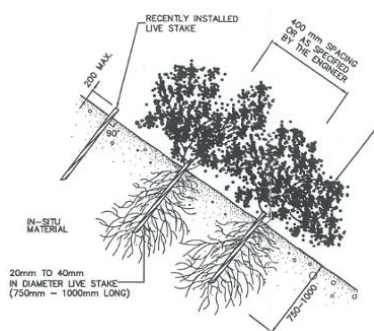
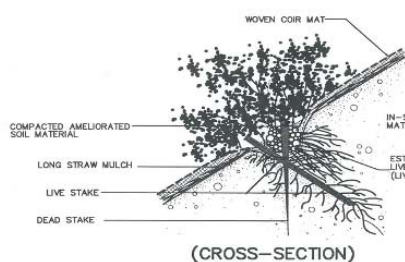
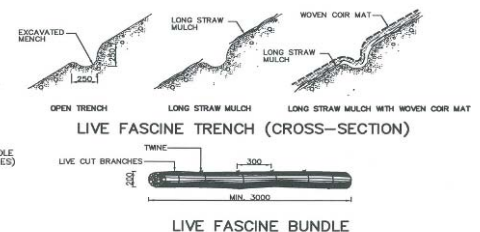
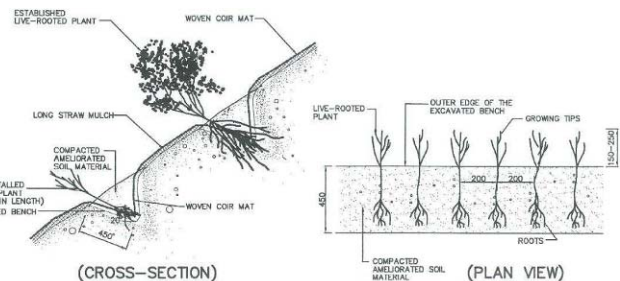
Soil bioengineering measures may be divided into two categories, ‘living’ and ‘combined living and non-living’ approaches. The ‘living’ approach includes traditional direct planting of grasses, shrubs or trees, and also newer soil bioengineering techniques that reinforce and stabilize the soil by using the stems or branch cuttings from adventitious rooting plants materials. The ‘combined living and non-living’ approach to soil bioengineering comprises the use of inert structural components in combination with live plants materials. The inert structural elements are used to provide immediate support, and their importance reduces with time as the plants as the root system develops.

### 2.4 Types of Soil Bioengineering Measures potentially suitable for Man Made Slopes in Hong Kong

As described in Campbell et al. (2008), most types of soil bioengineering methods are effective at controlling surface erosion, thereby they are potentially appropriate for application to man-made slopes in Hong Kong. However, specialized soil bioengineering methods that are used for controlling rills, local slumps, or limited to application on gentle slopes are considered not suitable for man-made slopes. For the ‘combined living and non-living’ approach, as the structural elements are limited to about 1.5m in height, the measures will provide limited stabilizing forces which are likely to be insufficient for man-made slopes that generally require larger supporting forces. Based on the consideration of the suitability and effectiveness of different soil bioengineering measures, four types of soil bioengineering measures, Live Stakes, Live Fascines, Brushlayers and Hedgelayers were selected for further study as presented in Table 1 and Figures 1 to 4.

Table 1: Soil Bioengineering Measures Implemented in this Study

| Soil Bioengineering Measures | Description                                                                                                                                                                                                                              | Material Type                               | Approaches |
|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------|
| Live Stakes                  | Live branches or plant stems cuttings, that root readily from cuttings. Usually, all side branches are removed prior to installation.                                                                                                    | Live branch cuttings with adventitious root | “Living”   |
| Live Fascines                | Bundles of live branch cuttings laid in shallow trenches constructed along the contour.                                                                                                                                                  | Live branch cuttings with adventitious root | “Living”   |
| Brushlayers                  | Live branch cuttings with adventitious root installed along constructed benches, laid approximately perpendicular to the slope face with overlapping layers of the live branch cuttings with the growing tips directed out of the slope. | Live branch cuttings with adventitious root | “Living”   |
| Hedgelayers                  | Live rooted plants installed along constructed benches, laid perpendicular to the slope face with the growing tips directed out of the slope.                                                                                            | Rooted plants                               | “Living”   |

Figure 1: Details of Live Stakes  
(Extract from Sotir, 1996)Figure 2: Details of Live Fascines  
(Extract from Sotir & McCaffrey, 1997)Figure 3: Details of Brushlayers  
(Extract from Sotir & McCaffrey, 1997)Figure 4: Details of Hedgelayers  
(Extract from Sotir & McCaffrey, 1997)

## 2.5 Limitations of Soil Bioengineering Measures

The application of soil bioengineering measures is limited by the thickness of the soil that act as a rooting medium for plants. Soil bioengineering measures are not suitable for steep slopes (over about 50°), as excavation works is required during implementation and instability of the slope may result from the excavation.

## 3 METHODOLOGY

### 3.1 Trial Site Selection

Budget was available for the trial implementation of bioengineering measures at four slopes. This was to enable the evaluation of different factors affecting the performance of the implemented soil bioengineering

measures. Slopes were selected from 2 LPM works contracts based primarily on criteria including slope gradients (from 35° to 50°), geology, presence of existing vegetation and accessibility for monitoring during the trial. Slope orientation and slope condition were also considered. The background information of the four selected slopes is summarized in Table 2.

Table 2: Soil Bioengineering Measures Implemented in this Study

| Feature No.          | Location   | Slope Angle (°) |                  | Geology  | Rock / Boulder Exposed | % of Existing Vegetation |
|----------------------|------------|-----------------|------------------|----------|------------------------|--------------------------|
|                      |            | (Average)       | (Installed Area) |          |                        |                          |
| 5NE-D/C2 (Site A)    | Tuen Mun   | 55              | 40               | Volcanic | No                     | 100                      |
| 6SE-C/C92 (Site B)   | Tsuen Wan  | 55              | 45               | Volcanic | No                     | 80                       |
| 7NW-D/C424 (Site C)  | Tsuen Wan  | 40              | 35               | Volcanic | No                     | 100                      |
| 14NW-A/C129 (Site D) | Chi Ma Wan | 60              | 50               | Granitic | Yes                    | 80                       |

### 3.2 Assessment for Measures Performance

The assessment for the implemented soil bioengineering measures is evaluated based on the viability and the growth performance of the plants. Monthly field inspections were conducted to evaluate the plant's viability and the growth condition of the plants under different climatic conditions. The field inspections included assessment of the growth performance and general health condition. Site characteristics including degree of exposure of the slopes to sun light, degree of moisture of soil, degree of weeds on slopes were also reviewed in the field inspections.

## 4 IMPLEMENTATION OF THE SOIL BIOENGINEERING MEASURES

During July of 2009 and August 2010, a comprehensive range of the soil bioengineering measures were designed and implemented in various species combinations on the four selected slopes. It is noted that the plant species were carefully selected so they are compatible with the soil bioengineering measures. Four main types of soil bioengineering measure (Table 3) were implemented as shown in Plates 1 to 4. Both live branch cuttings and rooted plants were used, as the completed measures are intended to blend in with the surrounding.

Table 3: Soil Bioengineering Measures Implemented in the Field Trials

| Soil Bioengineering Measures | Plant Species               | Chinese Name | Measures Implemented |                    |                     |                      |
|------------------------------|-----------------------------|--------------|----------------------|--------------------|---------------------|----------------------|
|                              |                             |              | 5NE-D/C2 (Site A)    | 6SE-B/C92 (Site B) | 7NW-D/C424 (Site C) | 14NW-A/C129 (Site D) |
| Live Stakes                  | <i>Ficus Microcarpa</i>     | 細葉榕          | ●                    | ●                  | ●                   | ●                    |
|                              | <i>Salix Babylonica</i>     | 垂柳           |                      |                    |                     |                      |
| Live Fascines                | <i>Ficus Microcarpa</i>     | 細葉榕          | ●                    | —                  | —                   | ●                    |
|                              | <i>Gardenia Jasminoides</i> | 白禪           |                      |                    |                     |                      |
| Brushlayers                  | <i>Gardenia Jasminoides</i> | 白禪           | ●                    | —                  | ●                   | —                    |
|                              | <i>Salix Babylonica</i>     | 垂柳           |                      |                    |                     |                      |
| Hedgelayers                  | <i>Ficus Microcarpa</i>     | 細葉榕          | ●                    | ●                  | ●                   | ●                    |
|                              | <i>Melastoma Candidum</i>   | 野牡丹          |                      |                    |                     |                      |

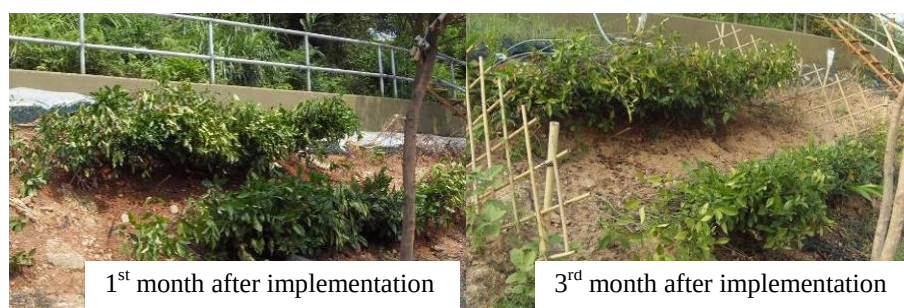


Plate 1: 5NE-D/C2 (Site A) - Brushlayers



Plate 2: 6SE-B/C92 (Site B) - Hedgelayers

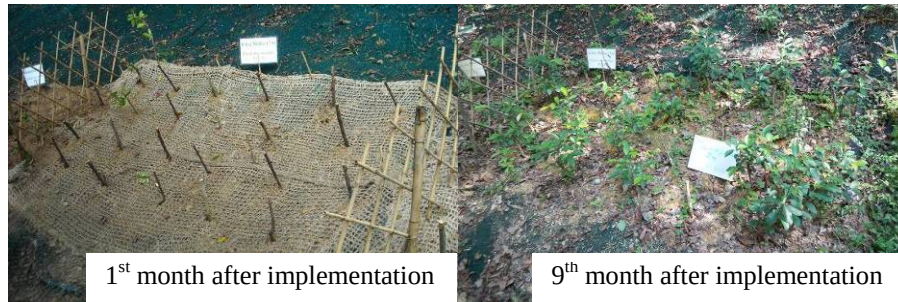


Plate 3: 7NW-D/C424 (Site C) - Live Stakes



Plate 4: 14NW-A/C129 (Site D) - Live Fascines

## 5 PERFORMANCE OF THE MEASURES

Monitoring of the performance of the planted material is still ongoing, but available results indicate variable performance of the measures. From the monitoring results up to December 2010, the survival rates for each species for the measures are summarized in Table 4.

Table 4: Summary of the Survival Rate of Soil Bioengineering Measures and Plant Species Implemented

| Soil Bioengineering Measures | Plant Species               | Chinese Name | Species Survival Rate (%) |        |        |        |         | Comparative Performance* |
|------------------------------|-----------------------------|--------------|---------------------------|--------|--------|--------|---------|--------------------------|
|                              |                             |              | Site A                    | Site B | Site C | Site D | Overall |                          |
| Live Stakes                  | <i>Ficus Microcarpa</i>     | 細葉榕          | 25                        | 62.5   | 79.2   | 75     | 60.4    | Good                     |
|                              | <i>Salix Babylonica</i>     | 垂柳           | 4.2                       | 37.5   | 25     | 31.3   | 24.5    | Fair                     |
| Live Fascines                | <i>Ficus Microcarpa</i>     | 細葉榕          | 10                        | —      | —      | 55     | 32.5    | Moderate                 |
|                              | <i>Gardenia Jasminoides</i> | 白禪           | 5                         | —      | —      | 70     | 37.5    | Moderate                 |
| Brushlayers                  | <i>Gardenia Jasminoides</i> | 白禪           | 91.1                      | —      | 72.2   | —      | 81.7    | Excellent                |
|                              | <i>Salix Babylonica</i>     | 垂柳           | 0                         | —      | 5.6    | —      | 2.8     | Poor                     |
| Hedgelayers                  | <i>Ficus Microcarpa</i>     | 細葉榕          | 100                       | 70     | 93.3   | 100    | 90.8    | Excellent                |
|                              | <i>Melastoma Candidum</i>   | 野牡丹          | 76.7                      | 20     | 50     | 75     | 55.4    | Good                     |

\* The comparative performance of the species is defined as follows:

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

As shown in Table 4, the survival rates of Live Stakes and Live Fascines were relatively low (4.2 to 25%) at Site A. By contrast, Brushlayers and Hedgelayers generally performed well (76.7 to 100%) except for the

species of *Salix Babylonica* (0%). The reason for the disparities may be due to the microclimate of Site A which is relatively dry and is not favorable for the establishment of the live cuttings materials of Live Stakes and Live Fascines. At Site B, the performance of both of the Live Stakes and Hedgelayers were observed to be satisfactory. It was noted that, the species of *Ficus Microcarpa* achieved a relatively high survival rates. This may be due to the fact that *Ficus Microcarpa* is a relatively tough species compare to *Salix Babylonica* and *Melastoma Candidum*. At Site C, all of the implemented measures performed well (50 to 93.3%) except for the species of *Salix Babylonica* (25% for Live Stakes and 5.6% for Brushlayers). The reason for the disparities may be due to the viability difference (*Salix Babylonica* requires humid environment for growing). At Site D, all of the implemented measures performed well (55 to 100%) except for the species of *Salix Babylonica* (31.3% for Live Stakes).

The performance of Live Stakes was satisfactory as the overall survival rate achieved 60%. For Live Fascines, the large difference of the survival rates may be because the establishment of Live Fascines is greatly dependent on the humidity of the site. In the site trials, the performance of Brushlayers and Hedgelayers were very satisfactory as the overall survival rate of 81.7% and 90.8% respectively.

