METHODS OTHER THAN RECOMPACTION FOR UPGRADING LOOSE FILL SLOPES

GEO REPORT No. 162

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PREFACE

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

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R.K.S. Chan
Head, Geotechnical Engineering Office
January 2005

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FOREWORD

This study reviews the methods other than recompaction that have been used, tried or considered by the GEO for upgrading loose fill slopes. A few private projects have also been reviewed. The advantages and limitations of the methods are given in this report.

This study was undertaken initially by Mr S K Wai and subsequently Mr C K Siu under the supervision of Mr Y K Shiu and Mr H C Chan respectively.

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ABSTRACT

In Hong Kong, loose fill slopes are conventionally upgraded by excavating and recompacting the top 3 m of fill to at least 95% relative degree of compaction. However, the conventional recompaction method has several practical limitations and the industry has asked for alternative methods for upgrading loose fill slopes when circumstances render conventional recompaction undesirable.

This Technical Note documents the review of the methods other than recompaction that had been used in improving the stability of loose fill slopes. This study identified 12 alternative methods that had been used in Hong Kong. The engineering principles, construction methods, practical limitations and effectiveness of the various methods are discussed in the report.

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1. INTRODUCTION

Loose fill slopes in Hong Kong are usually upgraded by recompacting the top 3 m (vertical thickness) of fill to at least 95% relative degree of compaction, and with the provision of surface and subsurface drainage measures (GCO, 1984).

The recompaction method has some practical limitations. Services often need to be diverted and vegetation, particularly trees, removed to make way for construction. Inadequate access and working space for transportation and storage of filling materials and manoeuvring of plant render it unsuitable for congested sites such as those located next to a busy road or surrounded by buildings. During construction, due care has to be exercised on temporary drainage and stability of the temporary cut, particularly when the works have to be carried out through the wet season.

The industry has asked for alternative methods to deal with circumstances where the conventional recompaction method is deemed undesirable.

This Technical Note presents the results of a review of the methods other than recompaction for treating loose fill slopes in Hong Kong. The review covers the methods that have been used, tried or considered largely within the Geotechnical Engineering Office (GEO). A few cases of private slopes were also covered.

2. THE REVIEW

2.1 General

A list of methods other than recompaction that were employed in treating loose fill slopes under the LPM Programme was compiled by examining the Slope Information System and Landslip Preventive Measures (LPM) Information System. Information on alternative loose fill slope treatment works undertaken by the private sector and other government departments was gathered from other GEO divisions. There were 12 alternative methods employed for fill slope improvement over the past 20 years or so, and 35 slopes have been selected for review under the present study. The list of slopes selected and documents reviewed, including Stage 3 Study Reports, Maintenance Manuals, GEO reports and in-house files are given in Table 1. The study has been undertaken with the assistance of Binnie Black & Veatch Hong Kong Limited (BBVL), who took up 20 of the slopes, covering 7 methods (viz. root reinforcement, removal of loose fill, bored pile wall at crest of slope, replacement with rock fill or cement stabilised soil, placement of soil or rock fill onto existing slope, soil nails and grouting), for detailed reviews. The review included an assessment of the performance of the slopes by site inspections (BBVL, 2002).

Based on their general design philosophy, the methods can be broadly grouped into three categories, viz. surface protection and root reinforcement, variations to recompaction, and alternative upgrading methods, as summarised below:

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Category	Method	
	No.	Description (Plate No. in bracket)
Surface protection & root reinforcement (Figure 1)	1 2	Rigid Surface Cover (1) Root Reinforcement* (2)
Variations to recompaction (Figure 2)	3 4 5 6	Removal of Loose Fill* (3) Bored Pile Wall at Crest of Slope* (4) Replacement with Rock Fill or Cement Stabilised Soil* (5) Placement of Soil or Rock Fill onto Existing Slope* (6)
Alternative upgrading methods (Figure 3)	7 8 9 10 11 12	Soil Nails* (7) Minipiles (8) Soil Cement/Lime Columns Grouting* (9) Dynamic Compaction (10) Displacement Piles (11)

Note: * denotes methods reviewed by BBVL (2002).

The list of slopes given in Table 1 under the first two categories are not exhaustive. They are just some examples to illustrate the methods. The list of slopes for the category "alternative upgrading methods" included all the sites that could be identified.

Most of the fill slopes examined in the present study were located immediately below a road. Many have buildings and other amenity facilities close to the slope toe. The slopes were generally formed between 1940's and 1970's, except the ones at Government House which were probably formed around 1850's. With heights generally ranging from about 10 m to 20 m (maximum 35 m and 40 m respectively in two cases), the slopes inclined between 28 degrees and 35 degrees. They were mostly vegetated before upgrading.

GEO landslip records were reviewed and there was no failure incident associated with the 36 slopes since the completion of the improvement works. Plates 1 to 12 show the conditions of some slopes (one case for each treatment method) upon completion of works, during construction and/or at the time of inspection in the course of the current study.

Salient points of each method are described in the following sections under the respective categories.

2.2 Surface Protection and Root Reinforcement

2.2.1 General

This category of methods involves no or minimal engineering works. Strictly speaking, they are not slope upgrading works. Nevertheless, the methods have been used to sign-off slopes in a few cases, are included here for completeness.

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2.2.2 Method 1 - Rigid Surface Cover (Plate 1)

This method involves the application of a rigid surface cover on the existing slope surface and the provision of surface and/or subsurface drainage measures (Figure 1). Steep or protruding parts of the existing slope profile are often trimmed to improve local stability, as well as to provide a uniform profile for the construction of the surface cover and the surface drainage measures. Tree rings are usually provided for preserving existing mature trees. The method neither increases the density of fill nor alters its properties. It aims to prevent surface infiltration that could lead to saturation and possible liquefaction of the loose fill.

Two slopes treated with this method under the LPM Programme were reviewed (slopes referenced 11NW-B/F55 at So Uk Estate and 11SW-D/F147 below Mt Nicholson Quarters). Slope 11SW-B/F55 is a 9 m high slope comprising about 9.5 m thick fill. The slope crest area was paved and results of groundwater monitoring throughout the wet season in 1995 showed that groundwater level was below the slope toe level. It was considered that, by properly protecting the slope face against infiltration and installing horizontal drains, a low groundwater level could be maintained whence the potential for liquefaction failure could be kept low. The calculated minimum factor of safety of the slope was 1.37 and upgrading works against shear failure were considered not necessary by the designer. The LPM works comprised construction of 150 mm thick reinforced sprayed concrete and a row of 10 to 14 m long horizontal drains. The sprayed concrete was covered by a layer of granite blocks to enhance the visual appearance of the slope. It was also highlighted in the slope maintenance manual that the installed horizontal drains were classified as special measures requiring regular monitoring in accordance with Geoguide 5**.**

Slope 11SW-D/F147 is a 13 to 16 m high fill slope. Ground investigation indicated that the thickness of the fill varied from 4 to 7 m and all the piezometers were dry throughout the monitoring period from March 1989 to July 1992. Recompaction was not recommended in view of the close proximity of the required temporary excavation to existing occupied buildings and limited space for temporary stockpiling of fill material. An option of rigid surface cover with slope crest cut-off drain was proposed. Soil nails bonded to in-situ ground were installed at locations where it was necessary to upgrade the stability of the slope against sliding failure. The LPM works option was endorsed by the Geotechnical Control Conference in 1989.

