

## **The Application of Recycling Material for the Sustainability of Slopes: A Case Study of Two Sites in Hong Kong**

Johnny Y.N. Mok

*Centre of Applied Technologies, Hong Kong College of Technology International, Kowloon, Hong Kong  
johnnymok@hkct.edu.hk*

Daniel T.P. Ho

*Toyo Greenland Co., Ltd., Hong Kong  
danielho@toyogreen.com*

Brian H.Y. Leung, Abid Nadeem

*Centre of Applied Technologies, Hong Kong College of Technology International, Kowloon, Hong Kong  
brianleung@hkct.edu.hk, abidnadeem@hotmail.com*

### **Abstract**

Recycling materials are being increasingly used to prevent the growth of waste materials; to reduce the consumption of raw materials; to save energy as well as to reduce greenhouse emissions. In Hong Kong, the construction industry generates about 11 million tonnes of demolition waste each year which amounts to about 4 times as much as of municipal solid waste. This construction waste could produce about 2.3 million tonne of recycling waste annually. Recycling of waste material can be considered as the key concept of modern waste management and is classified as the third component of waste hierarchy to relieve the waste pressure on the society. In Hong Kong, both waste management and ecological rehabilitation of man-made slopes are major concerns in the society. The objective of this paper is to appraise the merits of applying recycling material such as Hydro Mulching and to analyze the scope and various possible applications of recycled materials for slope stability. The major constraints of this innovative idea of applying hydro-mulching for the restoration of the ecological rehabilitation of the slope are discussed and integrated merits of this approach are provided.

### **Keywords**

Concrete and rockfill slope, Sustainability, Ecological rehabilitation, Waste material, Hong Kong

### **1. Introduction**

Hong Kong is a densely populated city with a population of about 7 million people. With a total area of only about 1,100 sq km (425 sq miles), it is essential to maintain equilibrium between the economic development of the society and the maintenance of the natural environment. The production of waste material in Hong Kong has imposed tremendous amount of pressure in this regime due to rapid increase of economic activity and population growth. The ever increasing demand in land and the high living standard has enabled further development of the society and it is difficult to maintain an equilibrium development in the society including economy and the well being of the natural environment.

Hong Kong is facing the challenges to provide enough housing within the limited resources of flat land. With most area situated on hilly terrain, a large portion of the land was derived from the excavation of slopes for the construction of residential and economical buildings. Further, waste material arising from construction sites also produced large amount of construction wastes generated during the construction phase. The sustainability of the regime due to rapid development in this area is a big concern. As construction is taking place continuously in Hong Kong, the amount of solid waste and its disposal have become a serious environmental problem, leading to visual pollution, public health hazards, and water and air pollution. With the growth of the population and the wider use of bottles and cans, the problem of litter and waste could spoil the beauty of the local environment. In addition, the discarded solid waste, if untreated, will decay, producing bad smells and pollute the sea. Moreover, a significant portion of the developed land is situated in slope area subject to large amount of rainfall in the summer; the stability of these slopes is a major concern.

The idea of providing green man-made slopes with waste material enhances the aesthetics of environment, but also can serve the purpose of erosion control and slope stabilization as well as elimination of waste material each year. Technical guidelines were developed (GCO, 1984) by the government for the use of vegetations for slope surface protection.

## **2. Rain Induced Slope Problem in Hong Kong**

Rain induced slope is a problem in Hong Kong which is usually due to the development of low pressure trough and tropical cyclone during the summer in the hilly slope area of Hong Kong. There are several incidents of exceptionally heavy rainfall during the summer in the past thirty years which caused many catastrophic landslides. These slides had caused some loss of life and a significant amount of property damage. In order to ensure safety of slopes, geotechnical control measures were enforced on building and infrastructure developments (Chan, 1977). Disastrous landslides associated with heavy rainfall for the past included Sau Mau Ping Resettlement Estate in 1972, Po Shan Road in 1972, Kwun Lung Lau in 1994 as well as Fei Tsui Road and Shum Wan Road in 1995. Currently there are nearly 57,000 man-made slopes and retaining walls which are registered in the government slope catalogue for slope monitoring purposes.

