Sustainable Engineering Practices in Landslip Prevention and Mitigation Works in Hong Kong

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ABSTRACT

Over the last few decades, Hong Kong has made tremendous progress in managing the landslide risk through a comprehensive slope safety management system developed by Geotechnical Engineering Office (GEO) of Civil Engineering and Development Department. One of the key components of the system is the implementation of slope retrofitting and landslide hazard mitigation works under the Landslip Prevention and Mitigation (LPMit) Programme. While the primary objective of the LPMit Programme is to contain the landslide risk, the GEO strives to attain and promote sustainability when carrying out the LPMit works. The GEO integrates the concepts of sustainability in the works implementation process. The GEO also embraces new technologies and makes continuous improvements in slope engineering and landscaping practices through applied research and development work.

This paper presents the continuous efforts made by the GEO to strive for green and sustainable engineering practices in LPMit works in Hong Kong. Recent initiatives that have made notable contributions to more sustainable practices under the LPMit Programme would be highlighted in the paper, including slope greening and ecological enhancement, carbon footprint assessments of slope works, and adoption of sustainable construction practices.

Keywords: *slope greening, carbon footprint, green construction technology*

1. BACKGROUND

Hong Kong has a population of over 7 million but only a small land area of about 1,100 km2, much of which comprises steeply sloping terrain. Development pressure resulting from population growth and economic expansion since the 1950's led to intensive urbanization of the lower portions of hillsides in many parts of Hong Kong. The dense urban development, coupled with hilly terrains and high seasonal rainfall, renders the landslide problems in Hong Kong particularly acute.

In the aftermath of several serious landslides with multiple fatalities in the 1970s, the Landslip Preventive Measures Programme was launched in 1977 by the Geotechnical Control Office (renamed Geotechnical Engineering Office (GEO) in 1991) to deal with substandard man-made slopes that pose a significant safety risk to the community. In 2010, the Landslip Preventive Measures Programme was successfully completed and dovetailed by a long-term Landslip Prevention and Mitigation (LPMit) Programme, the scope of which has been extended to cover both upgrading of substandard man-made slopes and landslide hazard mitigation works on vulnerable natural terrain. The annual expenditure under the LPMit Programme is about HK$1,000 million.

While the primary objective of the LPMit Programme is to contain landslide risk, the GEO strives to attain and promote sustainability when carrying out the LPMit works. Sustainability is regarded as a necessary and attainable goal under the LPMit Programme, through process improvement, innovation and promotion of shared learning. Recent initiatives that have made notable contributions to more sustainable practices under the LPMit Programme are highlighted in the paper, including slope greening and ecological enhancement, carbon footprint assessment of slope works, adoption of sustainable construction practices, enhancement of biodiversity, etc.

2. SLOPE GREENING AND ECOLOGICAL ENHANCEMENT

Slopes are found almost everywhere in Hong Kong, with a substantial portion of urban developments being located near to hillsides or formed slopes. It is Government's policy to make slopes look as natural as possible, with a view to achieving the overall aim of creating a visually acceptable and ecologically sustainable slope environment (Figure 1). With the growing awareness of sustainability and greater demand for a better living environment by the public, landscape treatment of slopes has become an integral part of LPMit works. Input by professional landscape

architects is provided at the early stage of the design process to ensure that landscaping input is fully integrated with geotechnical input.

Figure 1: Slope greening above Bowen Road before (left photo) and after (right photo) works

Under the LPMit Programme, existing vegetation, including trees and shrubs, is preserved wherever practicable. As for man-made slopes, vegetation is used as surface cover wherever possible. The finished slope profile is designed to be suitable for hydroseeding as far as practicable. Any use of hard surface cover, which could generate undue heat island effect, is under stringent control. If hard surfacing is found unavoidable e.g. on slope safety grounds, visual impact mitigation measures such as planter holes, screen planting at the toe and decorative facing are provided wherever practicable. As regards natural terrain mitigation works, landscape treatments such as vertical greening, screen planting and toe planters are provided to minimize the visual impact of mitigation works and blend them with their surrounding environment (Figure 2). With the concerted efforts by the local geotechnical professionals, more than 300,000 nos. of shrubs are planted annually as part of the LPMit works, and that largely enhance the appearance of the city as well as contribute to providing a greater carbon sink to remove carbon dioxide in the atmosphere.

Figure 2: Vertical greening at a rigid barrier above Yu Tung Road, Lantau

The GEO has been establishing and advancing the best practice of landscape treatment on slopes through applied research and development work. In the early 2000s, the GEO worked with the Kadoorie Farm and Botanic Garden to conduct a planting trial of native small tree and shrub species on steep slopes. Later on, further studies on the application of various vegetation species for slope greening helped to develop various planting methods and suitable vegetation species for landscape use on slopes (Choi et al., 2009). Studies were also undertaken to assess the performance of different greening techniques, such as mulching systems and cellular systems, and to identify vegetation species that can successfully establish and self-sustain on steep slopes (Lui & Shui, 2006). In the mid-2000s, the GEO completed a study of old masonry walls with trees in order to develop a methodology for assessing the effects of trees on the stability of masonry walls. In addition, GEO proposed various methods for preserving the constituent wall trees and the wall fabric when upgrading a substandard masonry wall (CM Wong, 2011).