No signs of distress were observed during the site inspections.

The advantages of this method are:

- Vegetation clearance is not required.
- Temporary excavation is not required.
- Easier to construct and cheaper than recompaction.

The limitations of this method are:

- Only applicable to fill slopes where groundwater level is well below the fill body.
- Only applicable to fill slopes where there is little potential development of perched water in the fill due to surface

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recharge or leakage from water carrying services.

2.2.3 Method 2 - Root Reinforcement (Plate 2)

The benefits of trees to the environment and stability of slopes have long been realised (GCO, 1984). The studies that were carried out around mid-1980's on two slopes located at So Uk Estate (slope 11NW-B/FR42) and Leighton Hill (slope 11SW-B/FR42) respectively have been reviewed.

Tree surveys, and measurements of the distribution, diameters and tensile strengths of the roots were conducted during the studies in the 1980's. Tree roots were found to gather abundantly within the top 2 m, and it was estimated that the presence of tree roots could increase the shear strength parameter c' by 1.4 to 2.2 kPa, resulting in an increase in factor of safety of the slope against shallow, superficial slips by 10% to 50%.

The beneficial effects of tree roots were only regarded as temporary measures and substantial upgrading works were subsequently carried out in both slopes in the late 1990's. The works at slope 11NW-B/FR42 comprised toe wall construction and placement of soil fill on top of the existing slope profile (i.e. Method 6). The works at slope 11SW-B/FR42 involved recompaction of the top 3 m of loose fill and installation of soil nails bonded into in-situ ground. No signs of distress or failures have occurred at the slopes throughout the years up to the time when the slopes were upgraded.

The advantages of this method are:

- Vegetation clearance is not required.
- Temporary excavation is not required.

The limitations of this method are:

- Tree root reinforcing effects are only effective in stabilising shallow slips and stabilisation works, e.g. soil nails, are required for deeper slips.
- Additional measures, e.g. sub-surface drainage, are needed to reduce the liquefaction potential of the loose fill.
- Significant site-specific investigation is needed to quantify the tree root reinforcing effects.

2.3 Variations to Recompaction

2.3.1 General

This category of methods works on similar principles as the conventional recompaction method, as illustrated in Figure 2. Methods 3 (removal of loose fill) and 4 (bored pile wall at crest of slope) eliminate the landslide risk of the slope. Methods 5 (replacement with rock fill or cement stabilised soil) and 6 (placement of soil or rock fill onto existing slope) ensure that the fill in the top few metres of the slope is adequately compacted by replacement and additional filling respectively.

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2.3.2 Method 3 - Removal of Loose Fill (Plate 3)

This method eliminates landslide risk by complete removal of fill. It can be adopted when the fill layer is thin (typically not exceeding 4 m) and its extent is known with a reasonable degree of certainty. A crest retaining wall may need to be built in order to preserve the crest area from being removed by the cutting. The retaining wall can take various forms, e.g. a free standing L-shape structure or a wall supported on bored piles, depending on site conditions such as the working space available and the depth and quality of the founding material.

The advantages of this method are:

- Liquefaction potential of loose fill is eliminated.
- Temporary excavation is not required.
- Easier and cheaper to construct than recompaction.

The limitations of this method are:

- Requires total removal of vegetation.
- Requires use of heavy construction plant and large working and site access for stockpiling of excavated soil and movement of plant.
- Requires measures to ensure stability of temporary cutting at the crest and of the nearby ground, and to protect any structures and services in the area.
- Only applicable to fill slopes with relatively thin layer of fill.
- Requires adequate geotechnical engineering or engineering geological input to ensure that all the loose materials are removed.

2.3.3 Method 4 - Bored Pile Wall at Crest of Slope (Plate 4)

Where facilities of significant consequence in the event of slope failure locate only at the crest of a fill slope but not below it, an option is to construct a retaining structure, e.g. a bored pile wall, to retain the high consequence facility at the crest. This method has been applied typically to the situation where fill was used to bridge a small valley on a natural hillside during the construction of roads in the early days. The filling often gave rise to an inadequately compacted fill slope with a relatively thin layer of fill supporting a section of road. Retaining structure may be constructed along the crest of the fill slope to ensure the integrity of the road above it in the event of failure of the slope.

All the three cases examined in this study were located above natural hillside continuing below for a considerable distance. Any debris arising from the failure of the fill slopes would run onto the natural terrain with insignificant consequences. The retaining structure comprised bored piles with a reinforced capping beam at its top, which was in turn tied back by soil nails anchored in decomposed rock or bedrock. Drainage piles consisting of no-fines concrete were installed between the bored piles to drain off any groundwater from the back of the wall. No substantial treatment was carried out to the fill slope except for the

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necessary drainage, surface protection and landscaping works. There were reports of ground settlements during the construction of bored piles, probably due to the actions of ground vibrations and compressed air involved in the percussive drilling and the loads imposed by the construction plant and equipment. This method effectively addressed the need to protect the crest facilities in each respective case.

BBVL (2002) reviewed two of the cases (slopes referenced. 11SW-D/F31 and 15NE-B/F35) and observed minor surface erosion in one case (slope referenced 15NE-B/F35 at Shek O Road).

The advantages of this method are:

- Vegetation clearance is not required.
- Temporary excavation is not required.
- Ground settlements and vibrations can be minimised by using lightweight bored piling machine.

The limitations of this method are:

- Generally more expensive than recompaction and other methods.
- Only applicable to fill slopes without toe facilities of significant consequences and where the land use below the slope is unlikely to be changed in the near future.

2.3.4 Method 5 - Replacement with Rock Fill or Cement Stabilised Soil (Plate 5)

This method is essentially recompaction except that higher strength materials, e.g. rock fill or cement stabilised soil, are used as the backfilling material instead of soil. When rockfill is used, the final surface is often protected either with a rigid concrete cover or a thin layer of compacted soil fill with an erosion control mat.

The use of rock fill facilitates compaction and handling on site as the amount of testing and sampling is significantly reduced and rock fill is less prone to erosion and washout than soil during construction. As rock fill or cement stabilised soil can stand in a steeper gradient, there is less demand for land both at the crest and the toe, as well as for the toe retaining wall.

Six cases involving this were reviewed. BBVL (2002) reviewed two of the cases and reported that there was no sign of distress observed during the site inspections. The method was assessed to be effective.

The advantages of this method are:

- Can result in steeper re-constructed/backfilled slope gradient, hence less demand for land both at the crest and the toe.
- Facilitates compaction and Rock fill is less prone to erosion and washout during than soil construction.

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The limitations of this method are:

- Requires total removal of vegetation.
- Requires use of heavy construction plant and large working and site access for stockpiling of excavated soil and movement of plant.
- Requires measures to ensure stability of temporary cutting at the crest and of the nearby ground, and to protect any structures and services in the area.

2.3.5 Method 6 - Placement of Soil or Rock Fill onto Existing Slope (Plate 6)

This method involves placing of 3 m thick compacted soil fill, rock fill or cement stabilised soil onto the existing slope profile. If there is not enough land available at the toe, a retaining wall will need to be constructed along the toe to retain the newly placed fill.

Four cases were reviewed in this study. BBVL (2002) carried out detailed review on two of the cases and reported that the method had effectively addressed the concerns for upgrading the loose fill slopes.

The advantages of this method are:

- Requires significant less excavation, hence less disturbances, than conventional recompaction.
- Reduces the time and cost of construction if toe wall is not required.