## **3. Waste Material Problem in Hong Kong**

In Hong Kong, both waste management and ecological rehabilitation of man made slopes are major concerns in the society. Recycling of waste material using Hydro mulching technique is one of the common methods for establishing green covers for slope protection. The application of green technology in slope protection has many intrinsic virtues such as providing environmental friendly visual appearance, improving air quality, minimizing sunlight reflection, reducing noise and as well as lowering the ambient temperature around the slope area in the summer season.

Extensive research conducted by Southern China Agriculture University (SCAU) and the field trials in Hong Kong demonstrated the possibility of using locally produced organic compost. Fiber Soil using SCAU organic compost had higher nutrient contents than imported organic composts. In addition, vegetation on man-made slopes, where SCAU organic compost was applied, could be established faster and last longer in dry winter season.

Using local organic compost on slope greening could both provide better greening results than imported organic compost, and also relieves the pressure on landfills in Hong Kong. Based on the current trend of slope greening, it was estimated that about 200,000 m<sup>2</sup> man-made slopes would be enhanced per year.

Using the Fiber Soil with local organic compost will help reducing about 7,700 m<sup>3</sup> of green waste per year. A research is currently being conducted for determining the proper proportion of SCAU organic compost in Fiber Soil that can promote the best plant growth and reduce green waste dumping to the landfill in the future.

#### **4. Environmental and Vegetation Conditions in Hong Kong**

It is well known that the topography in Hong Kong is complicated. The surface features ensure that overland flow will occur in rainfall events of moderate to high intensities. The surface runoff increases in low permeability soils during high intensity rainstorms in summer monsoon season. Water will stay on the ground surface when rainfall intensity is greater than the capacity of the soil for absorbing water. Potential evapotranspiration is the upper boundary condition in the simulation of water content redistribution in soils. Although the rainfall data show much variability, the use of the average daily rainfall can usually be used in the simulation.

One of the important factors in the simulation of the vegetation is the Leaf Area Index. It is a factor that affects the slope stability performance. Leaf area index is an important parameter relating to the potential soil evaporation and potential transpiration. Many simulation programs such as SWATRE (Belmans et. al. 1983) have been used successfully to simulate the water movement in soil through the plant roots.

With the introduction of plant characteristics, it is possible to perform simulation of vegetation parameters such as plant height, root depth and leaf area index. The leaf area index is a function of the soil surface covered by plants. A high degree order of polynomial equation can adequately predict the leaf area index of the vegetation based on soil cover as variable.

#### **5. Geotechnical Engineering Analysis Methods**

Two different methods such as Janbu and Morgenstern and Price have been used extensively in Hong Kong as it is feasible to use computer program to solve slope stability problem. The input parameters include soil properties and pore pressures in the analyses. Non-circular methods such Janbu (1954) and Morgenstern (1965) methods have been used quite widely to analyze failure surface and to search for the minimum non-circular failure surface.

Morgenstern and Price is another method used commonly which is based on force and moment equilibrium concept for each slice with an assumption that the inter-slice forces inclination takes a functional value. This method was originally formulated based on limiting equilibrium theory and by considering only the moment equations of individual slices.

Upon completion of the slope stability analysis, most of the softwares generate a graphical output which can indicate the grid slip surface and associated minimum factor of safety. Recently, comprehensive software known as Combined Hydrology and Stability Model (CHASM) developed by Wilkinson *et al.* (2000) has been used quite commonly. The software incorporates vegetation and soil parameters to solve slope stability problem by non-circular slip failure surface incorporating Janbu method of analysis. This model has received much attention in the modeling of slope stability which is affected by the surrounding environment.

## 6. Recycling of Waste Material with Hydro Mulching

The application of hydro mulching involved the installation of wire mesh with anchor and sub-anchor followed by fertilizer strip installation. Spacers are fixed under the Turf Reinforcement Mat in order to indicate the thickness of fiber soil sprayed on the top. The fiber soil which is a derivation of waste material generally consists of peat moss, compost, slow release fertilizer and bonding agent and then mixed with grass seeds.

Recently, researchers of New Fertilizer Resource Laboratory of Southern China Agriculture University (SCAU) have developed a rapid-composting method, called Bio-Chemical Composting Treatment. Its treatment generally increases the decomposition rate of organic fiber of collected green waste, and the process of composting is reduced from 180 days to 15 days. SCAU organic compost is also odorless, and its initial nutrient quality is higher than that of the imported organic compost (Table 1).