## 6 CONCLUSIONS

There is a wide variation in the performance of different measures and plant materials used. Among the four types of measures implemented, Brushlayers and Hedgelayers showed better performance (55.4-90.8%) in terms of survival rate except for the relatively low survival rate for the species of *Salix Babylonica*. Live stakes and Live Fascines appeared to achieve a satisfactory performance (24.5-60.4%). During the field inspections, no observable surface erosion was found within the selected site. However, most of the measures have only been implemented on the slopes inspected for about or less than one year. The long-term performance of the measures and plant materials will require further assessment.

## ACKNOWLEDGEMENTS

This paper is published with the permission of the Head of the Geotechnical Engineering Office and the Director of Civil Engineering and Development Department, the Government of the Hong Kong Special Administrative Region.

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# Landscape Design for Natural Terrain Hazard Mitigation Works at Tung Chung

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## ABSTRACT

Based on recent literature review, there is limited application of landscape treatments to Natural Terrain Hazard Mitigation Works (NTHMW) locally and internationally. In a project of NTHMW near to the North Lantau Highway and Yu Tung Road, more systematic design principles and guidelines on good practice for landscape treatments for debris-resisting barriers have been developed (Geotechnical Engineering Office, 2010). This paper presents the design of NTHMW adopting the principles and guidelines developed. A preliminary landscape and visual impact assessment shall provide qualitative evaluation in option design focusing on the impact on the landscape resources, the landscape character and the potential visual impact on the adjacent Visually Sensitive Receivers (VSRs), i.e. who view the proposed works. More importantly, the design options are assessed on whether landscape and visual design mitigation measures proposed for each option can mitigate the impact to an acceptable level. Once the preferred option design is selected, the detailed landscape design shall focus on the specific hard and soft landscape treatments. Example of works showing the systematic design for NTHMW at Tung Chung will be discussed.

## 1 INTRODUCTION

The proposed NTHMW at Tung Chung is located along the North Lantau Highway and Yu Tung Road near Tung Chung Eastern Interchange. The site as shown in Figure 1 is characterized by semi-natural woodland and scrubland. Some existing trees are found within the study areas of the Project. A number of key VSRs are identified. They include the nearby residents, hikers along Tung Mui Path and passengers from aircrafts approaching the International Airport at Chak Lap Kok.

## 2 DESIGN PRINCIPLES AND GUIDELINES

The design principles and guidelines developed under the Project include the following:

- **Preservation of Existing Trees** – existing individual trees or tree groups shall be preserved as much as possible based on an integrated engineering landscape design solution.
- **Responsive Design to Surrounding Landscape Settings** – the design, deposition and profile of the debris barriers shall be responsive and compatible to the broad variations in surrounding landform and topography.

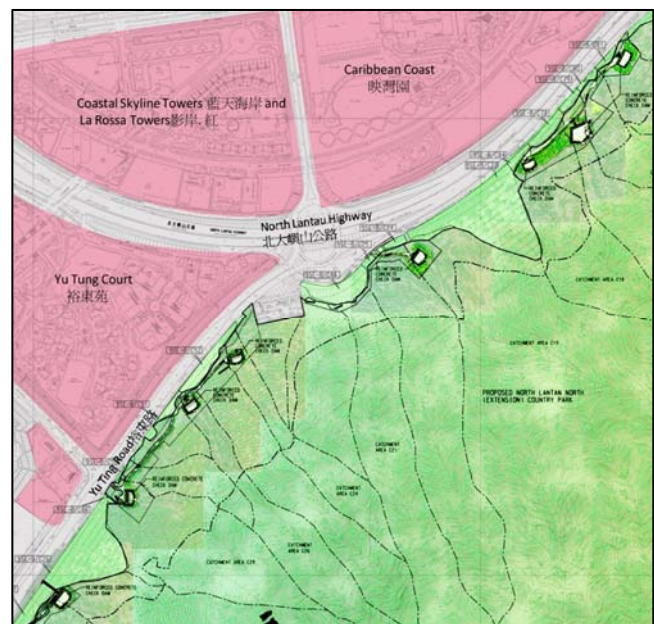


Figure 1: Locations of proposed NTHMW

- **Visual and Aesthetic Harmony** – the proposed engineering structures and associated landscape treatments in terms of tonal quality, colour and texture shall blend in with the surroundings to create visual harmony between the artificial and natural landscape so as to minimize potential adverse visual impact on the adjacent VSRs.
- **Self-sustainable with Minimal Maintenance** – the selection of landscape treatments shall be self-sustainable after establishment period with minimal maintenance requirements.
- **Enhancing Biodiversity** – the proposed landscape treatments shall aim at enhancing biodiversity. Selection of soft landscape shall make reference to the existing vegetation found on site.

An illustration of a typical debris resisting barrier with the application aforesaid design principles and guidelines is shown in Figure 2.

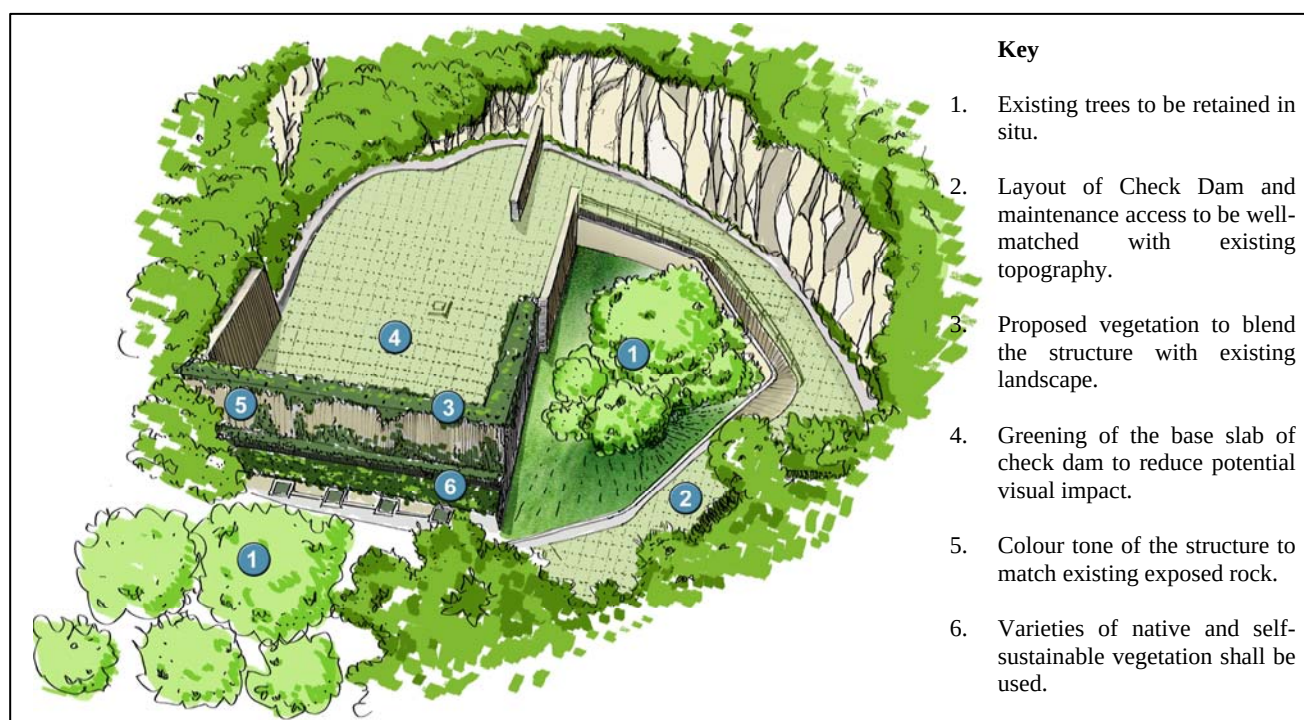


Figure 2: Design principles and guidelines for typical debris resisting barriers

### 3 RECOMMENDED OPTION FOR LANDSCAPE DESIGN

For the NTHMW at Tung Chung, a number of engineering design options with corresponding landscape treatment proposals were proposed. The positive and negative aspects of various options in terms of engineering and landscape perspective were assessed. One of the catchments under the Project is selected for discussion in this paper to illustrate the design principals and guidelines on good practice for landscape treatments.

Concrete check dam (approx. 30m x 25m x 5m) was proposed at the toe of the stream course of the catchment as the preferred engineering design option (see Figure 3). The preferred option would have the least disturbance on the existing vegetation. Because the check dam is relatively localized and small in scale, the impact on the existing landscape character is thus the smallest. The recommended option would be the least visually intrusive solution to the residential VSRs at adjacent high-rise buildings. The appearance of the concrete structure can be further enhanced by screen planting to an acceptable level from landscaping point of view.

Due considerations of the practicability, cost-effectiveness and sustainability of proposed landscape treatments for the recommended option were evaluated as shown in Table 1.

Based on the findings in the evaluation, proposed landscape treatments included retention of existing trees, screen planting as visual buffer, planting in crest and toe planter, climber on wall surface and colour treatments for concrete structure. The landscape proposals are illustrated in Figure 3.

Table 1: Assessment of application of landscape treatment

| Landscape Treatment                             | Practicability | Cost-effectiveness | Sustainability | Design Considerations                                                                                  |
|-------------------------------------------------|----------------|--------------------|----------------|--------------------------------------------------------------------------------------------------------|
| Retention of existing tree                      | √√             | √√                 | √√             | • Existing vegetation will be retained where practical.                                                |
| Screen planting as visual buffer                | √√√            | √√√                | √√             | • Proposed planting to create visual buffer to screen proposed structure from road users.              |
| Planting in crest and toe planter               | √√√            | √√                 | √√             | • Cost-effective and practical to soften the edge of structure for visual mitigation                   |
| Climber on wall surface                         | √√√            | √√√                | √√             | • Cost-effective and practical to mitigate the perceived scale and bulkiness of the proposed structure |
| Grasscrete on surface structure                 | √√             | √√                 | √√             | • Effective to mitigate visual impact on VSRs from adjacent high rise buildings.                       |
| Mural/ artwork                                  | √√√            | √                  | √              | • Practical but not preferred in this location given screened view by trees.                           |
| Colour treatment for exposed concrete structure | √√√            | √√                 | √√             | • Subtle colour to blend in with surrounding environment.                                              |

√√√ High √√ Moderate √ Low

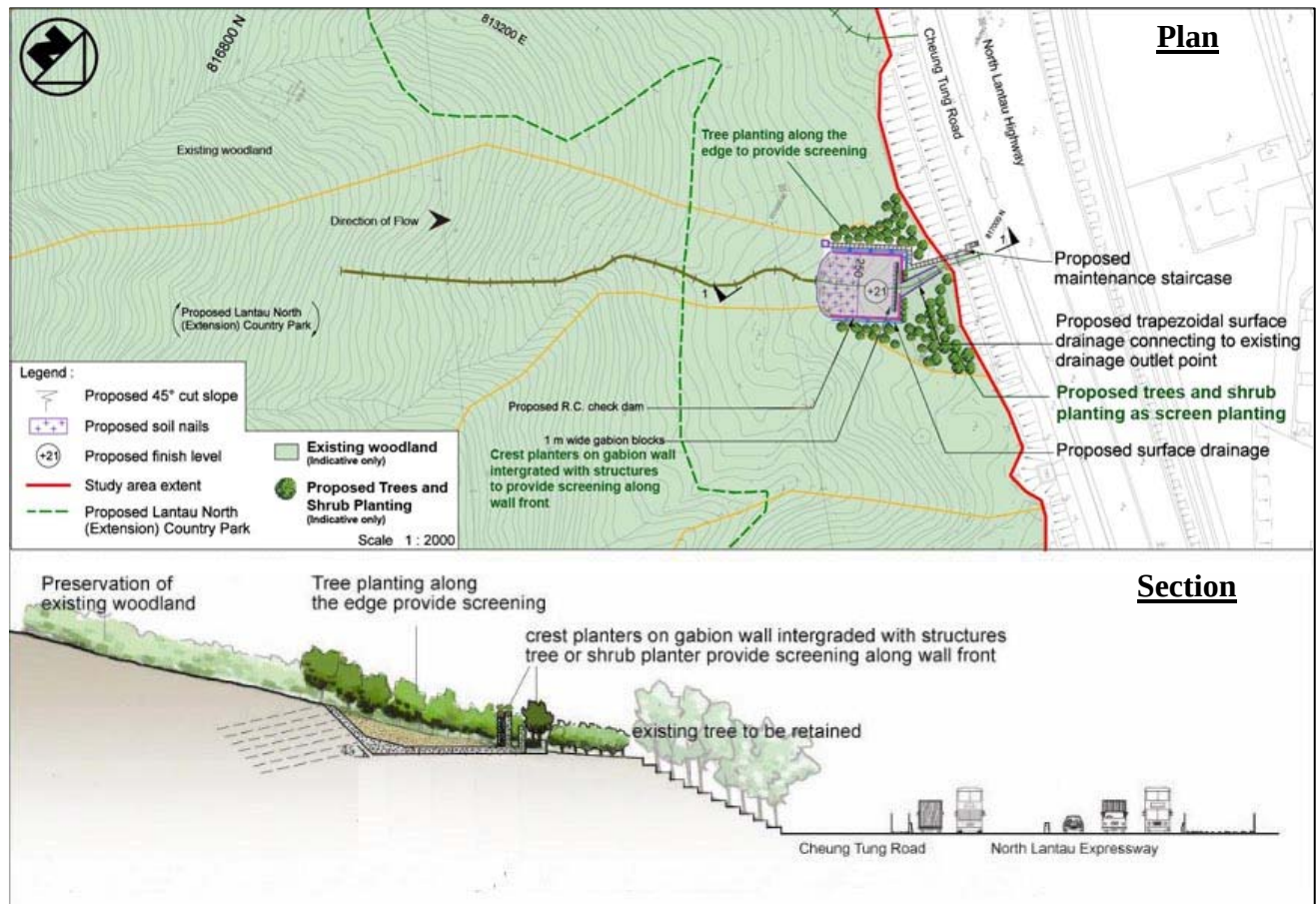


Figure 3: Adopted option – reinforced concrete check dam and associated landscape

#### 4 DETAILED DESIGN

Under the NTHMW for the study area of the project, a total of eight concrete check dams and three sections of flexible barriers were proposed.