The limitations of this method are:

- Requires total removal of vegetation.
- Results in a larger fill slope than before, which is generally undesirable.

2.4 Alternative Upgrading Methods

2.4.1 General

The methods under this category upgrade loose fill slopes either by reinforcing the slope (Methods 7 and 8) or by modifying the properties of the fill (Methods 9 to 12).

Methods 7 (soil nails) and 8 (minipiles) can also be used to improve substandard retaining walls that are often located at the crests or toes of such slopes. As percussive drilling and grouting are usually involved in the installation of soil nails and–minipiles, considerations are often given to minimising ground disturbance due to drilling and avoiding excessive grout leakage/intrusion particularly in the fill. The piling/drilling methods and sequences need to be well scrutinized and controlled, and the soil nails and minipiles should be compatible with adjacent structures and services. The orientation of the soil nails may need to be adjusted in order to stay within site boundaries. The design philosophy of

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Methods 11 (dynamic compaction) and 12 (displacement piles) is same as the recompaction method but without excavating existing fill. The methods were employed for field trials in 1979 and 1980.

2.4.2 Method 7 - Soil Nails (Plate 7)

In this method, soil nails are installed through existing fill into the underlying stratum, e.g. CDG. The soil nails are typically connected to a rigid surface structure, e.g. reinforced shotcrete surface cover, for transmitting soil pressure from the loose fill slope to the soil nails. It is essentially an "anchored" retaining structure. The design objectives are to enhance the resistance against shear failure, to minimise surface water infiltration, and to retain the soil in the event of liquefaction.

The main concerns on the use of soil nails to stabilise loose fill are liquefaction potential and potential instability of the loose fill in between the soil nail heads due to inadequate arching effect within the loose fill material. Some practitioners worry that contraction of loose fill may occur at very little strain and hence there may not be sufficient resistance mobilised in the soil nails to prevent liquefaction failure at such a small strain. To address these concerns, a lot of studies on the behaviour of loose fill have been carried out by the HKIE Geotechnical Division Sub-committee on the use of soil nails in loose fill and by researchers in universities. Based on the findings of the studies, a design approach has been formulated by HKIE (2002) that includes the use of steady state shear strength of the fill for design and provision of a structural frame on the slope surface.

The design of eleven slopes were reviewed by the authors, and BBVL (2002) conducted detailed performance reviews on six of the slopes, which were upgraded in 1994-2001. There was no observed sign of distress, and the overall performance of the method was considered good (BBVL, 2002).

The advantages of this method are:

- Tree felling is generally not required.
- Temporary excavation is not required.
- Construction works are less sensitive to weather conditions and overall construction period is shorter when compared with recompaction.

The limitations of this method are:

- The scheme is generally more expensive than recompaction.
- Additional precautionary measures have to be taken to prevent construction problems related to nail installation such as settlement, loss of grout and hole collapse.

2.4.3 Method 8 - Minipiles (Plate 8)

The review identified one case (slope referenced 11SW-B/F42 at Leighton Hill) that

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was completed around the mid 1980's. The works involved construction of 3 rows of 6 m long 220 mm diameter minipiles. The minipiles were designed as laterally loaded piles to resist against sliding failure and were installed into the underlying competent stratum. Additional measures, including surface protection and sub-surface drains, were provided to minimize water ingress into the slope, hence liquefaction potential.

The slope fell within the boundary of a residential development and further upgrading works were completed in early 2000. The works included recompacting the top 3 m of loose fill and installing soil nails to further enhance the stability of the fill slope against sliding failure. There were no reported signs of distress at the slope from mid-1980's to early 2000.

The advantages of this method are:

- Tree felling is generally not required.
- Temporary excavation is not required.
- The use of lightweight minipiling machine can minimise ground settlements and vibrations.

The limitations of this method are:

- Requires additional measures to address the concern of liquefaction of loose fill, e.g. provision of surface protection, sub-surface drainage or structural support to retain liquefied soil.
- Only applicable to fill slopes without toe facilities of significant consequences and where the land use below the slope is unlikely to be changed in the near future.
- This scheme is much more expensive than recompaction.

2.4.4 Method 9 - Soil Cement/Lime Columns

This method consists of mixing the loose fill in-situ with lime or cement grout to form columns or panels of strengthened soil, thereby improving slope stability against shear failure and liquefaction.

Colmix, a patented augering and mixing method, was considered in 1999 for upgrading a slope located below Wan Chai Gap Park (slope referenced 11SW-D/F116). The method was eventually not adopted because the presence of gravel, cobbles, brick and concrete fragments in the fill could pose problems for the augering and mixing processes, and would require the use of heavy plant and equipment and/or ground treatment processes such as pre-grouting. Temporary working platform may therefore need to be constructed on the slope possibly by use of granular fill or heavy steel sections. All these would increase the cost significantly. Moreover, large working space and access would be required. The need for use of heavy plant for penetrating obstructions, that are commonly found in fill, also limits the applicability of the method in Hong Kong.

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2.4.5 Method 10 - Grouting (Plate 9)

Soil strengthening is achieved by injecting cement or cement bentonite grout into the soil matrix. The grouting process also reduces the liquefaction potential of the loose fill because voids are filled up by the cement grout.

BBVL (2002) reviewed two cases using this method, both of which were for treating the loose fill behind retaining walls with the total height of the wall and the retained slope ranging between about 5 m and 8 m. The final slope surfaces in the two cases were vegetated and shotcreted respectively. The tube-a-manchette (TAM) method was used to inject the grout into the ground through pre-installed grout holes at about 500 mm spacing. In the case along Alnwick Road (slope referenced 11NW-B/FR12), raking drains were installed through the retaining wall after the grouting as subsurface drainage. Post-construction verification was carried out by digging trial pits, sampling and carrying out GCO probe tests, and relevant laboratory tests, to ensure that the design specification and improvement had been achieved. There was no sign of distress observed during site inspections and the effectiveness of the method was greatly dependent on the properties of the existing fill.

The advantages of this method are:

- Vegetation clearance is not required.
- Temporary excavation is not required.
- Involves shorter construction time and is a cheaper option than recompaction.

The limitations of this method are:

- The extent and effectiveness of grouting, hence the method, depends largely on the permeability of the soil mass and grout setting time, which are difficult to predict (BBVL, 2002).
- There are potential adverse effects of cement grout on vegetation growth.
- The use of conventional cement-based pressure grout may cause significant ground distress under low overburden stresses, i.e. at shallow depths.

2.4.6 Method 11 - Dynamic Compaction (Plate 10)

Densification of the top few metres of fill can be achieved by dropping a heavy weight (a few tonnes) from a few metres height onto the slope surface (Rodin, 1981).

Documents relevant to four application cases in the early 1980's were reviewed. In these cases, the actual mass and shape of the weight, drop height, number of blows, working sequence and spacing of compaction passes were adjusted and verified on site. Compaction was carried out in the downhill direction from the crest to toe on alternate strips of about 1.25 m width, followed by compaction on the intervening strips. A crane was either placed at the slope crest or at the slope toe for lifting and dropping of the weight, which was also tied

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to an anchorage point at the crest. When the weight was released, it fell along the radius of the tie wire and struck normal to the slope surface.