In recent years, GEO carried out studies on the use of solar panels for automatic irrigation systems for slope planting works (Lui, 2006), use of bio-engineering techniques that involved direct planting, live fascines and cribwalls, etc. to repair large landslides scars (Campbell, 2007), enhanced detailing of tree rings and improved

specifications for erosion control mats on slope surface. The key findings of these studies, together with the latest best practice on slope landscaping, have been promulgated in the "Technical Guidelines on Landscape Treatment on Slopes" (GEO, 2011), which largely promotes shared learning across the industry.

Apart from slope greening, the GEO explores ways of enhancing the ecology while implementing the slope works. In particular, the GEO promotes the use of native plant species in landscaping of slopes, in view that native vegetation species can provide habitats for birds and insects, which in turn will enhance biodiversity and natural succession. The goal is to provide a bio-diversified vegetation cover, which is ecologically stable and hence more sustainable.

The GEO's efforts in enhancing local ecology were showcased by a project which involved upgrading a group of 24 slopes along South Lantau Road in Lantau Island. The project replaced the hard surface covers on these slopes by vegetation with suitable native plant species. Based on detailed ecological surveys conducted at different stages of the project, a gradual increase in the various species of plants and animals, such as birds, insects and reptiles, was recorded at the slopes after completion of the upgrading works, with signs of regeneration of local plant species (Figure 3).

Figure 3: Enhanced ecology and biodiversity at South Lantau Road, Lantau

The GEO is particularly mindful of any possible adverse ecological impact arising from the LPMit works. For slope works affecting environmentally sensitive areas such as Country Parks or Sites of Special Scientific Interest, ecological experts are engaged to conduct ecological surveys. Where there is presence of rare plant or animal species e.g. wild orchids, egrets, etc. that could be affected by the slope works, appropriate special measures, such as transplanting, or in-situ protection before the works and close monitoring during construction, would be adopted to abate such adverse impact. In one recent LPMit project near Tai Po Market Egretry, which was the fourth largest colony in Hong Kong for egrets, the GEO has adopted a pragmatic approach and properly programmed the LPMit works in order to minimize the possible impacts or disturbances to the breeding of special bird species, with close monitoring to verify that the proposed strategy has worked well in practice.

3. CARBON AUDIT AND ASSESSMENT OF GEOTECHNICAL WORKS

There has been a growing demand to improve practice in the construction industry to help combat the problems of global warming and climate change. Various studies have been initiated by GEO in recent years with a view to reducing the carbon footprint in the implementation of LPMit works.

In the early 2010s, the GEO arranged for a detailed carbon audit of the implementation of LPMit works. The carbon audit was carried out at 54 selected sites, covering a range of typical LPMit works including soil nailing, reinforced concrete construction, slope cutting, filling and compaction works, rock slope treatment works, construction of steel flexible barriers, etc. The scope of the audit included direct greenhouse gas emission and removal, such as combustion of fuels in stationary sources and mobile sources, as well as indirect greenhouse gas emission such as electricity assumption, staff travel and embodied carbon in raw materials. The carbon audit provided valuable data to GEO for carbon management in respect of LPMit works.

The GEO attempted to further improve the LPMit design practice by incorporating the evaluation of carbon emissions of different design options in the option assessment stage. In this regard, a simple calculation tool, which allows quantification of the carbon emission of typical LPMit works, has been developed. The scope of the present carbon assessment focuses primarily on the carbon emission during the construction phase of LPMit projects, covering the following sources of carbon emission:

- Embodied carbon content of the construction materials (i.e. cradle to site approach) due to extraction, processing and transportation involved during the production of the materials;
- Carbon emission arising from the transportation of materials and construction plant, both within and outside the territory of Hong Kong;
- Carbon emission arising from the fuel consumption of the construction plant or machinery;
- Carbon emission arising from waste treatment; and
- Carbon impact due to felling of mature trees.

Assumptions on carbon emissions are mainly based on published data (EPD & EMSD, 2010, Hammond & Jones, 2011, Leung et al., 2010) as well as other reliable and locally surveyed data. These assumptions are subject to refinement when more reliable and updated data become available, and flexibility is allowed in the tool for such updating in future.

The tool allows local geotechnical practitioners to better appraise the carbon emission of various design options in a consistent and transparent, albeit simplified, manner, and the decisions made can be communicated more readily to the public or other stakeholders. It also provides useful insight on where potential carbon reductions can be made. For example, in soil nailing works, which is a common type of slope treatment works in Hong Kong, the main carbon emission would be the embodied carbon emission of materials (Figure 4). A study was therefore initiated to look into the possibility of reducing the embodied carbon emission of materials for soil nailing by partly replacing the cement in grout by ground granulated blast furnace slag (GGBS).