Making reference to the findings and recommendations adopted in the option design stage, one of the main landscape design objectives was to screen the proposed engineering structures and blend in the structures to adjacent landscape as far as possible to minimize the potential visual impacts. Tree screen planting, planting on the vertical surface, toe planter, crest planting to soften the structures as well as planting on the flat surface of the check dam were proposed. A number of landscape initiatives have been proposed to ensure that the landscape treatment proposal could achieve the design intent. They are illustrated in Figure 4.

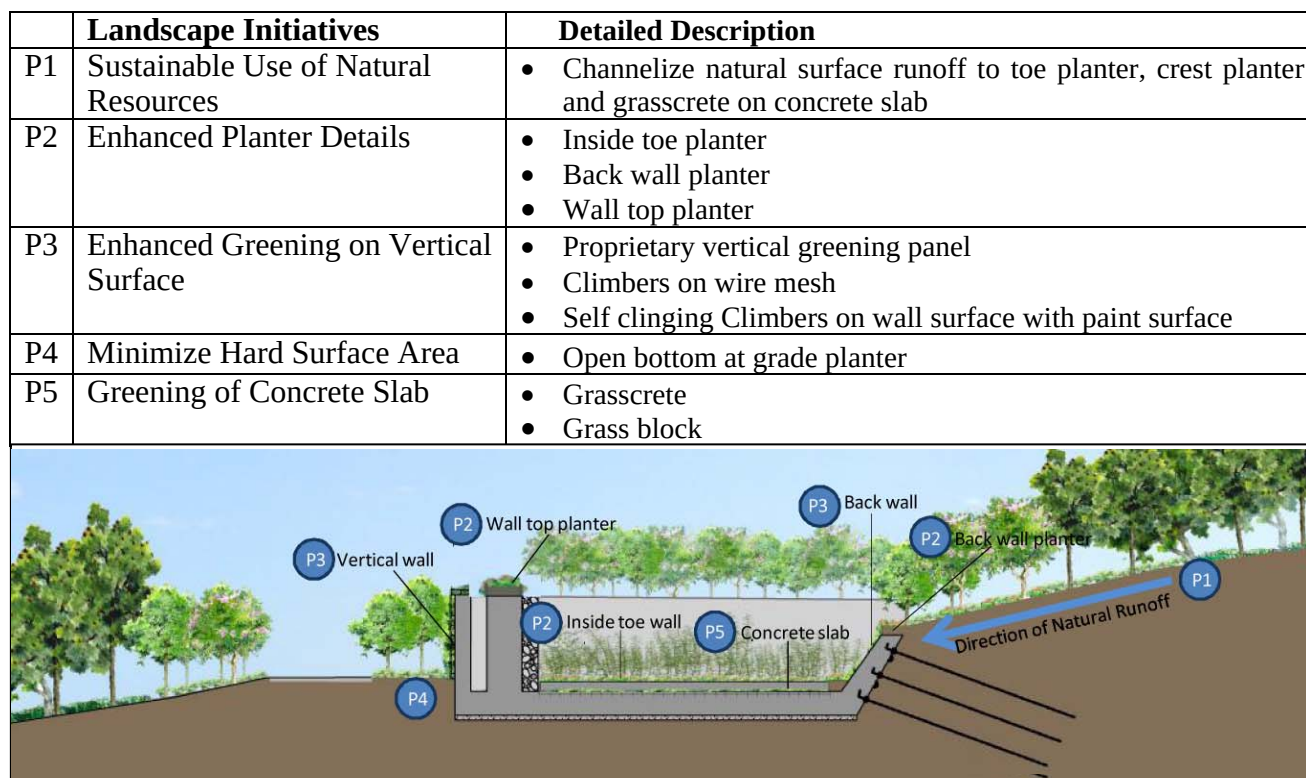


Figure 4: Detailed landscape proposals for check dams

Based on field observations, among those eight check dams, there is continuous surface runoff in six of the existing stream courses most of the year. The surface runoff would be useful for providing continuous water supply to the vegetation proposed within the check dams. Initiatives have been proposed for sustainable use of these natural resources to provide necessary water irrigation to the proposed planting particularly for planting areas on concrete structures such as toe planters, crest planters and planting on concrete slabs of the check dams. Water from the surface run off would be channelized by a series of piping systems to the designated planting areas (see Figure 5).

Toe planters with shrubs and climbers were proposed to soften the inner walls of the check dams (See Figure 6). Crest planters with shrubs and climbers were proposed to soften the wall top (see Figure 7). Safe access should be provided for routine horticultural maintenance. Minimum 600mm high planters were proposed on the top of the back walls to provide better greening transition to the proposed climbers on the back walls (see Figure 8).

The vertical facade of the check dams would be one of the key visual concerns that needs to be addressed. A number of greening proposals on vertical surface were proposed (see Figure 9). Traditional self-clinging climbers on concrete structure would provide satisfactory greening effect. However, there would be a limited choice of climber species. Climbers on wire mesh were proposed to explore more species diversity for the check dams. In addition, proprietary vertical green panels which can provide instant landscape effect were proposed to one of the check dams as a pilot scheme.

Apart from the check dams, access roads and the associated lay-by areas for maintenance vehicles to carry out occasional debris removal may also cause significant visual impacts. Landscape treatments for the facilities included planting areas with trees and shrubs at both sides of the access roads to provide screen to adjacent high rise residential VSRs (see Figure 10).

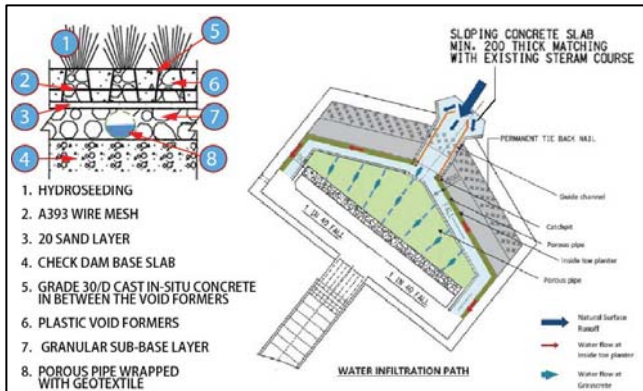


Figure 5: Channelizing natural surface runoff

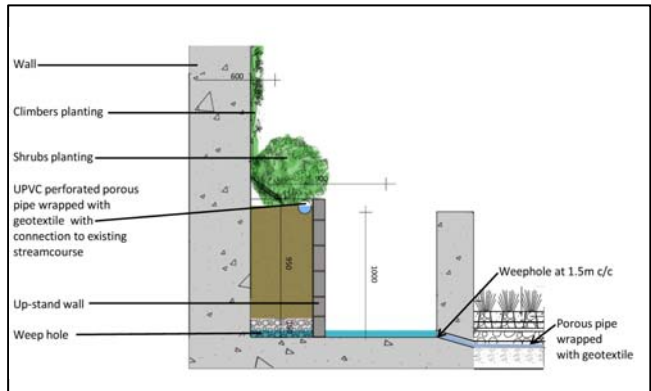


Figure 6: Enhanced toe planter details

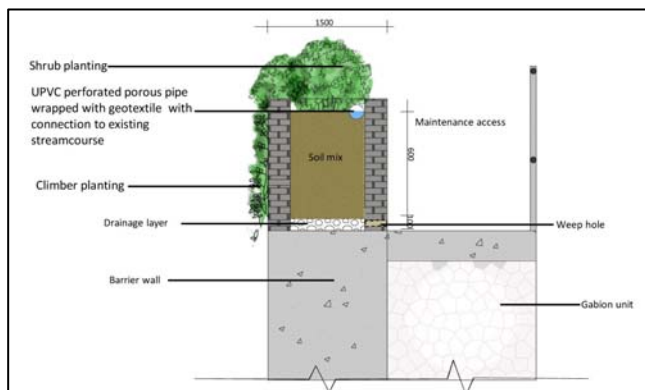


Figure 7: Enhanced crest planter details

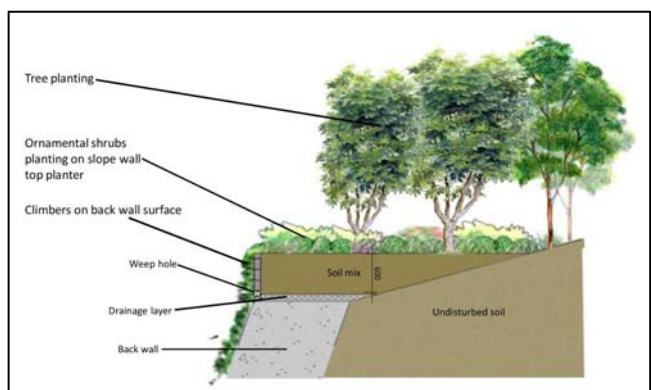


Figure 8: Enhanced back wall planter details



Figure 9: Greening on vertical wall

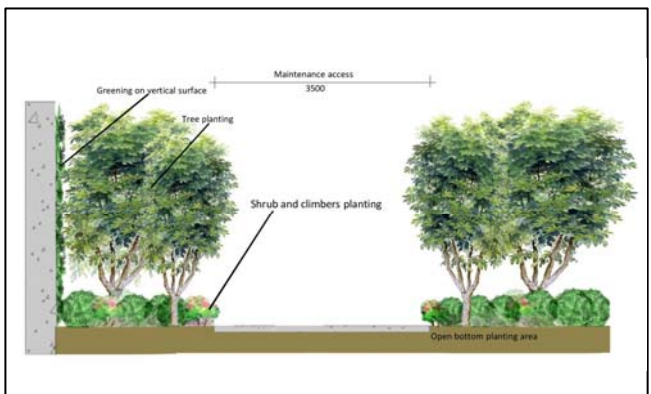


Figure 10: Maximizing planting areas

Because the location of the NTHMW is near the Hong Kong International Airport, there would be many air flight passengers who can see the check dams from aircrafts. The appearance of the base slabs of the check dams should be carefully addressed (see Figure 11). Traditional grasscrete was proposed. In addition, Grass Block in High-density polyethylene (HDPE) as a pilot scheme was also proposed to provide greening on the base slabs.

Proposed flexible barriers are generally considered less visually intrusive. However, during construction, existing vegetation around the barriers should be preserved in situ. Climbers were proposed to blend in the barriers with the surrounding landscape (see Figure 12).

Landscape maintenance for planting works plays a very important role for the success of landscape treatment. Early liaison with the future maintenance party should be made to agree the level of maintenance allowed for the proposed landscape works. Under this Project, the soft landscape works will be maintained on a bi-annual basis. Therefore, plant species proposed are primarily native species which require minimal



Figure 11: Traditional Grasscrete surface

horticultural care were not considered.

Photomontages have been prepared to illustrate the existing condition during construction (See Figure 13), the intended landscape effect at the end of establishment period (see Figure 14) and the landscape effect when planting become mature (see Figure 15). It is considered that even with the colour treatment and planting proposed for the concrete check dam, there would still be some landscape and visual impact upon completion of the landscaping works. However, when the buffer planting and climbers become mature, the impact due to the NTHMW would become negligible.

## 5 CONCLUSIONS

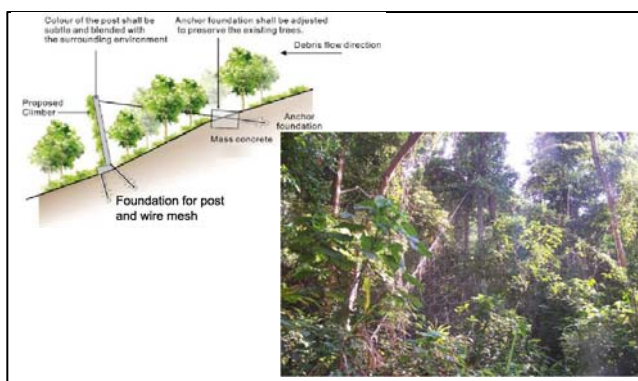
The design of NTHMW relies on seamless collaboration between geotechnical engineers and landscape architects who should be working hand in hand towards the goals and objectives set out for the project. Both hard and soft landscape works play an important role in mitigating the potential landscape and visual impact of NTHMW.

## ACKNOWLEDGEMENTS

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

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ongoing maintenance. Planting materials that are invasive or require regular pruning and intensive



Figure 13: Existing condition during construction



Figure 14: After completion of landscape works



Figure 15: Effect when planting matured

# Overview of Special Tasks in the Landslip Preventive Measures Programme

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## ABSTRACT

As part of the continuous development and self-improvement of the Landslip Preventive Measures (LPM) Programme, numerous special tasks have been conducted under various LPM consultancy agreements to supplement in-house efforts on geotechnological development and process improvement. Since the late 1990s, the Geotechnical Engineering Office, in collaboration with geotechnical practitioners and research institutions, have completed about 50 special tasks. In general, these special tasks can be classified into four categories, namely (i) technical development, (ii) quality assurance, (iii) data collection and (iv) process improvement. The findings of the special tasks and the respective improvement initiatives are largely reflected in the LPM process and the practitioners are generally benefitted. This paper gives an overview of the special tasks completed by the LPM consultants, where findings of the representative tasks from each of the four categories are presented and discussed.

## 1 INTRODUCTION

Being a technically complex, challenging and safety-related project, it is essential for the Landslip Preventive Measures (LPM) Programme to have a built-in mechanism to sustain its long-term development and self-improvement. The introduction of special tasks is one of the key components of the mechanism where the findings and the respective improvement initiatives are largely reflected in the LPM process and the practitioners are generally benefitted. Over the past ten years, the Geotechnical Engineering Office (GEO), in collaboration with the local geotechnical practitioners and research institutions, have completed about 50 special tasks. In general, these special tasks can be classified into four categories, namely (i) technical development, (ii) quality assurance, (iii) data collection and (iv) process improvement. This paper gives an overview of the special tasks, where findings of the representative tasks from each of the four categories are presented.