Verification testing was carried out by means of GCO probe and in-situ density tests as well as by measuring settlements of the fill. The settlements recorded in the trials ranged between about 500 mm and 900 mm. Seismic surveys were also carried out, and the wave velocities measured before and after the compaction showed significant differences indicating a decrease in porosity.

The advantages of this method are:

- Temporary excavation is not required.
- Shorter construction time than recompaction.

The limitations of this method are:

- Requires total removal of vegetation.
- Causes significant ground vibrations and settlement during construction and appropriate measures, e.g. isolation trenches, are needed to prevent causing damages to adjacent structures.
- Requires detailed design and site verification of construction scheme, including compaction effort and layout, which lengthens the construction period.

The significant environmental nuisance of the method renders it not an effective alternative to recompaction.

2.4.7 Method 12 - Displacement Piles (Plate 11)

In this method, displacement piles, e.g. hollow steel casings with a detachable pile shoe or precast concrete piles**,** are driven into the ground. During driving, the piles displace the soil sideways and compress it and densify it by the associated vibrations. After driving, the pile shoes of the hollow casings are removed. The casings are then backfilled with suitable granular material. The backfill is compacted with a drop hammer and the casing is withdrawn.

This method was tried out at a fill slope at Tsz Wan Shan (slope referenced 11NE-A/F55) in 1979, with the pile spacing at about 1.5 m staggered, the depth of pile at about 3 m and an uphill working sequence. About 90% relative degree of compaction was achieved between 1 m and 3 m depths, and 95% at locations close to the piles. There was no significant soil densification within the top one metre, probably due to heaving of the ground. No sign of distress was observed during the recent site inspection in early 2002.

A similar scheme had been designed for upgrading a fill slope above Bridges Street, Sheung Wan (slope referenced 11SW-A/CR90). The scheme involved the driving of precast concrete piles at 2 m spacing by use of a relatively lightweight hammer. The concept was to densify the fill in-situ and confine the extent of failure, if occurred, to within the 2 m compartments, while preserving the trees as far as possible. The scheme was however not

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implemented due to access problems on site.

The advantages of this method are:

- Tree felling can be minimised.
- Earthworks are not required.
- Ground settlements and vibrations can be minimised by using lightweight bored piling machine.

The limitations of this method are:

- More expensive than recompaction
- Requires vegetation removal.
- Requires use of small diameter piles with lightweight driving rigs to minimise ground vibration, settlement and disturbance to adjacent structures.
- Requires large number of closely spaced piles to achieve adequate compaction throughout the slope.
- Requires subsequent compaction of heaved soil between piles, which lengthens the total construction period.

3. CONCLUSIONS

This Technical Note consolidates the experience gained todate in treating loose fill slopes by methods other than recompaction. Various methods have been identified here including those that have only been used on trial bases and those that were considered as options but actually not constructed. Site conditions vary from site to site and each case warrants its own assessment. This will hopefully form a convenient reference benefiting future exercises of choosing appropriate design schemes.

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Table 1 - Summary of Methods other than Recompaction for Upgrading Loose Fill Slopes (Sheet 1 of 5)

Method		Slope No.	Location	Slope Height	Slope Inclination		Facilities		Year of Works Completion	Reference Documents	
No.	**Description**				**Before Works**	**After Works**	**Crest**	**Toe**		**Stage 3 Study Report**	**Maintenance Manual**
Surface Protection and Root Reinforcement											
1	Rigid Surface Cover	11NW-B/F55	So Uk Estate	9 m	28°	28°	Road - path - block	Road - path - block	1998	S3R 31/96	MM59/99
		11SW-D/F147	Mt. Nicholson Quarters	13 m~16 m	35°	32°	- Residence (Mount Nicholson Gap Flats)	- Residence (Evergreen Villa)	1992	S3R 27/90	-
2	Root Reinforcement	11NW-B/FR42*	So Uk Estate	9 m	30°	30°	Buildings	Buildings	N/A	ADR 4/85	
										S3R 4/97	MM 28/99
		11SW-B/FR42*	Leighton Hill	12 m~25 m	22°~40°	22°~40°	Road and buildings	Buildings	N/A	GCO Report 6/85 GEO - GCI 2/E1/11SW-B/FR42 GEO - GCI 3/4/3030/98	
Variations to Recompaction											
3	Removal of Loose Fill	11SE-A/F49*	C Kwei Wah Shan College, North Point	4 m-10 m	35°-40°	30°	-Natural slope and road	-Parking lot -Temporary structure	1999	S3R 66/98	MM 76/99
		11SW-D/FR144*	Between Lingnan College And Bowen Road, Hong Kong	21.3 m	48°	42°	-Bowen Road	- School building about 25 m away	1997	S3R 10/95	MM 38/98
		10NE-B/F15*	Cheung Ching Estate, Tsing Yi (Behind Ching Too House)	40 m	35°	34°	-Access road	- Children playground	1997	S3R 12/95	MM 28/98
		11SE-A/FR38*	Belilios Public School, Tin Hau Temple Road	(Refer to Option 7 - Slope No. 11SE-A/FR38)							

Table 1 - Summary of Methods other than Recompaction for Upgrading Loose Fill Slopes (Sheet 2 of 5)

Method		Slope No.	Location	Slope Height	Slope Inclination		Facilities		Year of Works Completion	Reference Documents	
No.	**Description**				**Before Works**	**After Works**	**Crest**	**Toe**		**Stage 3 Study Report**	**Maintenance Manual**
4	Bored Pile Wall at Crest of Slope	11SW-D/F31*	Peak Road	12 m	35^{o}- 45^{o}	35^{o}- 45^{o}	- Peak Road	- Natural slope	1997	S3R 58/96	MM 204/98
		11SW-C/F57	Peak Road	12 m	35^{o}-45^{o}	35^{o}-45^{o}	- Peak Road	- Natural hillside	1998	S3R 27/97	MM 009/99
		15NE-B/F35*	Shek O Road	20 m	28^{o}-43^{o}	28^{o}-43^{o}	- Shek O Road	- Natural slope	2000	S3R 135/97	MM 68/2000
5	Replacement with Rock Fill or Cement Stabilised Soil	15NE-B/F36*	Shek O Road	13 m	35^{o}-40^{o}	35^{o}-40^{o}	- Shek O Road	- Natural slope	1999	S3R 84/97	MM 120/99
		11SE-D/FR175	Fei Tsui Road	40 m	30^{o}-65^{o}	30^{o}-38^{o}	- Service reservoir	Fei Tsui Road	1997	S3R 40/96	MM 39/97
		11NW-B/F82	Beacon Hill Road	15 m	42^{o}	42^{o}	Road	Buildings	1998	Files No: GEO - GCME 3/5/DH301/77/K BD - BD DH301/77/K	
		11NW-D/FR40	Chung Hau Street	30 m	32^{o}	35^{o}	Road	Slopes and Road	2002	S3R 35/2001	-
		11SE-D/F43	Shek O Road	15 m	35^{o}	33^{o}	Road	Natural slope	1999	S3R 66/97	MM 122/99
		11NW-D/FR196* (Section 1-1)	Maryknoll Convent School	5.5 m	35^{o}	35^{o}	Road	Open space	2002	File No. GCME 3/5/DH89/72/K	
6	Placement of Soil or Rock Fill onto Existing Slope	7SW-D/F29*	Below Lion Rock Tunnel Road	26 m	32^{o} to 38^{o}	33^{o}	Road	- Natural slope	1999	S3R 75/97	MM 37/99
		7SW-D/FR33*	Below Lion Rock Tunnel Road	32 m	32^{o} to 38^{o}	30^{o} to 33^{o}	Road	- Natural slope	1999	S3R 75/97	MM 37/99
		11SE-D/FR175	Fei Tsui Road	(Refer to Method 9 - Slope No. 11SE-D/FR175)							
		A loose fill slope	Near Caritas Medical Centre	Approx. 20 m	33^{o}	33^{o} and 60^{o}	Road	Building	-	A reinforced earth scheme considered, but not constructed; information supplied by CGE/A, ref. GCA4/21/2 dated 24/7/2001.	