**Table 1: Initial Nutrient Concentrations of Fiber Soil Mix using SCAU or Imported Organic Compost**

| Fiber Soil Mix using          | Conductivity<br>(100 $\mu$ S/cm) | Organic<br>Matter<br>(g/kg) | Total<br>Nitrogen<br>(%) | KCl - N<br>(mg/kg) | Total<br>Phosphorus<br>(%) | Total<br>Potassium<br>(%) |
|-------------------------------|----------------------------------|-----------------------------|--------------------------|--------------------|----------------------------|---------------------------|
| SCAU Compost<br>(Treatment)   | 20.05                            | 41.01                       | 1.77                     | 682.24             | 1.14                       | 1.44                      |
| Imported Compost<br>(Control) | 22.60                            | 49.43                       | 0.73                     | 811.32             | 0.63                       | 0.48                      |

The soil mix is a highly permeable material which allows roots of vegetation to penetrate into the planting medium which is the most important factor in promoting fast vegetation growth with the chosen seed mix. Besides, the soil mix is a self-sustained material being proved to be non-washed out under the heavy rainstorm on step slope in Hong Kong. It is light in weight compared to traditional topsoil and has cohesive ability to provide surface erosion control functions. On the other hand, distinctive Eco-Bay has been used for plantation of scrubs and small trees.

In application, spraying machinery is used to spray the mortar to cover the whole slope and the fiber soil. It is a good planting media and its high air permeability will encourage development of the rooting system. It could also retain moisture and nutrients for roots to improve bioengineering strength of vegetation so as to hold soil particles to prevent erosion. A biodegradable erosion control mat, Geomat, is laid to provide the temporary surface erosion control until the successful establishment of vegetation.

## 7. Case Study No. 1 at Kwai Chung

The Princess Margaret Hospital, Kwai Chung project was the first site to adopt organic hydro-mulching recycled materials for slope rehabilitation. The site has residential buildings nearby, patients and residents can easily walk around the streets near the surrounding area. The surface of the slope at the Hospital was originally covered by 100 mm thick shotcrete underlain by rock and soil with a slope area of about 5,000 sq m. The slope height varies from 5 m to 10.8 m without intermediate berm and platform in some area. The slope is about 93 m wide orientated from East to South West. The overall surface of the slope is smooth on well-trimmed area or shotcrete buttress with rough rock outcrop in some areas. The slope gradient facing the South-West is generally 55° with the greatest angle of about 80° along the East side. The slope is exposed to strong wind in the winter season and high rain and hot sunshine in the summer.

The management of Princess Margaret Hospital operating under the Hospital Authority initiated the project in year 2000. The idea was to holistically restore the ecology of the surrounding area as shown in Figure 1. The existing shotcrete slope was suggested to treat with organic hydro-mulching recycled material to maintain the slope integrity as well as providing an environmental friendly greening effect. The organic hydro-mulching system is comprised of a double layer of non-woven fertilizer strip which is installed inside the three dimensional PVC coated wire mesh and fixed on any non-soil surface slope with galvanized mild steel anchor and sub-anchor to provide full vegetation cover to the slope.



**Figure 1: Project Site Located at Princess Margaret Hospital, Kwai Chung**

The restoration work was started in September 2000 and completed within three months. The slope was overhauled with fresh green vegetation and covered with some of the pioneer species of grass seeds germinate which demonstrated the first step of greening up process very shortly. After half year, the vegetation assessment revealed that the slope had satisfactory performance. The slopes around were covered with the healthy vegetation of climbing flower (Figure 2). As this is a native flowering climber and an evergreen species in Hong Kong, it requires less maintenance and is green all year around and yellow flowers can be grown throughout the year.