## 2 OVERVIEW OF SPECIAL TASKS

### 2.1 Background

To address the high public expectation on slope safety, the LPM output was substantially increased since the commencement of the 5-year Accelerated LPM Programme in 1995, followed by the 10-year Extended LPM Programme in 2000. In association with such a large LPM output, there has been a need to outsource some of the developmental work to geotechnical practitioners and research institutions. To this end, special tasks were introduced in the LPM consultancies since the late 1990s to help to streamline the LPM processes and to establish new standards and good practice in the investigation, design and construction of LPM projects. The first special task was carried out in 1999 in which the procedures and methodology of traffic impact assessment for LPM works were reviewed and improved. Since then, the GEO, in collaboration with local

geotechnical practitioners and research institutions, have completed about 50 special tasks under the LPM Programme, which cover the following four categories:

#### Technical development

- Investigation of various aspects relating to the design and construction of soil nailing technology including nail reinforcement materials, soil nail heads, slope facing systems, pull-out testing practice, etc.
- Exploration of stabilization methods other than conventional re-compaction, such as use of compacted rockfill, jet grouting technique, etc, for treatment of loose fill slopes.
- Improvement in the design and construction of greening and landscaping works through a series of studies in bio-engineering techniques, vegetation species, wall trees, etc.
- Review and improvement of other key components in slope works such as stepped drainage channel hydraulic design methodology, surface and sub-surface drainage systems, erosion control mats, soil cement for erosion control, etc.

#### Quality assurance

- Preparation of training materials on supervision of LPM works.
- Development of the procedures for making applications for excavation permits in relation to LPM works.
- Updating the procedures for Stage 2 Studies of private slopes.

#### Data collection

- Compilation of an inventory of slopes affecting schools.
- Identification of the GEO checking status of selected man-made slopes.
- Survey of the plant and equipment for the construction of LPM works to roadside slopes.

#### Process improvement

- Review and analysis of the causes of delay and cost variations for LPM and related ground investigation works.
- Review and analysis of public complaints and queries relating to LPM and related ground investigation works.
- Review and analysis of the results of site safety audits on LPM and related ground investigation works.
- Streamlining of the procedures for Stage 2 Studies of private slopes.

Some notable special tasks in each of the above four categories are elaborated in paragraph 3 below.

### *2.2 Implementation arrangement*

Special tasks are initiated on need basis when areas in the LPM process that warrant improvement are identified. The following are the common triggering parties:

- In-house design engineers, site engineers, engineers managing LPM consultancies and engineers managing other GEO studies who identify areas for improvement in the process of planning, design and construction of LPM works.
- Local geotechnical practitioners and researchers who identify innovative design/construction approach, new technology or skills that are suitable and worthwhile for further investigation in the LPM works.
- Other Government departments and stakeholders who request geotechnical expert advice or input from GEO.

- Members of the public who raise their concerns on slope safety that are genuine and crucial in meeting the general public's expectation.

As special tasks are generally regarded as quick-wins to address specific LPM issues arising from time to time, each of the tasks is more effectively carried out as an integral part of an LPM consultancy. When the need for a special task is justified, the GEO would identify a forthcoming LPM Consultancy suitable for performing the special task, mainly by matching the programme and scope of the project. Meanwhile, the GEO would also collaborate with the triggering parties to develop a technical specification detailing the services and deliverables to be provided under the special task.

### 3 SOME NOTABLE SPECIAL TASKS

#### 3.1 *Improvement of hydraulic design methodology for stepped drainage channels*

The task was initiated by the GEO in response to the concerns on the observed overflow, and hence the capacity, of stepped drainage channels during heavy rainfall. The study included a review of local and overseas literature on the design methodology, and field tests for verification of improved design method (MCL, 2006).

Among the design methods adopted by various countries, the one proposed by Chanson (1994) is considered the most comprehensive and suitable for Hong Kong's conditions. The flow in the stepped channel is divided into nappe flow and skimming flow regimes. In a nappe flow regime, the total elevation fall is divided into a number of small free-falls. The kinetic energy is dissipated by the development of hydraulic jumps on the channel steps. This flow regime, however, often occurs in a relatively flat stepped channel or low flow rate. On the other hand, the water in a skimming flow regime flows down the stepped face as a coherent stream, skimming over the steps and cushioned by the recirculating fluid trapped between the channel steps. The external edges of the channel steps form a pseudo-bottom over which the flow passes. Most of the energy in the flow is dissipated through the recirculation vortices beneath the pseudo-bottom. In general, skimming flow occurs under high flow conditions or in steep stepped channels. As the stepped drainage channels in Hong Kong are usually steep, it is anticipated that the flow with relatively high kinetic energy would require a high energy-dissipating capability channel. In the improved design method, a skimming flow assumption is recommended since skimming flows dissipate energy more efficiently.

Field tests were carried out at four sites on Hong Kong Island (Bowen Road, Mount Davis Reservoir, Yiu Hing Road and Chai Wan North FWS Reservoir) between March and June 2006 to verify the design assumptions (Figure 1). The tests showed good agreement between the observed and design capacity using the improved design method. The improved design method was then promulgated through GEO Technical Guidance Note No. 27 (TGN 27) in 2006 (GEO, 2006). The recommendations given in TGN 27 have also been incorporated in the Stormwater Drainage Manual published by the Drainage Services Department.



Figure 1: Field test of stepped drainage channel

#### 3.2 *Study of masonry walls with trees*

During the urban development of Hong Kong in early days, it was common that masonry retaining walls were formed in association with the construction of houses and roads (Figure 2). Trees, in particular banyan trees, were often found growing spontaneously on these old masonry walls. The majority of these old masonry walls with trees are found in northern part of Hong Kong Island, especially in the Mid-Levels. As the old masonry walls with trees constitute an important and beautiful landscape element and heritage of urban Hong Kong, special efforts have been made to preserve the existing trees and masonry block patterns, without compromising on slope safety.

A special task was carried out in 2005 to review and identify suitable methods for upgrading these old masonry walls, whilst at the same time preserving the masonry blocks and existing trees (CMW, 2005). Emphasis was also placed on the assessment of the effects of tree roots and stems on the stability of the masonry walls. Based on the study, the root system of the trees growing on masonry walls could have some beneficial effect on the stability of the masonry walls. However, due to inherent uncertainties and the difficulties in quantifying the beneficial effect of tree roots, the study suggested that this effect could be ignored in the stability analysis of masonry walls. In contrast, the surcharge of wall trees was found to have adverse effect on the stability of masonry walls. Wind forces on wall trees may also cause additional sliding forces and overturning moments to act on the masonry walls.

Apart from design consideration, the study has identified that soil nail installation, construction of hand-dug caissons, flying buttresses (where space permits) or a combination of these methods can effectively preserve the masonry blocks and the wall trees. Some precautionary measures to avoid damage to the masonry blocks and wall trees during the course of upgrading masonry walls are also recommended.



Figure 2: Study of old masonry walls with trees



Figure 3: Training course on supervision of soil nail construction

### 3.3 Training materials on supervision of soil nail installation

Since the mid-1990s, soil nailing has become one of the most common slope upgrading methods in Hong Kong, mainly due to its robustness as well as ease and economy of construction. To upkeep the quality of slope upgrading works, the GEO commissioned a special task in 2000 on producing a set of training kit for supervision of soil nail installation. It was intended to equip the site supervisory staff with the necessary knowledge and skill on supervision of soil nailing works to ensure compliance with the required standards.

The training kit comprises a set of presentation materials, a series of video clips and training notes illustrating the proper soil nail installation procedures and the necessary site checking process. The crucial installation procedures that deserve special attention include hole drilling, bar installation, grouting, pull-out test and soil nail head construction. The common deficiencies and examples of poor workmanship as well as the corresponding mitigation/remedial measures were summarised. Apart from workmanship, the key site safety aspects were also identified and discussed. The basic soil nail design principles were also covered in the training kit set so that the importance of good workmanship could be better appreciated.

Since the completion of the special task, the training kit has been adopted as the official training materials in the half-yearly training course jointly organized by the GEO and the Hong Kong Polytechnic University. Up to February 2011, 26 courses have been arranged, and more than 1,300 candidates have attended the courses (Figure 3). The training notes have also become a popular and practical guidance for local site staff involved in the supervision of soil nailing works.

### *3.4 Preparation of an inventory of slopes affecting schools*

Under the LPM Programme, high priority has always been given to man-made slopes affecting facilities of high landslide consequence such as buildings and major roads. In this regard, high-priority slopes affecting different facilities within the boundaries of schools including school buildings, playgrounds, footpaths, access roads, car parks, etc were selected for further action. This entailed the establishment of a comprehensive and up-to-date database on man-made slopes affecting schools in order to facilitate the selection of the most deserving slopes for LPM action on the basis of the latest information.

In order to establish an accurate database of man-made slope affecting schools within the shortest possible time, the GEO has commissioned three special tasks under three different consultancy agreements. An efficient methodology for slope identification was then developed, and the potential slope candidates were verified through field inspections. Through the three special tasks, a database of some 1,600 slopes affecting school facilities was finally established, and this has enabled the GEO to deal with the high priority slopes affecting schools promptly under the LPM Programme.

### *3.5 Review and analysis of complaints*

The GEO, and the LPM consultants and contractors always regard public complaints as valuable feedback for self-enhancement and improvement of the LPM process. In the early 2000s, a special task was carried out to review and analyse the LPM related complaints received by the GEO from 1999 to 2001 (HCL, 2002).

The complaints are generally associated with four categories, namely nuisance, temporary traffic management, working method and access problem. These four categories of complaints have made up almost 75% of the total complaints received. Among the nuisance category, over half of the complaints are related to dust generated from soil nailing or spray concrete works, and muddy water caused by either run-off from the sites or blockage of surface channels.

The review has also identified Hong Kong Island, Kowloon and Sai Kung as the three “hot spot” districts with substantial number of complaints. The characteristics of these “hot spot” districts were identified, which include: (i) number of active works sites on roads where no suitable alternative route was available to motorists, (ii) active sites adjacent to Country Parks, and (iii) social/economic characteristics of the resident population.

Having characterized the nature of complaints, recommendations for improvement in the LPM process were given. It was affirmed that various simple measures are indeed effective complaint mitigation measures. These include the promulgation of GEO Information Notes, the distribution of pamphlets to residents of NT villagers where works are to be carried out, the erection of warning signs, the specifying of more stringent noise levels than those allowed under EPD, etc. Apart from these mitigation measures, it recommended improvement on ways to deal with complaints by conducting a benchmarking exercise by comparing the GEO complaints procedures and mitigation measures with other large public organizations. The findings of the study had formed a solid basis to catalyze the enhancement of the GEO complaint handling procedures.

## **4 CONCLUSION**

The introduction of special tasks since the late 1990s has proven to be an effective means to enhance and improve the LPM Programme. The findings of the special tasks are often presented in the regular LPM liaison meetings with LPM consultants and contractors. This has provided a good platform for experience sharing and gathering feedback among geotechnical practitioners who may involve in similar works. In general, the geotechnical practitioners have benefitted from the improvement initiatives reflected in the LPM process. Currently, there are more than 10 special tasks being carried out by consultants under the post-2010 Landslip Prevention and Mitigation (LPMit) Programme.

To ensure a wider spectrum of local practitioners that can benefit from the special tasks, the more important and successful findings of the tasks would usually be incorporated into GEO guidance documents, sample tender documents of LPM works contract, working procedures, etc. This arrangement has become a built-in mechanism which allows the geotechnical community to collaborate to meet Hong Kong's need for the highest standard of slope safety.

## ACKNOWLEDGEMENTS

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# Technical Developments on Quality Assurance of Soil Nailing Works Under the Landslip Preventive Measures Programme

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## ABSTRACT

Soil nailing has been widely used to stabilise slopes in Hong Kong since the mid-1990s because of its reliability and ease of construction. Like any other buried engineering works, the quality of soil nails is difficult to check once constructed. In 2001, the Geotechnical Engineering Office (GEO) began to identify and try out some non-destructive methods to achieve this objective. In 2004, the GEO adopted time domain reflectometry (TDR) technique to assess the quality of constructed steel soil nails with pre-installed wires at slopes upgraded under the Landslip Preventive Measures Programme. This paper gives an overview of the use of TDR technique in assessing the quality of steel soil nails with pre-installed wires and some development work for wider application of TDR in geotechnical engineering.

## 1 INTRODUCTION

Soil nailing was first introduced to Hong Kong in the 1980s and has become widely used as a slope stabilization measure since the mid 1990s because of its reliability and ease of construction. Similar to other buried engineering works, it is difficult to assess the quality of an installed soil nail in respect of the as-built length and the integrity of the cement grout annulus. Incidents of “short piles” and “short nails” in the late 1990s and early 2000s aroused concern of the industry over the quality assurance of buried engineering works.

To enhance the quality control of soil nailing works under the then Landslip Preventive Measures (LPM) Programme, the Geotechnical Engineering Office (GEO) strengthened site supervision and introduced independent site audits on soil nailing works, and in 2001 began to identify and try out potential non-destructive testing (NDT) methods that could be used to assess the quality of installed soil nails. The NDT methods are not to replace good supervision at the time of construction; they are to provide additional quality assurance and serve as a deterrent against mal-practices. Among the potential NDT methods examined, viz. sonic echo method, mise-a-la-masse method, electro-magnetic induction method, electrical resistance method (ERM), magnetometry and time domain reflectometry (TDR), TDR was found to be the simplest, relatively quick and least expensive (Cheung, 2003). In 2004, the GEO introduced TDR to its soil nailing works under the LPM Programme for pilot use during the independent site audit. Upon completion of the pilot programme in 2007, an independent review of TDR and other NDT methods (Lee & OAP, 2007) was conducted, which supported the continual use of TDR as an audit tool and suggested enhancement to the sampling strategy for testing. This paper gives an overview of the use of TDR in assessing the quality of installed soil nails, the sources of uncertainty of TDR, a case where TDR has identified anomalies and the corresponding follow-up action and some development work for wider application of TDR in geotechnical engineering.