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Table 1 - Summary of Methods other than Recompaction for Upgrading Loose Fill Slopes (Sheet 3 of 5)

Method		Slope No.	Location	Slope Height	Slope Inclination		Facilities		Year of Works Completion	Reference Documents	
No.	Description				Before Works	After Works	Crest	Toe		Stage 3 Study Report	Maintenance Manual
Alternative Upgrading Methods											
7	Soil Nails	12NW-C/F3	Leung Fai Tin, Clear Water Bay Road	7.5 m	- Upper part $=20^{o}\sim30^{o}$ - Lower part $=70^{o}$	- Upper part $=20^{o}$ - Lower part $=45^{o}$	- Clear water Bay Road to footpath	- Village houses	1999	S3R 103/98	MM 139/99
		15NE-A/F41*	Stanley Gap Road, No. 6 Stanley Village Road	13.5 m	$36^{o}\sim40^{o}$	$36^{o}\sim40^{o}$	- Stanley Gap Road	- Residence	1995	S3R 194/97	
		11SW-B/FR117*	Bowen Road, Tennis Court	14 m	35^{o}	29^{o}	- Service reservoir	- Road	1997	S3R 30/95	MM 182/98
		11SW-D/F147	Mt. Nicholson Quarters	(Refer to Option 1 - Slope No. 11SW-D/F147)							
		6SW-D/F35*	Siu Lam Psychiatric Centre	10 m	30^{o}	30^{o}	- Playground	- Recreational area - Upper berm, occupied buildings.	1996	S3R 11/95	MM 43/98
		11SW-B/FR44	Government House, Upper And Lower Albert Road	14 m to 20 m	30^{o} to 55^{o}	30^{o} to 55^{o}	- Government house	- Road	1998	S3R 2/96	MM 14/98
		11SW-B/F45	Government House, Upper And Lower Albert Road	14 m to 20 m	30^{o} to 55^{o}	30^{o} to 55^{o}	- Government house	- Road	1998	S3R 2/96	MM 14/98

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Table 1 - Summary of Methods other than Recompaction for Upgrading Loose Fill Slopes (Sheet 4 of 5)

Method		Slope No.	Location	Slope Height	Slope Inclination		Facilities		Year of Works Completion	Reference Documents	
No.	**Description**				**Before Works**	**After Works**	**Crest**	**Toe**		**Stage 3 Study Report**	**Maintenance Manual**
7 cont'd	Soil Nails	11SE-A/FR38*	Belilios Public School, Tin Hau Temple Road	18.5 m	60^{o}	40^{o}	Road	Play ground (school)	1999	S3R 71/98	MM 81/99
		11SW-A/FR83*	Hill Road	18.5 m	50^{o} to 75^{o}	30^{o} to 55^{o}	Residential	School	1993	S3R 5/92	-
		11SW-B/FR42*	Leighton Hill, Causeway Bay	25m	35^{o}	35^{o}	Road	School	1986	S3R 8/84	-
		11NW-B/FR12* (Section B-B)	Moonbeam Terrace, No. 2 Alnwick Road	10 m	35^{o}	35^{o}	Road	Building		File No. GCME 3/5/DH37/98/K	
8	Minipiles	11SW-B/FR42*	Leighton Hill	12~25 m	-	22^{o}~40^{o}	Road	Buildings	1986	File No. GCI 2/E1/11SW-B/FR 42 and 43	
9	Soil Cement/ Lime Columns	11SW-D/F116	Below Wan Chai Gap Park	23 m	29^{o}	-	Road	Natural Slope	works not carried out	File No.: GCD 2/A1/11SW-D/F116	
10	Grouting	11NW-B/FR12 (Section A-A)	Moonbeam Terrace, No 2, Alnwick Road	Approx. 10 m (including the toe wall)	35^{o}	35^{o}	Buildings	Road	2001	Files No.: GCME 3/5/DH37/98/K BD DH37/98K	
		11NW-D/FR196 (Section 2-2)	Maryknoll Convent School, Waterloo Road	Approx. 5.5 m (including the toe wall)	35^{o}	35^{o}	Building	Road	2001	DH Order No. DH2/K/98C	
11	Dynamic Compaction	7SW-C/F7 (Renamed 7SW-C/FR7)	South of Kerry CDI Godown Centre	22 m	-	30^{o}	Road	Factory	1997	GCO Reports 3/80 and 4/80	

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Table 1 - Summary of Methods other than Recompaction for Upgrading Loose Fill Slopes (Sheet 5 of 5)

Method		Slope No.	Location	Slope Height	Slope Inclination		Facilities		Year of Works Completion	Reference Documents	
No.	**Description**				**Before Works**	**After Works**	**Crest**	**Toe**		**Stage 3 Study Report**	**Maintenance Manual**
11 cont'd	Dynamic Compaction	7SW-C/FR51 (Removed)	Shek Lei Estate	16 m	34^{o}	34^{o}	Playground	Building	-		
		11SE-B/FR3 (Renamed 11SE-B/C554)	Ko Chun Road	6 m	-	38^{o}	Residential	Road	-	GCO Reports 3/80 and 4/80	
		11NW-D/F7 (Removed)	Homantin	19 m	30^{o}	30^{o}	Vacant platform	Vacant platform	-	GIU Report No. G56-52442	
12	Displacement Piles	11SW-A/CR90	Bridges Street, Sheung Wan	8 m	35^{o}	35^{o}	Road	School	Works not implemented due to access problem	S3R 132/98	N/A
		11NE-A/F55	Tsz Wan Shan	Approx. 10 m	31^{o}~33^{o}	31^{o}~33^{o}	Housing Platform	Park	-	GEO Report 3/80	

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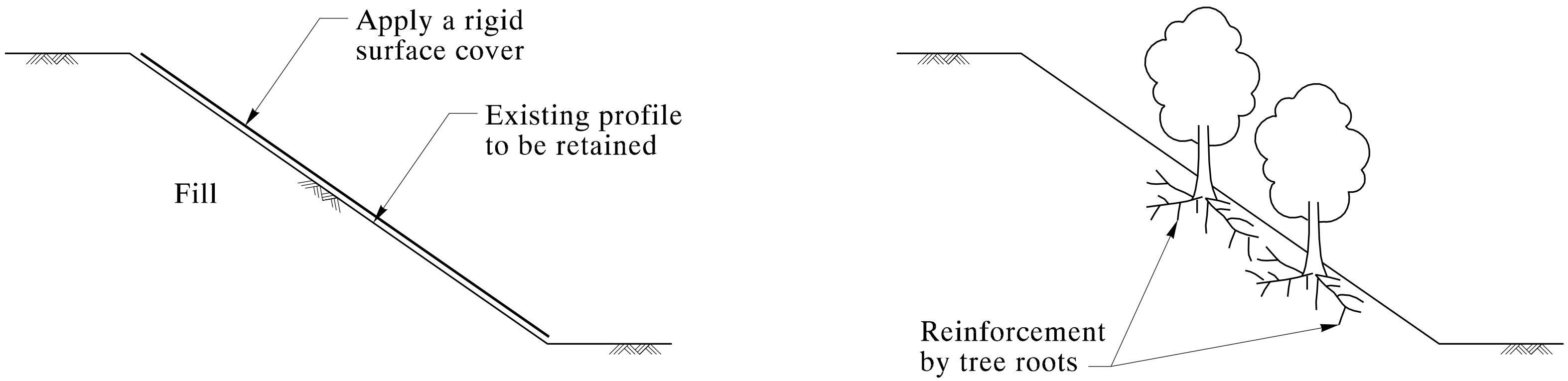