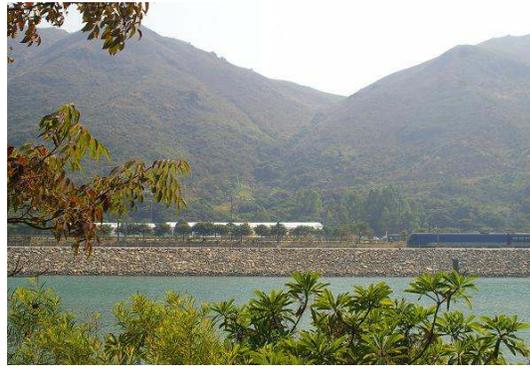
**Figure 2: View of the Kwai Chung Project Site before and 2 Years after Green Slope Construction**

### **8. Case Study No. 2 at Disney Land**

The second project site is located at Yam O near the Fresh Water Services Reservoir of Lantau Island where a system of pipeline was constructed within the site of the country park in the Southern part of the Island. The construction of the project was initiated in the year 2003 where an agreement has been established between the government and the Disney International to restore the site near Disney Land of Lantau Island as the slope was designed to be covered by rockfill that will cause adverse visual impact to visitors of Hong Kong Disneyland. The Toyo Greenland Company was assigned to green up the slope in order to provide excellent visual appearance for visitors and rehabilitate the ecosystem of the site area.

Initially organic hydro-mulching system was adopted in such a large rock slope area and it is a first of its kind in Hong Kong with project location near the wild life area of Yam O and realizing that people can easily walk around the area for recreation and picnic. With the idea to rehabilitate a man-made rockfill slope in Yam O, it is hoped that new habitats can be established and nutrients can be recycled. It was found that the average gradient of the slope is about 45° with slope height of 24 meter and slope length of 34 meter.

The hydro-mulching company was undertaking to restore the ecology of the slope around the area as shown in Figure 3. The existing rockfill slope was treated with organic hydro-mulching which serves to maintain the slope integrity as well as providing an environmental friendly greening effect. The mulching system comprises of a double layer of non-woven fertilizer strip which is installed inside the three dimensional PVC coated wire mesh and fixed on rock slope with galvanized mild steel anchor and sub-anchor to firm support beneath the rock.



**Figure 3: Project Site Located at Yam O (Disney Land) in Hong Kong**

The construction project lasted for seven months and ended in May 2004 and it only took a few months after hydro-mulching installation that the slope was changed to fresh green. Some of the pioneer species of grass seeds even germinated very rapidly. As the plantations are native flowering and evergreen species, hence very low maintenance was required. The flower was green all year around as shown in Figure 4.



**Figure 4: View of the Project Site before and 4 Years after Green Slope Construction**

## **9. Concluding Remarks**

Upon completion of the two projects, both slopes have been covered with green throughout all seasons for the past years upon completion. The organic hydro-mulching system is now adopted by local engineer and architect to be used as a cost effective methodology to enable vegetation to grow on concrete or difficult hard rock slopes. Besides it was found that local native species of shrub and flower can be adopted into such system which would enhance the ecology restoration of surrounding environment.

Both projects received numerous professional attentions both locally and internationally due to its innovative idea. The project was awarded as Excellence in Technology in year 2003 and 2006 by International Erosion Control Association, Awards of Environmental Excellence, U S A. The project also

received an Outstanding Greening Project Award in 2002, provided by Leisure and Cultural Services Department, HKSAR.

Based on previous discussions, organic hydro-mulching seems to be a viable method to control waste material and at the same time preventing slope surface erosion as well as restoring the appearance of the problematic slopes. In addition to the slope stability problems as mentioned above, the view of the property in front of the slope can also attain a higher property price with price difference to be as much as 15 percent because of aesthetic appearance of the slope.

## 10. References

- Belmans, C., Wesseling, J.G. and Feddes, R.A. (1983). "Simulation of the water balance of a cropped soil: SWATRE". *Journal of Hydrology*, Vol. 63, pp. 271-286.
- Chan, R.K.S. (1997). "Geotechnical control of private sector building works". *Proceedings of the Symposium on Building Construction in Hong Kong*, Hong Kong.
- GCO. (1984). *Geotechnical Manual for Slopes*, 2<sup>nd</sup> Edition, Geotechnical Control Office, Hong Kong Government.
- Janbu, N. (1954). "Application of composite surface for stability analysis". *European Conference on Stability Analysis*, Stockholm, Sweden.
- Morgenstern, N. R. and Price, V.E. (1965). "The analysis of the stability of generalized slip surfaces". *Geotechnique*, Vol. 15, pp. 79-93.
- Wilkinson, P., Brooks, S. M. and Anderson, M.G. (2000). "Design and application of an automated non-circular slip surface search within a combined hydrology and stability model (CHASM)". *Hydrological Processes*, Vol. 14, no. 11-12, pp. 2003-2017.