## 2 PRINCIPLE

TDR was first developed in the 1950s from the principle of radar. It is commonly used in the telecommunication industry to identify discontinuities in transmission line. The technique has been applied to many other areas such as geotechnology, hydrology and material testing since the 1980s. TDR involves sending electrical pulses along a transmission line, which is in the form of coaxial or twin-conductor configuration, and receiving reflections or echoes induced by any discontinuities or mismatches in electrical

properties in the transmission line. By measuring the time for the pulses to travel from the pulse generator to the point of discontinuity/mismatch, the corresponding distance can be estimated.

If a wire is pre-installed alongside a soil-nail reinforcement, which is generally a steel bar, the configuration becomes analogous to a twin-conductor transmission line and the end of the grouted reinforcement-wire pair (a soil nail) becomes a discontinuity. This suggests that TDR can be used to determine the length of the installed nails (Cheung, 2003).

The pulse propagation velocity,  $v_p$ , along a reinforcement-wire pair depends on electrical properties of the material in close proximity to the pair. The pulse propagation velocity along a reinforcement-wire pair in air (i.e.  $v_p(\text{air})$ ) will be 2 to 3 times than that in cement grout (i.e.  $v_p(\text{grout})$ ). Hence, the pulse travel time along a soil nail with void in a grout annulus will be less than that in a fully grouted soil nail of the same length. In addition, a reflection will be induced at the grout-void interface as shown in Figure 1.

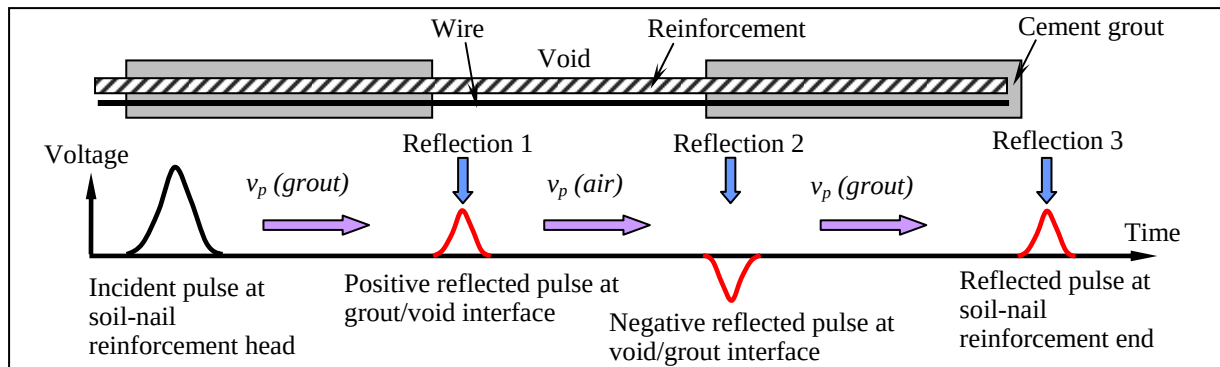


Figure 1: Theoretical TDR waveform of a soil nail with defect in grout annulus

The magnitude and polarity of the reflection when an electrical pulse reaches the location of discontinuity depend on the amount of changes in electrical impedance at the subject location and can be explained in terms of the reflection coefficient,  $\Gamma$  (Hewlett Packard, 1998):

$$\Gamma = \frac{V_r}{V_i} = \frac{Z - Z_o}{Z + Z_o} \quad (1)$$

where  $V_r$  is the peak voltage of the reflected pulse,  $V_i$  is the peak voltage of the incident pulse,  $Z$  is the electrical impedance at the point of reflection and  $Z_o$  is the characteristic electrical impedance of the grouted reinforcement-wire pair. When a pulse reaches the end of a soil nail, a positive  $\Gamma$  (i.e. positive pulse reflection) will occur due to an increase in the electrical impedance. Similarly, a positive reflection will be returned when a pulse passes from cement grout to void due to an increase in electrical impedance, and vice versa a negative reflection will be returned. Moreover, the pulse travel time is less than that in a fully grouted pair. Hence, one can in-principle determine the quality of an installed soil nail based on a TDR waveform.

If the wire is in electrical contact with the reinforcement at the end of a soil nail,  $Z$  will tend to 0 and  $\Gamma$  becomes negative. Figure 2 shows schematically some basic TDR waveforms for a standard transmission line and the corresponding soil nail with different configurations.

### 3 RELIABILITY OF TDR

Soil nails of various lengths and grout annulus configurations were prefabricated and tested to investigate the feasibility of using the technique to assess the quality of installed soil nails and the sources of uncertainty (Pun et al, 2007). Guidelines on testing procedure and interpretation of test results using TDR have been standardized to minimize the uncertainty of the technique as far as possible and to fulfill the requirements of using NDT for quality control of geotechnical works as stipulated in GEO (2004).

Uncertainties associated with the TDR test method and the inherent natural variation of quality of soil nails have been identified and assessed to facilitate the determination of the precision limit of the test method (i.e. test-related uncertainty) and the effect of inherent normal variation of soil nails on the test results (i.e. test-

unrelated uncertainty). Cheung (2006) shows that the 95% confidence level of the precision limit of a TDR test, which is not related to the natural variability in nail characteristics, is about  $\pm 5\%$ .

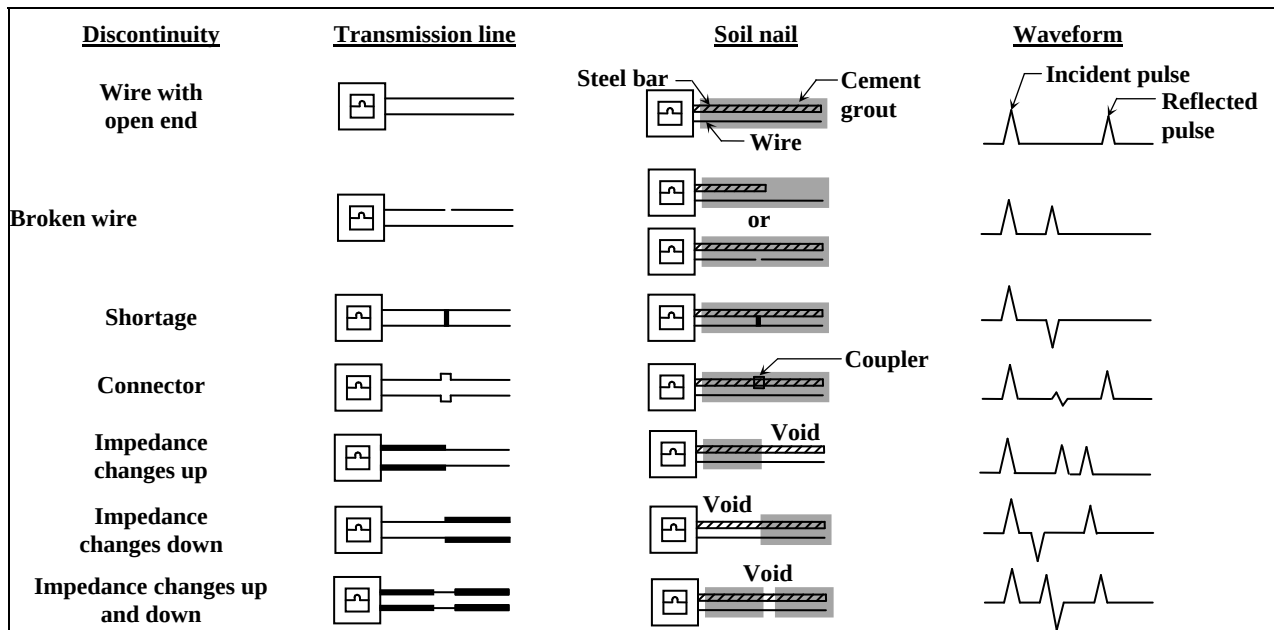


Figure 2: Basic schematic TDR waveforms of a transmission line and the analogous soil nail

Cheung (2006) reported that the uncertainty due to reinforcement size (both diameter and length), the ground conditions, and the presence of couplers appears to be insignificant when compared with other sources of uncertainty. The 95% confidence level of the overall error in length estimation using TDR is estimated to be about  $\pm 9\%$ . This increase in the uncertainty with respect to test-related uncertainty reflects indirectly the possible variability in the characteristics of soil nails within a site and across sites, that have been installed to the current construction practice.

#### 4 APPLICATION OF TDR AS QUALITY ASSURANCE

In 2004, GEO implemented a pilot quality assurance programme using TDR as part of the independent site audit to check the quality of soil nails with pre-installed wires at LPM sites. The objective of the programme is to experiment the use of TDR to supplement the site supervision in the quality control of soil nailing works. It also allows experience to be gained with the technique to facilitate further improvement. Under the programme, a small percentage of soil nails are selected from each LPM site for audit. Apart from the TDR test on calibration soil nails whose length needs to be known for the determination of the pulse propagation velocity, the tests on test nails are conducted and interpreted without prior knowledge of their lengths.

Based on the consideration of the uncertainty of the TDR test method and to balance the number of defective nails to be detected against the number of false alarm, an 'alert limit' was devised at  $\pm 15\%$  of the design length such that if the difference between the TDR-deduced length of a soil nail and its design length exceeds the alert limit, that soil nail is considered as anomalous and follow-up action will be initiated. A short TDR-deduced length could be due to either the as-built length of the reinforcement or the pre-installed wire or both is shorter than their corresponding design length and/or there are substantial defects in the grout annulus. In addition to the deduced length, the TDR waveforms could also provide some telltale signs of certain anomalies like grout defect.

Upon completion of the pilot programme in 2007 a review of the use of NDT in quality control of soil nailing works was conducted (Lee & OAP, 2007) and confirmed that TDR is an effective method in detecting soil nails with significant defect in length and grout. The review also recommended a modified sampling strategy for testing where soil nails at a site are grouped into one or more lots to suit the construction programme and are then selected for testing on a lot-by-lot basis.

The following sections describe a case to demonstrate how TDR helps identify defective nails. The subject cut slope is about 10 m high and 115 m long with an average slope angle of  $50^\circ$ . The upgrading works comprised 95 soil nails. All the soil nails were 7 m long and without couplers. During an independent site audit the TDR-deduced length of five out of ten test nails were found to be significantly shorter than their design length, and their TDR waveforms were anomalous. Further TDR testing of the remaining nails at the slope revealed two more nails with short TDR-deduced length and anomalous TDR waveforms. The seven nails with anomalous TDR test results, namely A13 to A17, B14 and C13, clustered together (see Figure 3(a)). The waveforms of these seven nails (e.g. Figure 3(c)) differ from those of the remaining 88 nails in two aspects (e.g. Figure 3(b)): (i) the presence of significant local reflections between the major reflection from the nail head and that from the nail end, and (ii) shorter pulse propagation time to the end of these nails.

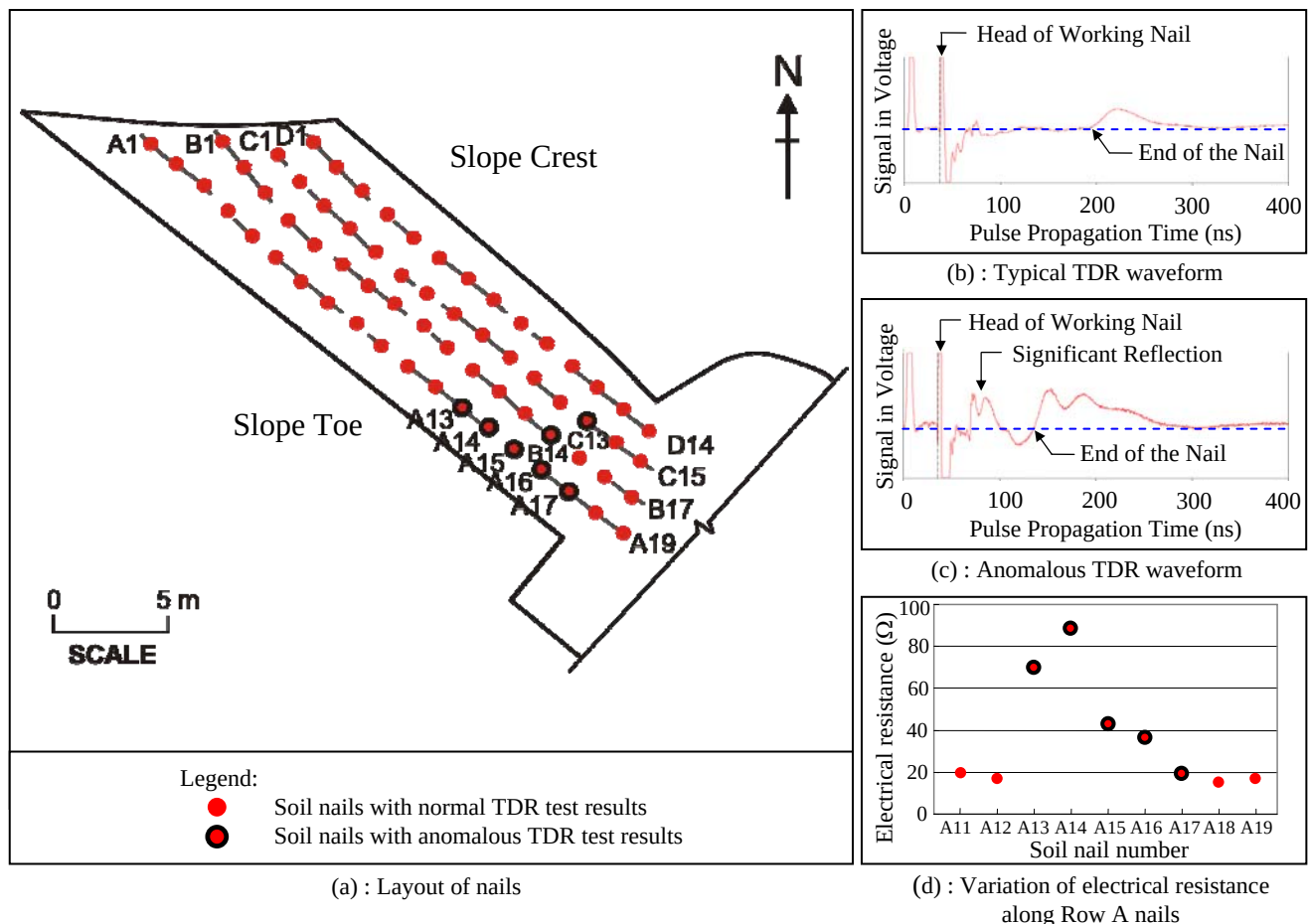


Figure 3: Layout of nails and TDR test results

The waveforms of the seven nails bear some resemblance of the characteristics of that with grout defects in Figure 1, suggesting the anomalies in these seven nails could be related to the presence of voids in the grout annulus. A review of the site records also indicated that significant grout take was encountered at these locations during the construction of the nails. To supplement the TDR tests, another NDT technique, ERM, was carried out. This method measures the electrical resistance between a soil nail and a remote electrode. It makes use of the spatial variation of the electrical resistance of soil nails as an indicator for checking the integrity of grout annulus. If the measured electrical resistance at a nail is found to be significantly different from those of the adjacent nails of the same configuration, there is a high probability that the nail is anomalous. This method does not require measurement involving the pre-installed wire and hence potential anomalies associated with damaged wire can be ruled out. Details of the method can be found in Cheung & Lo (2005). Figure 3(d) shows that the nails with high electrical resistance determined using ERM match with those with anomalous TDR results, lending support that the anomalies were related to existence of substantial voids in the seven nails. Due to the limited sensitivity of the test, ERM is only capable of detecting significant grout defect in a soil nail (Cheung & Lo, 2005). This explains why nail A17 was not identified as anomalous by ERM. It also highlights the importance of appreciating the merits and limitations of each NDT when they

are used in a complementary manner.