Method 1 - Rigid Surface Cover

Method 2 - Root Reinforcement

Figure 1 - Methods 1 and 2, Rigid Surface Cover and Root Reinforcement

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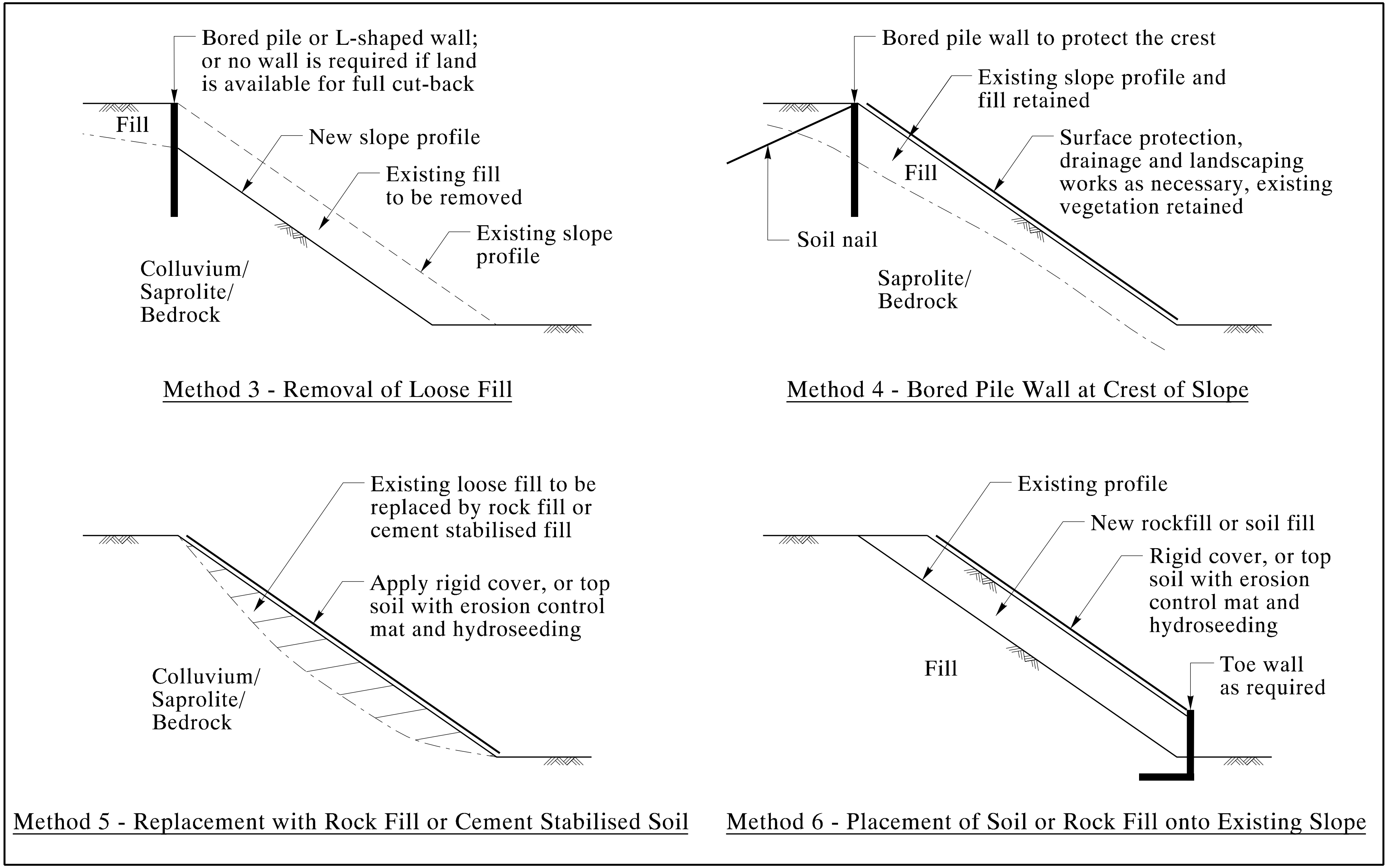

Figure 2 - Methods 3 to 6, Variations to Recompaction

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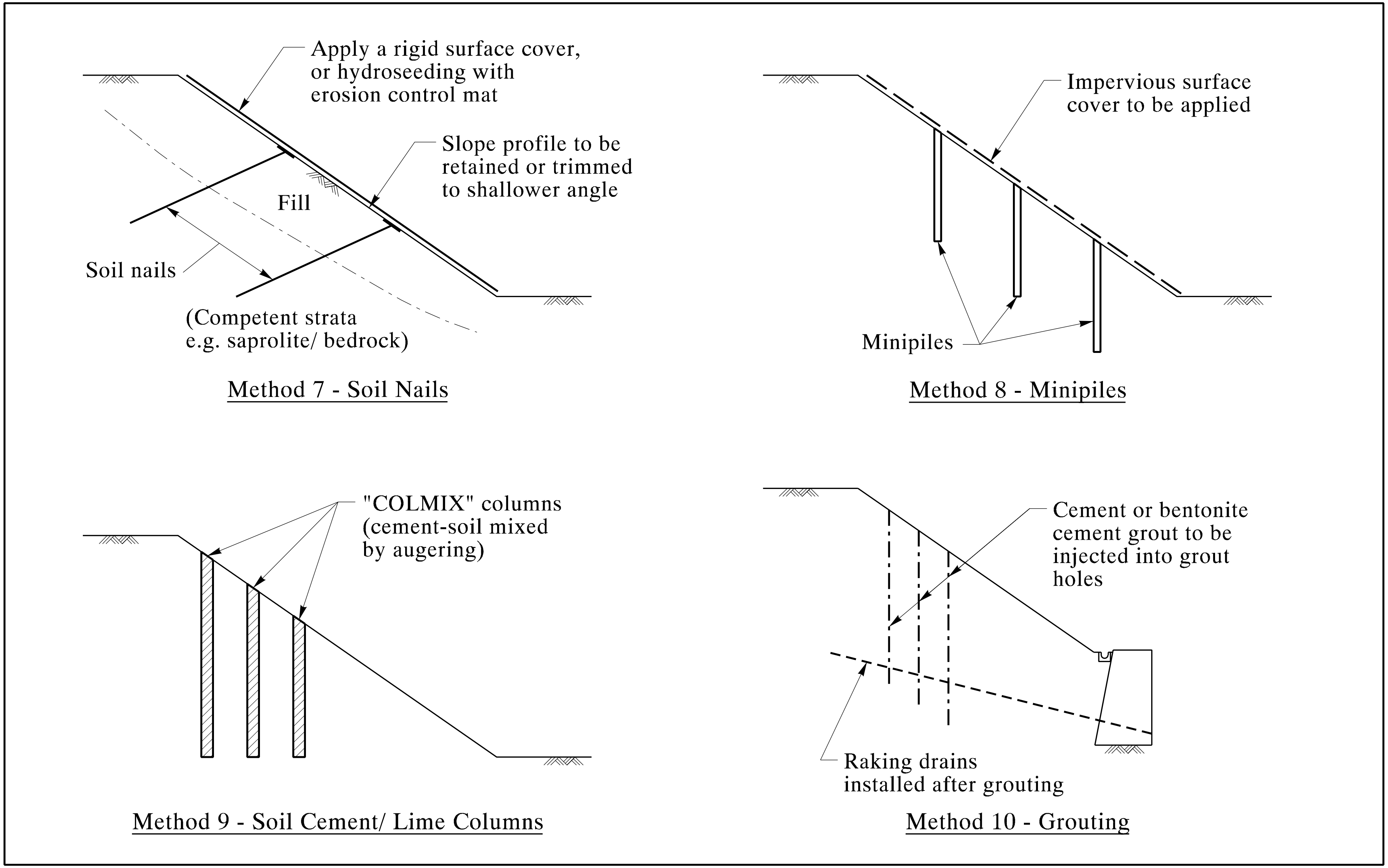