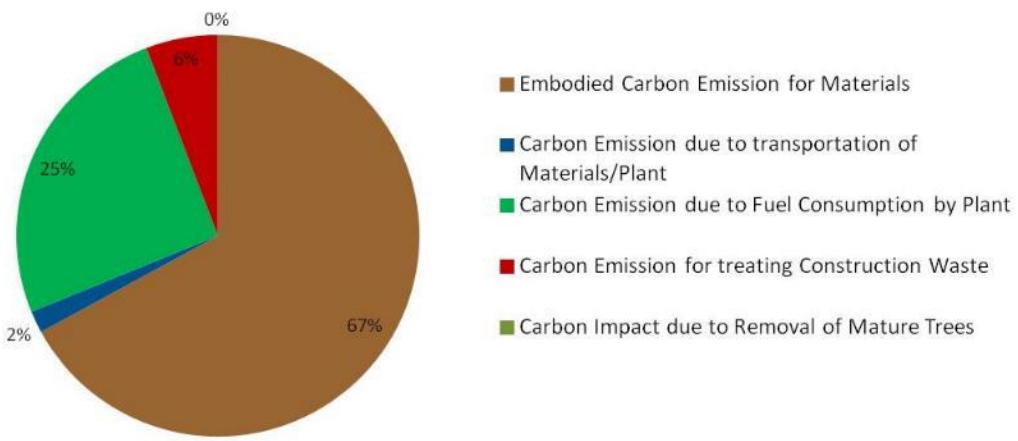

Figure 4: Example of carbon assessment of soil nailing works

4. SUSTAINABLE CONSTRUCTION PRACTICES

The GEO makes every endeavour to minimize the environmental impacts arising from the construction of LPMit works. A comprehensive site supervision system has been established to audit the workmanship and hence the reliability of the completed LPMit works. The works are closely monitored for strict compliance with the contractual and statutory environmental requirements and agreed mitigation measures. Surface runoff from the LPMit works sites is treated by adequately designed silt-removal facilities before discharging into stormwater drains (Figure 5). The area of exposed earth surfaces is kept to a minimum, and is covered with properly secured tarpaulins sheets for dust suppression (Figure 5). Caring site visits are regularly conducted by the directorate officers of GEO to ensure that the LPMit works are carried out in a safe, green and sustainable manner.

Figure 5: Water pollution control measures (left photo) and air pollution control measures (right photo) for the LPMit works

The GEO adopts green construction practices whenever applicable. As the combustion of fuel is one of the major sources of carbon emission during the construction of LPMit works, the contractors are encouraged to connect to the power grid as far as possible, instead of employing site generators, in order to reduce fuel combustion. B5 diesel (i.e. 5% biodiesel blended with 95% Euro V diesel) has to be used in all non-road based construction machinery, such as air compressors, excavators and compaction plant, for all LPMit works contracts. The use of electric vehicles with no carbon emission is also supported by the GEO, with active participation in their trial use and the incorporation of suitable provisions in the LPMit works contracts.

It is one of GEO's goals to reduce construction wastes generated by the LPMit works. The contractors are encouraged to adopt the 3R principles (i.e. Reduce, Reuse and Recycle) as far as practicable on site. For example, a tree shredding machine has been used in one of the LPMit works sites for chipping felled trees into wood chips that can be reused as mulch. Rubbish bins are provided in pairs at each LPMit works site, one for aluminum cans, one for plastic bottles and one for general refuse, in order to encourage recycling of workers' wastes. Re-usable construction materials, such as steel moulds for surface channels and steel accessories for temporary access, are adopted on site to reduce wastes. The excavated materials are reused on site for backfilling or as top soil for landscaping wherever possible. The contractors are also encouraged to use their best endeavours in identifying recycling facilities or other suitable construction sites where the construction and demolition (C&D) materials can be used in a beneficial manner.

Green site offices with various sustainable designs and features have been adopted in LPMit works contracts since 2015. These sustainable designs and features include measures to allow natural light and ventilation as much as possible, and the use of reusable materials, modular accommodation units, energy and water saving devices. Re-use of site offices, which can minimize waste generation due to the demolition and constriction of office, is encouraged by the incorporation of suitable provisions in the LPMit works contracts. In addition, GEO pays particular attention to the aesthetics of site hoarding. In this regard, decorative panels for reducing visual impact of site hoardings are adopted (Figure 6). These decorative panels are durable and reusable, as well as aesthetically pleasing to the public.

Figure 6: Decorative panels on LPMit site hoardings

The GEO embraces and adopts green construction technologies that help to reduce carbon emissions. The trial use of GGBS concrete in the construction of check dams has been initiated, noting that the carbon emission of GGBS concrete is up to 40% lower than normal OPC concrete. A number of other studies, such as green procurement, lean construction and Building Information Modelling, are ongoing with a view to further enhancing the sustainability of LPMit works.

5. CONCLUSION

The GEO is implementing a long-term LPMit Programme to contain landslide risks in Hong Kong to within an As Low As Reasonably Practicable (ALARP) level. Sustainable landscaping, engineering and construction practices have been adopted by the GEO in the implementation of LPMit works, in order to contribute to a green and safe living environment in Hong Kong. The GEO is dedicated to seeking continuous improvement for the enhancement of sustainability in the delivery of LPMit projects.

6. ACKNOWLEDGEMENT

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