The sizes of voids in the anomalous nails were estimated to be in excess of 2 m and it was decided to remove the concrete nail heads for inspection. Upon removal of the concrete nail heads of the seven nails, void sections were noted. The seven nails were subsequently replaced and TDR was used to check the grout integrity of the replacement nails both during grouting operation and after installation.

Up to December 2010, over 45,000 soil nails at about 2,200 LPM sites have been tested using TDR. Less than 1% of the tested nails exceeded the alert limit and further investigation was conducted. Most of the soil nails with short TDR-deduced length are isolated cases, i.e. anomaly found in only one or two soil nails at a site and additional TDR tests on adjacent soil nails do not reveal any anomaly. The use of other NDT methods or exhumation of soil nails to confirm the exact cause is considered not justified. Generally, a design review would be carried out assuming the anomalous nail to be not fully functional. During the course of implementation of the quality assurance programme, an experience-based chain of actions, as shown in Figure 4, gradually evolved.

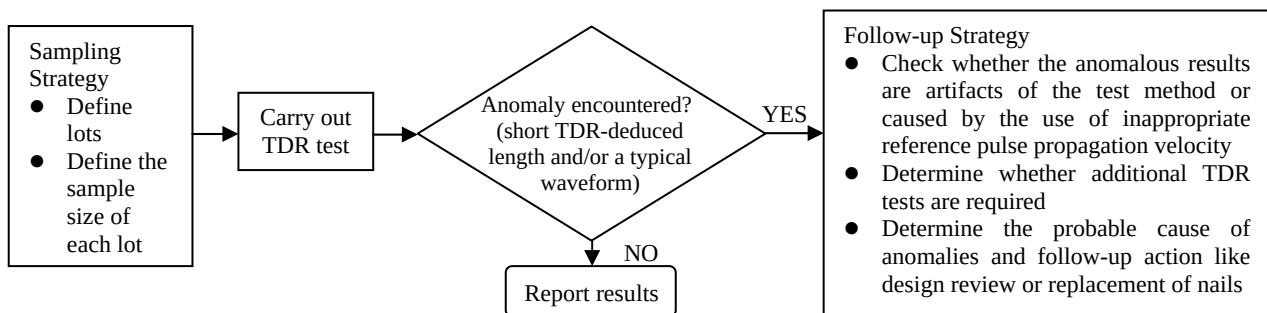


Figure 4: Chain of actions of the quality assurance programme

## 5 DEVELOPMENT WORK ON OTHER APPLICATIONS OF TDR

Apart from using TDR for quality control of soil nailing works, GEO has conducted development work to explore wider application of TDR to other facets of soil nailing works. In areas susceptible to significant grout loss, the location/depth along the soil-nail hole where grout loss takes place can be estimated by monitoring the pulse travel time in TDR measurements taken during the grouting process of the soil nail. By determining the pulse propagation velocity in air and in grout prior to the grouting or at adjacent nails, the length of the grouted section can be deduced as shown in Figure 5.

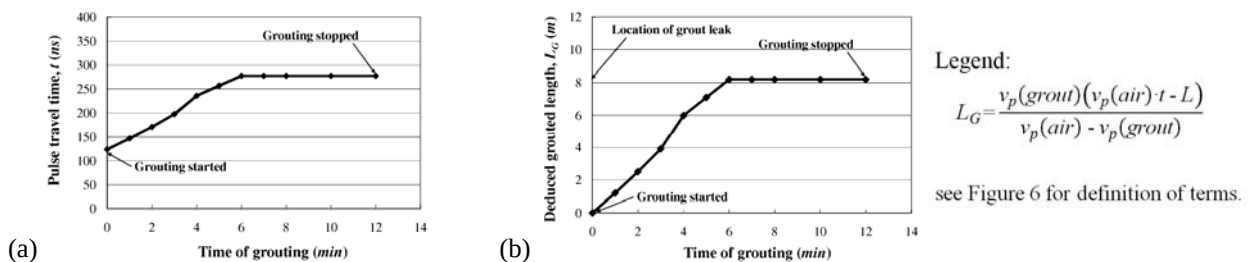


Figure 5: Use of TDR to deduce location of grout loss

Conventionally, the as-built grouted length of a soil nail in a pullout test is controlled by placing a packer between the grouted and the free length sections of the soil nails for pullout tests. As an alternative to the use of packer, one can in principle use TDR technique to detect the grouting front and stop injection of grout into the drillhole when the grout just fills up the intended grouted portion. This involves the installation of a wire with a length that equals the free length of the soil nail,  $L_v$  ( $L_v = L - L_G$ ) (see Figure 6). Following the principle described in Section 2, a positive reflection will be returned at the end of reinforcement-wire pair (i.e. end of the wire) prior to grouting (see Figure 6a). When the level of grout touches the end of the wire, the wire and the reinforcement will be electrically in contact via the fluid grout. Consequently, the polarity of the reflected pulse will switch from positive to negative (see Figure 6b). At this instant, the grouting operation can be stopped. The as-built grouted portion will have a shape and length similar to that shown in Figure 6(b). While the grouted length will continue to increase due to extra grouting during the time lapsed between the first

observation of reverse polarity of reflected pulse and the actual cessation of grouting and the surplus grout from the grout tube, field trials indicate that this could be overcome by making the wire slightly longer than the free length and confirm that the actual grouted length can be determined using TDR. The working procedure that has been developed together with the merits and limitations of the technique are presented in Cheung et al (2008).

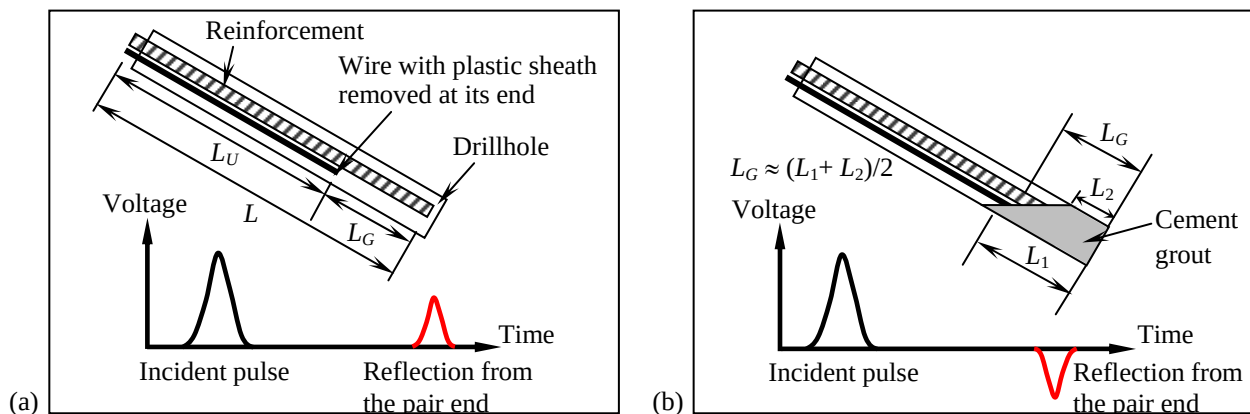


Figure 6: Theoretical TDR waveforms of a soil nail before and after grouting

## 6 CONCLUSIONS

The TDR technique is an effective tool to supplement site supervision in the quality control of soil nailing works, which cannot be assessed easily after construction. While TDR, like any other NDTs, does not give definitive answer to the cause of anomalies, it flags up soil nails that warrant further examination and, coupled with appropriate NDTs, the nature of anomalies can be ascertained.

## ACKNOWLEDGEMENTS

This paper is published with the permission of the Head of the Geotechnical Engineering Office, and the Director of Civil Engineering and Development of the Government of Hong Kong SAR.

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# Frequency Analysis of Extreme Rainfall Values

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## ABSTRACT

The Geotechnical Manual for Slopes adopts the extreme rainfall intensities based on frequency analysis of the rainfall data recorded at the principal raingauge of the Hong Kong Observatory (HKO) for the design of slope surface drainage. However, it is well recognised that the spatial distribution of rainfall is highly variable in Hong Kong. Therefore, the Manual recommends that for the design of major drainage structures, the validity of the IDF curves at different locations should be confirmed by undertaking an independent analysis of rainfall data obtained from the nearest raingauge. Since 1984, GEO has been operating a network of automatic raingauges. To date, some 26 years of rainfall data are available for 43 GEO raingauges. A study has recently been carried out to model the frequency distribution of the annual maximum rainfall using both the Gumbel distribution and the Generalized Extreme Value (GEV) distribution, in order to estimate the extreme rainfall intensities under different combinations of return periods and durations for the 43 GEO raingauges. Based on the derived extreme rainfall intensities, raingauge-specific intensity-duration-frequency (IDF) curves were fitted using the Wisner's formula. The raingauge-specific IDF curves have been compared with the IDF curves given in the Manual. Taking due cognizance of the uncertainties and limitations of the analysis, a new set of curves of extreme rainfall intensity is proposed for slope drainage design in Hong Kong.

## 1 INTRODUCTION

The key reference for estimating extreme rainfall intensities in Hong Kong is Peterson & Kwong (1981), which is based on the rainfall data recorded at the principal raingauge of the Hong Kong Observatory (HKO) in Tsim Sha Tsui during the period of 1947 to 1980 and the raingauge at King's Park Rise during the period of 1952 to 1980. The Geotechnical Manual for Slopes (GCO, 1984) recommends that the Rational Method should be used for general design of slope surface drainage. The method considers three components, viz. the runoff coefficient, the estimated catchment area and the design rainfall intensity for a given return period. GCO (1984) presents the extreme rainfall intensities derived by Peterson & Kwong (1981) in the form of Intensity-Duration-Frequency (IDF) curves.

The spatial distribution of rainfall in the hilly terrain of Hong Kong can be highly variable. GCO (1984) recognises the possible oversimplification of using the IDF derived from a few raingauges to represent the extreme rainfall intensities for the whole of Hong Kong. For the design of major drainage structures such as nullah and culverts, it suggests that site-specific analysis of rainfall data be carried out. For routine slope drainage design "in small catchments", it recommends using the above IDF curves.

Evans & Yu (2001) carried out statistical analyses of 14 years of rainfall data recorded at 46 GEO automatic raingauges and recommended that the extreme rainfall intensity should be reviewed when more than 20 years of rainfall data are available for analysis.

This paper presents the frequency analysis of extreme rainfall based on the rainfall data collected from the GEO raingauges with some 26 years of data. The frequency distribution of annual maximum rainfall was modelled using the Gumbel distribution and GEV distribution respectively. A likelihood ratio test was conducted and diagnostic plots were prepared to check the suitability of using the above two types of frequency distributions. The raingauge-specific IDF curves are then derived and compared with those given in GCO (1984).

## 2 COMPILATION OF RAINFALL DATA

The GEO has been operating a network of automatic raingauges since 1984, which collect 5-minute rainfall data round the clock. The system comprises 86 GEO raingauges installed over Hong Kong. A total of 43 GEO raingauges have collected some 26 years of records. The locations of these raingauges are shown in Figure 1. Frequency analysis was carried out to determine the extreme rainfall intensity based on the available data.



Figure 1: Locations of 43 GEO Raingauges with Some 26 Years of Rainfall Records

The rainfall data used in the frequency analysis were first compiled and checked to ensure that only reliable data would be used. Suspiciously high rainfall values in isolated raingauges were examined in detail by HKO and GEO. The rainfall pattern was compared with radar images taken during the same period and erroneous rainfall readings were removed. However, some precipitation records were found to be incomplete when preparing the data for analysis. The missing records were estimated using suitable interpolation methods based on reference to simultaneous records at nearby stations. In this study, the rainfall for any 5-minute intervals that had no value recorded or had been removed because it was deemed to be erroneous, was replaced by an interpolated rainfall value determined by means of the kriging method. This method is one of the most frequently used and efficient methods for spatial interpolation of rainfall data (e.g. Teegavarapu & Chandramouli, 2005; Ruelland *et al*, 2008). This process ensured that the rolling maximum rainfall of different durations were determined based on a complete record and would not be under-estimated.

The rolling annual maxima for different durations were computed for the period of 1984 to 2009. The rainfall durations considered in the present analysis range from 5 minutes to 31 days, i.e. 5-min, 10-min, 15-min, 30-min, 1-hr, 2-hr, 4-hr, 6-hr, 8-hr, 12-hr, 18-hr, 1-day, 2-day, 3-day, 4-day, 5-day, 7-day, 15-day and 31-day respectively. About 20,000 data points representing the rolling annual maxima for different durations from the 43 GEO raingauges were used in the frequency analysis.