Figure 3 - Methods 7 to 12, Alternative Upgrading Methods (Sheet 1 of 2)

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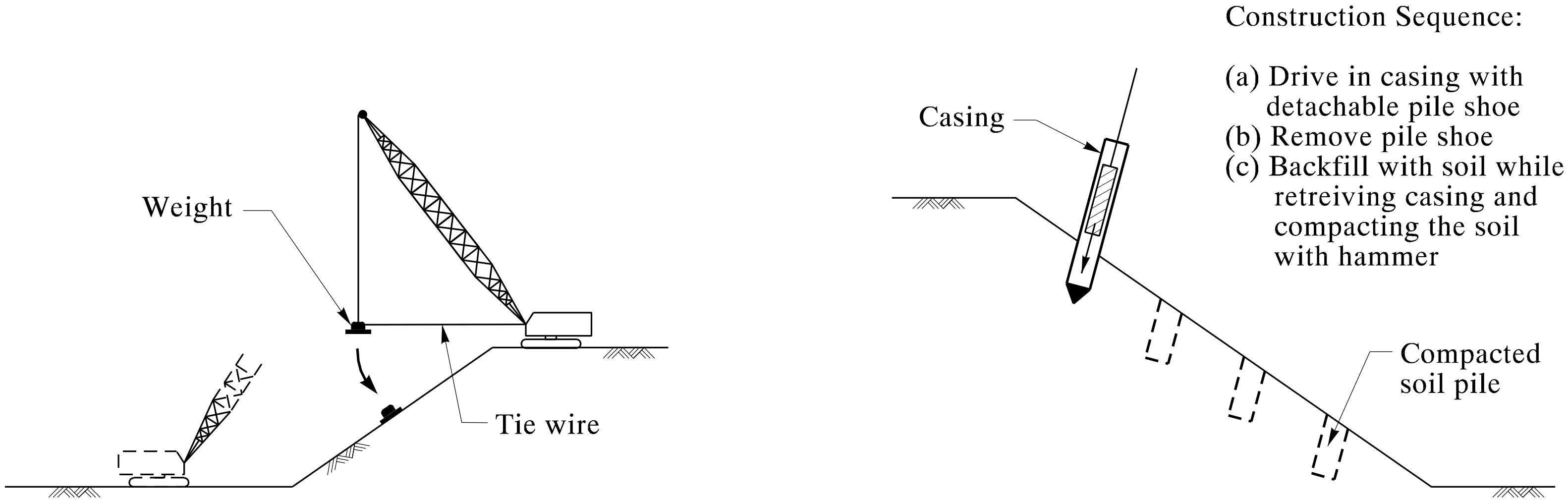

Method 11 - Dynamic Compaction

Method 12 - Displacement Piles

Figure 3 - Methods 7 to 12, Alternative Upgrading Methods (Sheet 2 of 2)

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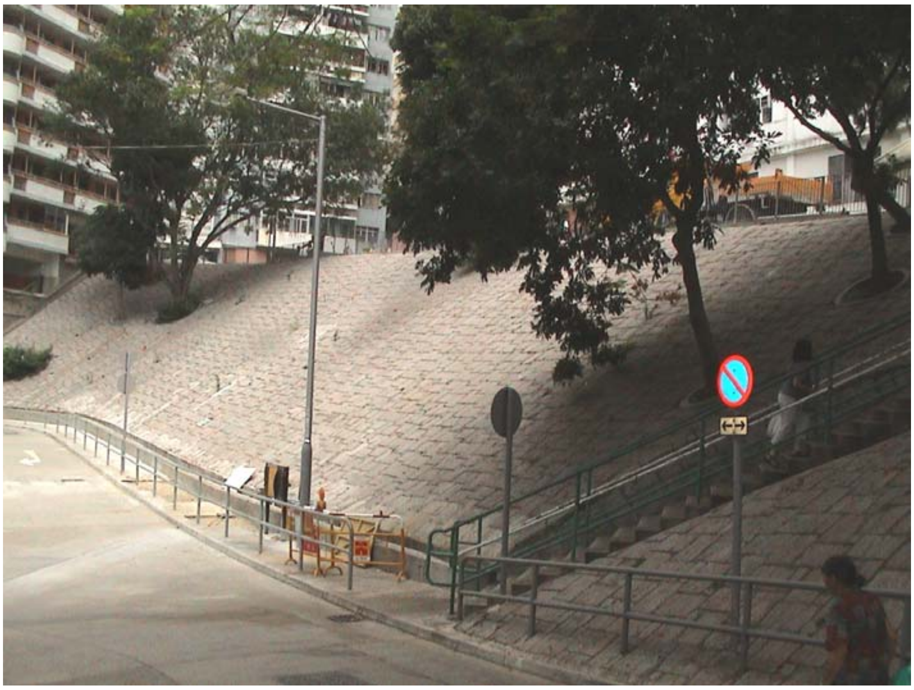
Upon Completion in 1998



In 2002

Plate 1 - Method 1: Rigid Surface Cover
(Slope Referenced 11NW-B/F55, So Uk Estate)