## 3 METHODOLOGY

### 3.1 Modelling of Annual Rainfall Maxima Frequency Distribution

The extreme value theory deals with the limiting distributions of a large collection of random variables. According to the theory, the maxima and minima of a block of observations will converge to three types of distributions, namely Type I, Type II and Type III extreme value distributions. Alternatively, these are known as Gumbel, Fréchet and Weibull distributions respectively. The three types of distributions have distinct forms to describe the tail behaviour (i.e. maxima or minima values). The Fréchet and Gumbel distributions have infinite variables but different rates of decay in the upper tail of the distribution, i.e. the Gumbel distribution decays exponentially, whereas the Fréchet distribution follows a polynomial decay. Gumbel and

Fréchet distributions have been found to be more suited in modelling the frequency distributions of extreme rainfall values (e.g. Kharin & Zwiers, 2005; Feng *et al*, 2007), because both of them are able to represent the ‘heavy-tail’ behaviour of extreme rainfall distribution. On the other hand, the Weibull distribution is generally adopted for some hydrological problems, such as drought flows (Chow *et al*, 1988).

Traditionally, the Gumbel distribution is adopted for the frequency analysis of meteorological data (e.g. extreme rainfall, temperature, etc.). The Gumbel distribution was adopted in the frequency analyses of extreme rainfall intensities in Hong Kong undertaken by previous researchers, e.g. Peterson & Kwong (1981); Lam & Leung (1994); Evans & Yu (2003); and Wong & Mok (2009). The common use of the Gumbel distribution can be attributed to the simplicity of its mathematical formulation and its comparatively good accuracy in estimating the statistical parameters (Koutsoyiannis, 2004).

In recent years, the GEV distribution has been gaining popularity, as it can describe the above three types of extreme distribution models using a single mathematical expression. The expression used in GEV is as follow:

$$G(z) = \exp \left\{ - \left[ 1 + \xi \left( \frac{z - \mu}{\sigma} \right) \right]^{-1/\xi} \right\} \quad (1)$$

It can be seen from the above that the GEV distribution is controlled by three statistical parameters, viz. a location parameter  $\mu$ , a scale parameter  $\sigma$ , and a shape parameter  $\xi$ . In particular, the shape parameter dictates the type of distribution with a distinct form of upper tail behaviour, i.e. Gumbel (Type I,  $\xi = 0$ ), Fréchet (Type II,  $\xi > 0$ ), and Weibull (Type III,  $\xi < 0$ ), respectively. Through the influence on the shape parameter  $\xi$ , the data themselves determine the most appropriate type of tail behaviour and preclude the necessity to make a prior judgment on the appropriate type of extreme value distribution. The three statistical parameters are determined by means of the method of Maximum Likelihood (ML). ML is considered to be a general and flexible method of estimating the statistical parameters (Coles, 2001). This method is also commonly adopted by academics and researchers in extreme rainfall analysis, e.g. Wong & Mok (2009); Feng *et al*. (2007); Kharin & Zwiers (2005); etc.

### 3.2 Selection of Distribution Models

The optimal distribution model is a simple model that can reasonably fit the observed data. The GEV distribution is a more sophisticated model than Gumbel distribution, as it has an additional statistical parameter (i.e. the shape parameter  $\xi$ ). The use of a more sophisticated model may bring about further improvement if sufficient data are available for deriving statistically meaningful results. Such improvement may be quantified by a likelihood ratio test (Coles, 2001), which is defined as:

$$D = 2 \{ \ell_1(M_1) - \ell_0(M_0) \} \quad (2)$$

where  $D$  = deviance statistic,  $\ell_1(M_1)$  = log-likelihood of a more sophisticated statistical model  $M_1$ ,

$\ell_0(M_0)$  = log-likelihood of a simpler statistical model  $M_0$ , which is a subset of model  $M_1$

Wilks (1938) showed that  $D$  is distributed approximately as a chi-square distribution, where its degree of freedom ( $k$ ) is the difference in the dimensionality of  $M_1$  and  $M_0$  (i.e. the difference in number of parameters in the parameter set, viz. 2 for Gumbel distribution and 3 for GEV distribution respectively). The significance of the improvement is judged by comparing  $D$  with a critical value  $\lambda$ , which is the  $(1-\alpha)$  quantile of the chi-square distribution, where  $\alpha$  is the significance level. The critical value  $\lambda$  with 95% quantile (i.e.  $\alpha = 0.05$ ) is 3.84. A comparison was made of the Gumbel and GEV distributions to examine the advantages of using a more sophisticated model (i.e. GEV distribution) in the frequency analysis, by reference to the results of the likelihood ratio test.

For frequency analysis of extreme values, the goodness-of-fit test of a distribution model typically involves presenting the data in 3 types of diagnosis plots, namely, probability plot, quantile plot and return level plot respectively, which depict the degree of agreement of the model with the data (Coles, 2001). In this study, the diagnosis plots were prepared to examine the applicability of the Gumbel and GEV distributions

respectively in modelling the extreme rainfall intensities.

### 3.3 Numerical Tool for Statistical Analysis

Computer software “R” version 2.9.0 was used to carry out the frequency analysis in this study. “R” is a computer program for statistical analysis and provides a wide variety of statistical solutions (e.g. linear and nonlinear modelling, classical statistical tests, etc.) and graphical techniques in plotting charts. It is available as a free and open resource, and is compiled and run on a wide variety of operation systems including UNIX platforms, Windows and Mac OS. More details about “R”, together with its source files and attached packages, are available on the official web site: <http://www.r-project.org/>.

### 3.4 Intensity-Duration-Frequency Curves

For engineering applications, it is common practice to present the extreme rainfall intensities as IDF curves. Lam & Leung (1994) used the Wisner's formula to derive the IDF curves for different return periods, which is expressed in the following form:

$$I = \frac{a}{(t + b)^c} \quad (3)$$

where  $I$  = extreme rainfall intensity in mm/hr,  $t$  = duration in minutes,  $(a, b, c)$  = Wisner's constants

A similar formulation is used in the present study to derive the IDF curves for different return periods for the 43 GEO raingauges. Koutsoyiannis (1998) suggests that families of IDF curves can be well described with constant values of  $b$  and  $c$ . In order to avoid masking the relationship between  $I$  and  $t$ , the upper-bound of the  $b$ -value is set as 5 in the analysis. Such an assumed upper-bound is in line with the range of  $b$ -values adopted by Peterson & Kwong (1981) and Lam & Leung (1994). The Wisner constants  $a$  and  $c$  were then determined such that the derived IDF curves would be the best-fit curves based on a linear regression of the extreme rainfall intensity. The IDF curves for return periods ranging from 2 years to 1,000 years were computed. It should be noted that for durations shorter than 5 minutes, the IDF curves were extrapolated by using Wisner's constants fitted using 5-minute rainfall data.

## 4 RESULTS

### 4.1 Sufficiency of GEO Raingauge Data

In general, the diagnosis plots illustrated that the Gumbel distribution has a higher degree of agreement with the data. It was noted that individual data points depart notably from the unit diagonals in the probability and quantile plots of some of the raingauges for both distributions. Individual data points are also located very close to the upper limit of 95% confidence level in some of the return level plots. For some other raingauges, the individual data points extend beyond the 95% confidence level limit. These observations reflect the uncertainty associated with a limited observation period of 26 years for the frequency analysis and that the fitted model may be dominated by the individual outlying data points. In particular, the GEV distribution uses 3 statistical parameters and correspondingly more data points would be required to achieve a good statistical fit as compared with the Gumbel model. It is therefore considered that the observation period of GEO raingauges may not be sufficiently long for the use of GEV distribution to derive extreme rainfall intensities.

### 4.2 Comparison of Gumbel and GEV Distributions

The results of the likelihood ratio tests for different raingauges and rainstorm durations show that the likelihood ratios exceed the critical values of the chi-square distribution (i.e.  $\lambda = 3.84$ ) only very occasionally. In this regard, the results suggest that the goodness-of-fit of Gumbel distribution is comparable to that of GEV distribution in most cases. Since both types of distributions are able to adequately represent the observed data,

the Gumbel distribution, which is simpler, has been adopted for frequency analysis based on the above-mentioned GEO raingauge data.

#### 4.3 Comparison of Computed IDF Curves

By applying the Gumbel distribution, extreme rainfall intensities for different combinations of durations and return periods have been computed and the raingauge-specific IDF curves derived. The IDF curves of Raingauge No. N14 (which is located at the peak of Tai Mo Shan at an elevation of 944 mPD) are much higher than that of the other raingauges. The higher IDF curves of Raingauge No. N14 might be a result of orographic effects. As such, the corresponding IDF curves from N14 should be applied judiciously as they may not necessarily be applicable.

The other 42 raingauge-specific IDF curves roughly form a band of curves with a similar trend that is generally consistent with that in GCO (1984). The variation of the raingauge-specific IDF curves may be attributed to the spatial variability of rainfall and uncertainties inherent in the frequency analysis. It is noted that the IDF curves given in GCO (1984) lie within the band of curves for rainstorms with durations shorter than 20 to 30 minutes. For longer duration rainstorms, however, the IDF curves in GCO (1984) are close to the upper bound of the band of the IDF curves derived from the 42 GEO raingauges.

### 5 PROPOSED REFERENCE DESIGN CURVES

The frequency analysis carried out in the present study is based mainly on analysis of past rainfall, which does not consider the possible influence of climate change. At present, HKO projected that the annual rainfall in Hong Kong would rise by the end of the 21<sup>st</sup> century and the year-to-year rainfall variability would increase with more extremely wet and dry years (Ginn *et al*, 2010). The increase in frequency of severe rainstorms could have an adverse impact on slope stability and more robust slope stabilisation measures and drainage provisions are called for. As a pragmatic approach, the upper bound rainfall intensities for different durations, based on the 42 IDF curves (i.e. excluding the Tai Mo Shan raingauge) from GEO raingauges and the existing design curves in GCO (1984), are proposed to be taken as the new reference design rainfall intensity for slope drainage provisions in Hong Kong (Figure 2). This will bring about an upward shift of the design rainfall intensity. For example, the use of the new reference design curves would result in an approximately 15% increase in the magnitude of the design rainstorm intensity for a 200-year return period event for 1-minute duration rainfall. The use of an upper bound IDF curves for the whole of Hong Kong would enhance the robustness of slope drainage design and help to reduce the vulnerability of slopes to severe rainfall (Tang & Cheung, 2011).

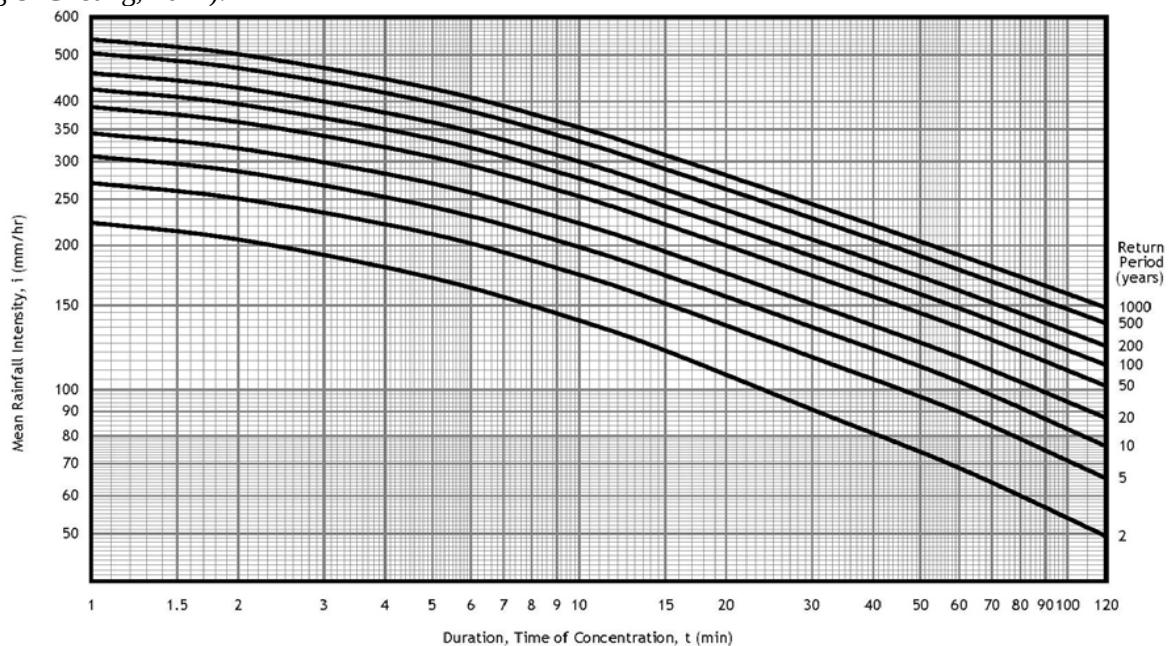


Figure 2: Proposed New IDF Curves for Slope Drainage Design (GEO, 2011)

## 6 CONCLUSIONS

In this paper, classical extreme value theory has been used to model the frequency distribution of extreme rainfall intensities based on the annual maximum rainfall data from 43 GEO raingauges. Although some 26 years of data are available, it was shown that they are not sufficiently long for applying the GEV distribution to derive extreme rainfall intensities. Gumbel distribution was found to be appropriate for modelling the frequency of extreme rainfall with the present data. The IDF curves given in Figure 2 are proposed to be adopted as the new reference rainfall intensity for slope drainage design in Hong Kong.

## ACKNOWLEDGEMENTS

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# Performance of Slopes Upgraded under the Landslip Preventive Measures Programme

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## ABSTRACT

The Landslip Preventive Measures Programme (LPMP) has brought about substantial improvement in slope safety in Hong Kong and a significant reduction in the number of landslide fatalities over the past 35 years. About 4,500 substandard Government slopes have been upgraded under the LPMP. The upgraded slopes have generally performed well. Landslides that occurred between 1997 and 2010 involving slopes upgraded under the LPMP have been reviewed under the Systematic Landslide Investigation (LI) Programme, which was launched in 1997. This paper presents the salient observations from the review, highlighting factors influencing the slope performance with respect to cut slopes, fill slopes and retaining walls. Improvement measures to slope engineering practice will also be discussed.