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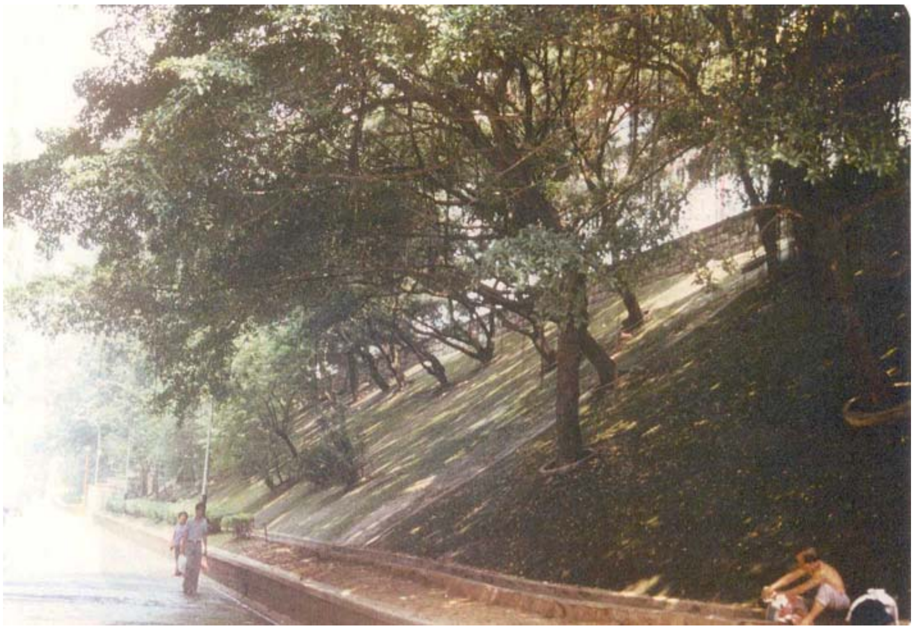
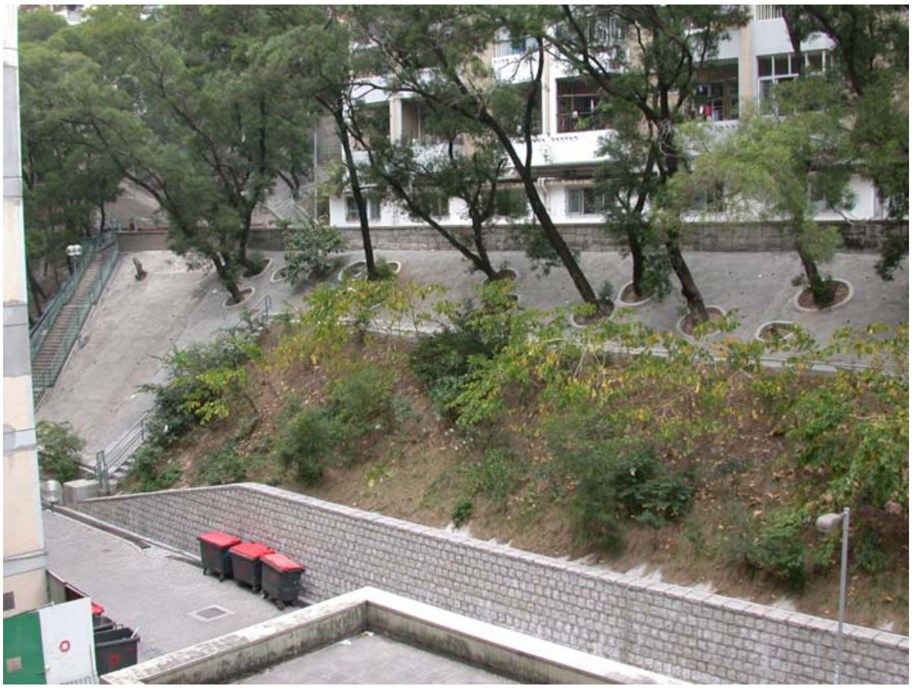


Condition as in 1985 During the Tree Roots Study



In 2002, with the Reprofiling and the Toe Wall Upgrading Works Completed

Plate 2 - Method 2: Root Reinforcement
(Slope Referenced 11NW-B/FR42, So Uk Estate)

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Upon Completion in 1997

In 2002

Plate 3 - Method 3: Removal of Loose Fill
(Slope Referenced 11SW-D/FR144, between Lingnan College and Bowen Road)

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Upon Completion in 1997

In 2002

Plate 4 - Method 4: Bored Pile Wall at Crest of Slope
(Slope Referenced 11SW-D/F31, Peak Road)

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Upon Completion in 1999

In 2002

Plate 5 - Method 5: Replacement with Rock Fill or Cement Stabilised Soil
(Slope Referenced 15NE-B/F36, Shek O Road)

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Upon Completion in 1999

In 2002

Plate 6 - Method 6: Placement of Soil or Rock Fill onto Existing Slope
(Slope Referenced 7SW-D/F29, below Lion Rock Tunnel Road)

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Upon Completion in 1996

In 2002

Plate 7 - Method 7: Soil Nails
(Slope Referenced 6SW-D/F35, Siu Lam Psychiatric Centre)

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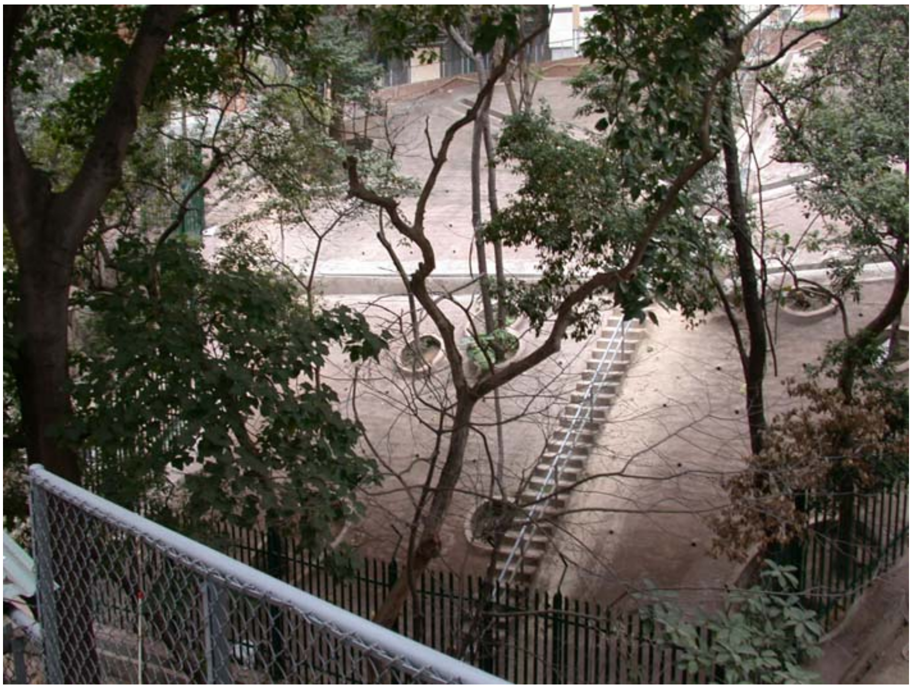
Condition as in 1998, Not the Minipiled Portion as below but Nearby



In 2002, the Minipiled Portion of Slope Covered with Shotcrete Surfacing
after the Upgrading Works Recently Completed

Plate 8 - Method 8: Minipiles
(Slope Referenced 11SW-B/FR42, Leighton Hill)

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Condition as in 2002; Works were Completed in 2001

Plate 9 - Method 10: Grouting
(Slope Referenced 11NW-D/FR196, Maryknoll Convent School, Waterloo Road)

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Works in Progress in 1979

Plate 10 - Method 11: Dynamic Compaction
(Slope Referenced 11NW-D/F7, Homantin; the Slope was Later Deleted)

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Works in Progress in 1979

In 2002, the Slope is Covered by Mature Trees with a Service Reservoir Constructed Some Distance Downhill by Excavating into the Natural Grounds

Plate 11 - Method 12: Displacement Piles
(Slope Referenced 11NE-A/F55, Tsz Wan Shan)

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GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.

GEOLOGICAL PUBLICATIONS

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

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

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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