## 1 INTRODUCTION

Hong Kong is unique in terms of its combination of high seasonal rainfall, steep terrain in close proximity to dense urban development and a large stock of potentially substandard man-made slopes. Following a number of landslide disasters in the 1970's that caused more than 150 fatalities (Plates 1 to 3), the Geotechnical Control Office (renamed the Geotechnical Engineering Office (GEO) in 1991) was set up in 1977 to tackle the acute slope safety problem and launched the LPMP to deal with existing high-risk substandard slopes formed without geotechnical input. Under the LPMP, substandard Government slopes affecting major roads and developments were upgraded, in addition to conducting safety-screening studies for private slopes, in a risk-based priority order. The LPMP has substantially reduced the overall landslide risk posed by man-made slopes.



Plate 1: The June 1972 Po Shan Road landslide (67 fatalities)



Plate 2: The June 1972 Sau Mau Ping landslide (71 fatalities)



Plate 3: The August 1976 Sau Mau Ping landslide (18 fatalities)

By 2010, about 4,500 substandard Government slopes have been upgraded under the LPMP. Landslides that occurred between 1997 and 2010 involving slopes upgraded under the LPMP have been reviewed under the Systematic LI Programme, which was launched in 1997 and subsequently became an integral part of the LPMP. This paper presents the salient observations from the review, including the failure rates of the upgraded slopes and factors influencing the slope performance with respect to cut slopes, fill slopes and retaining walls. Improvement measures to slope engineering practice will also be discussed.

## 2 LANDSLIDES INVOLVING SLOPES UPGRADED UNDER THE LPMP

Between 1997 and 2010, there were 70 landslides involving Government slopes upgraded under the LPMP. Of these, 6 were major landslides (i.e. failure volume  $\geq 50 \text{ m}^3$ ) and the remaining 64 were minor landslides (i.e. failure volume  $< 50 \text{ m}^3$ ) (Table 1).

Table 1: Landslides between 1997 and 2010 involving Government slopes upgraded under the LPMP

| Feature Type                         | Major failure<br>(failure volume $\geq 50 \text{ m}^3$ ) | Minor failure<br>(failure volume $< 50 \text{ m}^3$ ) | Total number of slopes<br>upgraded under the LPMP |
|--------------------------------------|----------------------------------------------------------|-------------------------------------------------------|---------------------------------------------------|
| Cut slopes                           |                                                          |                                                       | 3,600                                             |
| • <i>Unsupported soil cut slopes</i> | 1                                                        | 13                                                    |                                                   |
| • <i>Soil-nailed cut slopes</i>      | 0                                                        | 23                                                    |                                                   |
| • <i>Rock cut slopes</i>             | 0                                                        | 18                                                    |                                                   |
| Fill slopes                          | 5                                                        | 10                                                    | 640                                               |
| Retaining walls                      | 0                                                        | 0                                                     | 260                                               |
| Total                                | 6                                                        | 64                                                    | 4,500                                             |

For the period considered, the average annual failure rates of slopes upgraded under the LPMP<sup>1</sup> are 0.01% and 0.10% for major and minor landslides respectively. The corresponding success rates ( $= 1 - \text{failure rate}$ ) are 99.99% and 99.90% respectively, which meet the Government's target annual success rates of 99.8% and 99.5% for engineered slopes against major and minor landslides respectively.

## 3 CUT SLOPES

### 3.1 General

About 3,600 cut slopes have been upgraded under the LPMP. About 70% of them are soil cuts and the remaining are rock cuts or soil/rock cuts. Between 1997 and 2010, 55 landslides occurred on cut slopes upgraded under the LPMP, one of which was a major failure. Of these 55 landslides, 14 involved unsupported soil cuts (including the major failure), 23 involved soil-nailed cut slopes and the remaining 18 primarily involved rock cuts (Table 1).

### 3.2 Unsupported soil cut slopes

Up to the late 1980's, substandard soil cut slopes in Hong Kong were typically trimmed back to a less steep gradient without the provision of reinforcement or structural support, in order to achieve the minimum required factor of safety. Although the overall stability of the slopes has been improved, upgraded slopes involving unsupported soil cuts are vulnerable to local adverse geological and hydrogeological conditions and prone to large scale failures (GEO 2004a). During the period considered (i.e. 1997 to 2010), there were 14 landslides involving unsupported soil cuts, one of which was the major failures at Ching Cheung Road in July and August 1997. Further details of this major failure are presented below.

In July and August 1997, three successive failures occurred on an unsupported soil cut slope above Ching Cheung Road, which is a major urban trunk road connecting east and west Kowloon. The slope was upgraded under the LPMP between 1990 and 1992. The first two failures occurred in July 1997, which culminated in the major failure on 3 August 1997 (Plate 4). The scales of the failures were  $500 \text{ m}^3$ ,  $700 \text{ m}^3$  and  $2,000 \text{ m}^3$  respectively. The August 1997 landslide completely blocked a 50 m section of the road and trapped a vehicle, fortunately with no casualties. The trunk road was subsequently closed for about one month until completion of temporary slope stabilisation works.

The geology and hydrogeology of the landslide site was complex. The dominant material in the slope was highly and completely decomposed granite, intruded by basalt dykes up to 1.3 m thick in places. Extensive natural erosion pipes, up to 250 mm in height, were present throughout the weathered rock profile. Past slope

<sup>1</sup> Annual failure rate of slopes upgraded under the LPMP is calculated as the annual number of landslides involving slopes upgraded under the LPMP divided by the total number of registered man-made slopes upgraded under the LPMP.

instabilities probably resulted in local weakening of the groundmass and contributed to the development of the extensive system of erosion pipes in the slope. The detailed investigation (HAPL 1998) established that the landslides were probably caused by the build-up of adverse transient groundwater pressure, following severe rainfall in early July 1997 and the preceding months. The failures occurred at the location of a buried drainage line below a sizeable upslope catchment where concentrated groundwater flow was likely to have resulted in higher groundwater levels than that of the surrounding area.



Plate 4: The Ching Cheung Road landslide in August 1997

This landslide illustrates the vulnerability of unsupported soil cuts to undetected weaknesses in the groundmass. In the light of this, slopes previously upgraded under the LPMP or other public works projects involving unsupported soil cuts will be dealt with, in accordance with a risk-based priority ranking, under the Landslip Prevention and Mitigation Programme (LPMitP), which was launched in 2010 to dovetail with the LPMP.

### 3.3 Soil-nailed cut slopes

Since the 1990's, soil nailing technique has been widely adopted for upgrading existing substandard soil cut slopes under the LPMP. The use of soil nails is considered to be a robust solution in that it can accommodate local weaknesses in the groundmass through stress redistribution and hence is less vulnerable than unsupported cuts to undetected adverse ground conditions. A soil-nailed cut slope effectively behaves as an integral mass, exhibiting a ductile mode of failure. This would provide some prior warning of impending failure through the progressive development of slope distress as well as reduced debris mobility in the event of detachment. The promising performance of soil-nailed cut slopes under the LPMP is reflected in Table 1 in that no major failures have occurred on such slopes thus far. However, soil-nailed slopes are not immune to failures. Minor failures do occur from time to time (Table 1), mostly involving surface erosion or minor local detachment from the groundmass between soil nail heads (Plate 5). Potential for such minor failures may be reduced by improved detailing of the slope surface provisions and enhanced slope surface protection details (Ng et al. 2008).



Plate 5: Minor failure (10 m<sup>3</sup>) at Tai Lam Correctional Institution in 2009



Plate 6: Relatively large detachment (23 m<sup>3</sup>) at Kwai Chung Road in 1997

### 3.4 Rock cut slopes

Prescriptive measures for the stabilization of existing rock cut slopes have been widely adopted in Hong Kong for many years. Typical rock slope treatment works include rock dowels, concrete buttresses, dentition, rock mesh netting, etc. Between 1997 and 2010, there was no major failure. During this period, 18 minor failures occurred on rock cuts upgraded under the LPMP (Table 1). The majority of these failures involved minor rockfalls due to local adverse groundwater regimes and/or loosened or unstable blocks, many of which were initiated by tree root wedging action. Some involved relatively large detachment as observed in the 1997 Kwai Chung Road incident (Plate 6).

Minor rockfalls are difficult to guard against in design or deal with by monitoring. A pragmatic approach is to provide suitable protective and/or mitigation measures, such as rock mesh netting, rockfall catch fence and buffer zone where space permits, together with regular maintenance, as stipulated in GEO (2009).

## 4 FILL SLOPES

### 4.1 General

By 2010, about 640 fill slopes have been upgraded under the LPMP, comprising about 250 slopes upgraded by recompaction and the remaining slopes upgraded by other methods, such as soil-nails, rockfill, etc. Between 1997 and 2010, there were 15 landslides involving fill slopes upgraded under the LPMP (Table 1), consisting of 14 incidents on recompacted fill slopes and one major failure on a compacted rockfill slope.

### 4.2 Recompacted fill slopes

Up to the early 2000's, most of the substandard loose fill slopes in Hong Kong were upgraded by excavating and recompacting the top 3 m of fill to an adequate standard (i.e. dry density not less than 95% of maximum dry density), together with the provision of subsurface drainage behind the recompacted fill layer. Technical guidance on the investigation, design and construction of upgrading works for loose fill slopes using the recompaction approach has been stipulated in GEO (2004b). Between 1997 and 2010, 14 landslides occurred on slopes upgraded by recompaction under the LPMP, 4 of which were major failures. Key observations from a review of the major failures where detailed information is available are presented below.

- (a) Leakage of water-carrying services could result in large-scale washout failures. In the period considered, there were two major failures due to leakage or bursting of water-carrying services, involving fill slopes upgraded by recompaction under the LPMP. The largest failure (700 m<sup>3</sup>) occurred at Castle Peak Road near Kau Wah Keng Village in 2000 (Plate 7).



Plate 7: Major failure of a recompacted fill slope at Castle Peak Road in 2000



Plate 8: Failure of a compacted rockfill slope at South Lantau Road in 2003

- (b) Concentrated surface water flow due to inadequate surface drainage provision or detailing could also be a key contributory factor to major washout failures, as observed in the major failure of a recompacted fill slope at Waterfall Bay Park in 1999. Similar observation was also noted in a major washout failure on a compacted rockfill slope at South Lantau Road in 2003 (Plate 8). These landslides reflect more on the ineffective surface drainage system than the performance of the recompaction approach.



Plate 9: The distressed slope below Stubbs Road reported in 2004

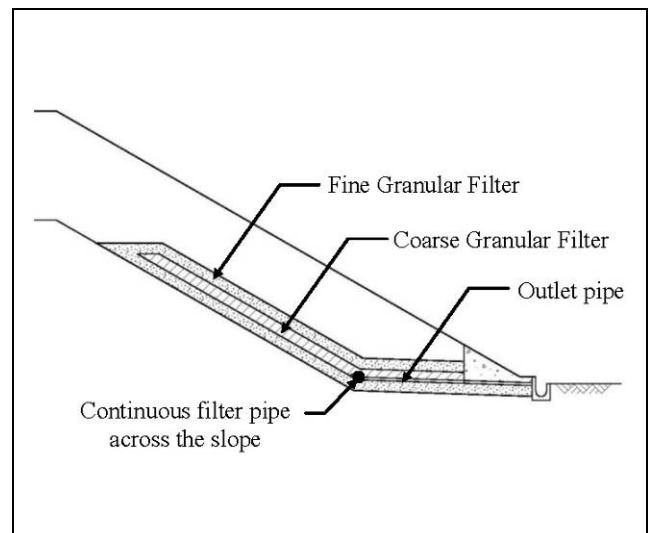


Figure 1: Revised subsurface drainage details for recompacted fill slopes

Apart from washout failures due to concentrated surface water flow or leakage of water-carrying services, landslides on recompacted fill slopes were generally ductile in nature and did not involve sudden and fast-moving debris as in liquefaction failure. A study of recompacted fill slope failures also reveals that inadequate subsurface drainage provisions could lead to build-up of groundwater pressure, giving rise to significant distress or slope movement. An example is the distressed slope below Stubbs Road reported in 2004 (Plate 9). To enhance the robustness of subsurface drainage, filter pipes can be provided at the upstream end of the subsurface drainage blankets (Figure 1). This would further prevent build-up of groundwater pressure behind the recompacted fill (FSWJV 2008).

#### 4.3 Soil-nailed fill slopes

The technique of using soil nails to upgrade existing loose fill slopes is becoming more popular since early 2000's. The works typically comprise the installation of soil nails in conjunction with a structural facing. Soil

nail installation is less sensitive to weather conditions as compared with the recompaction approach. An added advantage of the soil nailing technique is that mature trees can, by and large, be preserved. By 2010, around 100 loose fill slopes have been upgraded under the LPMP using soil nails. These slopes have performed satisfactorily so far with no reported landslides.

## 5 RETAINING WALLS

A total of about 260 retaining walls have been upgraded under the LPMP, many of which are masonry retaining walls. Typical stabilization methods for masonry retaining walls involve installation of soil nails or provision of a concrete skin wall to improve the stability of the existing masonry walls. Between 1997 and 2010, no landslide has occurred on retaining walls upgraded under the LPMP (Table 1).

## 6 CONCLUSIONS

The LPMP has brought about substantial improvement to slope safety in Hong Kong as reflected by the significant reduction in the number of landslide fatalities in recent years. Under the LPMP, some 4,500 substandard Government slopes have been upgraded upon its completion in 2010. The upgraded slopes have generally performed well. During the last 14 years (1997 to 2010), there were six major failures and 64 minor failures involving slopes upgraded under the LPMP, corresponding to an average annual success rate of 99.99% and 99.90% against major and minor failures respectively. The major landslides involved either failure of unsupported cut slopes or washout failures at recompacted fill slopes due to leakage of water-carrying services/concentrated surface water flow. Lessons learnt from landslide investigation have also led to enhanced understanding of slope behaviour, improved slope engineering practice and technical guidelines for enhancing the robustness of slope upgrading works under the LPMP, which was launched in 2010 to dovetail with the LPMP.

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