GEO PUBLICATION No. 1/2009

PRESCRIPTIVE MEASURES FOR MAN-MADE SLOPES AND RETAINING WALLS




GEOTECHNICAL ENGINEERING OFFICE
Civil Engineering and Development Department
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Captions of Figures on the Front Cover

Top Left : Soil Cut Slope at Princess Margaret Road, Homantin

Top Right : Soil and Rock Cut Slope at Tin Hau Temple Road, North Point

Bottom Left : Skin Wall at Heung Chung, Sai Kung

Bottom Right : Soil Cut Slope at Wo Chung Street, Homantin

FOREWORD

This Publication presents a recommended standard of good practice for the application of prescriptive measures as improvement works on existing man-made slopes and retaining walls in Hong Kong. The scope of application covers a range of prescriptive measures items in the form of preventive maintenance works, upgrading works or repair works to landslides.

Various types of prescriptive measures have been developed for soil/rock cut slopes, fill slopes and masonry/concrete retaining walls. The findings and recommendations of the studies on the formulation of the prescriptive measures framework are given in a series of technical reports and guidance documents published by the Geotechnical Engineering Office from 1995 to 2007. This Publication integrates and rationalises the recommendations and provides a comprehensive guidance document on the application of prescriptive measures to existing man-made slopes and retaining walls.

This document was prepared by a team consisting of Dr Raymond W.M. Cheung, Ms Becky L.S. Lui and Mr Lawrence K.W. Shum, under the supervision initially of Mr W.K. Pun and later Mr Ken K.S. Ho.

Copies of a draft version of this document were circulated to local professional bodies, consulting engineers, academics and Government departments. Many individuals and organisations made useful comments, which have been taken into account in finalising this Publication. All contributions are gratefully acknowledged.

Practitioners are encouraged to provide comments to the Geotechnical Engineering Office at any time on the contents of this Publication, so that further improvements can be made in future editions.

R.K.S. Chan
Head, Geotechnical Engineering Office
August 2009

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to give guidance on the application of prescriptive measures to existing man-made slope features, i.e. man-made cut slopes, fill slopes and retaining walls, in Hong Kong. The document is aimed at professionally qualified engineers, who are conversant with the relevant geotechnical engineering principles.

Prescriptive measures comprise pre-determined, experience-based and suitably conservative modules of works prescribed to man-made slope features to improve stability, or reduce the risk of failure, without the need for detailed ground investigations and design analyses. The guidelines set out in this document cover the application of prescriptive measures to existing man-made slope features including soil cut slopes, soil cut slopes with toe walls, rock slopes, concrete retaining walls, masonry retaining walls and fill slopes. This document does not cover the use of standardised debris-resisting barriers for natural terrain landslide risk mitigation (e.g. Sun & Lam, 2006).

General guidance on the application of prescriptive measures, together with the merits and limitations of their use, is outlined in Chapter 2. The required qualifications of personnel responsible for the design of prescriptive measures are also given in this chapter.

Chapters 3, 4 and 5 provide specific guidance on the application of different types of prescriptive measures.

Guidance on other pertinent considerations in respect of the application of the prescriptive design framework is given in Chapter 6.

2. APPLICATIONS

2.1 GENERAL

This Chapter provides general guidance on the application of prescriptive measures to man-made slope features in Hong Kong. The merits and limitations of the prescriptive approach, as well as the qualification requirements of the responsible personnel, are also outlined. Specific guidance on the application of different types of prescriptive measures is given in Chapters 3, 4 and 5.

2.2 DEVELOPMENT OF 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. However, the annual failure rate of engineered slopes, in particular those without robust engineering measures such as unsupported soil cuts (e.g. slope cut back with no structural support), is not low (Ho et al, 2003). Systematic landslide investigations carried out by the Geotechnical Engineering Office (GEO) revealed that failures in engineered slopes were mainly associated with problems including uncontrolled surface runoff and presence of adverse geological features and/or adverse groundwater conditions. This reflects the inherent uncertainties and limitations of the conventional analytical approach, which include inadequate engineering geological input during ground investigation, poor detailing in slope drainage provisions, etc.

As an alternative to the conventional analytical approach, the prescriptive approach provides an experience-based method for the design of slope improvement works. Prescriptive measures items are developed based on experience of their successful application in the past, which have been tested in the field and refined with time, with emphasis given to proper detailing having regard to the lessons learnt from landslide studies. It should be acknowledged that many of the established slope improvement provisions, standard details, etc. are by nature prescriptive.

The use of prescriptive measures is not a new concept in Hong Kong, as the prescriptive approach has long been adopted in some types of man-made slope works. These included rock slope stabilisation works (e.g. Brand et al, 1983; Dubin et al, 1986), and surface recompaction of loose fill slopes (e.g. GCO, 1984; Knill et al 1999). The idea of developing prescriptive measures for general use in improvement works on man-made slopes in Hong Kong was first considered in the 1980s (Malone, 1985). The use of prescriptive measures was formally recognised for retaining wall design in the second edition of Geoguide 1 : Guide to Retaining Wall Design (GEO, 1993).

The use of prescriptive measures had also been recognised as one of the approaches to geotechnical design in some overseas design codes. For example, Eurocode 7 (BSI, 2004) allows the use of prescriptive measures in situations where calculation methods are not available or are not necessary.

In 1995, the GEO embarked on the development of a prescriptive design framework and suitable prescriptive measures for use on man-made soil cut slopes. The study was aimed at formulating a prescriptive design methodology and promoting good practice in the application of prescriptive measures to man-made soil cut slopes. Different items of works were developed based on a study of local practice in slope improvement and upgrading works and case studies on conventional analytical design for the Government's Landslip Preventive Measures (LPM) Programme. In particular, 107 soil-nailed cut slopes designed analytically under the LPM Programme were reviewed to support the derivation of the prescriptive soil nail design approach for soil cut slopes. After extensive consultation, the GEO disseminated in 1996 the findings and recommendations of the study in the first edition of GEO Report No. 56 : Application of Prescriptive Measures to Soil Cut Slopes (Wong & Pang, 1996).

With experience gained by practitioners and successful application of prescriptive measures, the GEO carried out a series of further studies in 1998 to improve the guidelines and extend the scope of application of prescriptive measures. In these studies, another 197 soil-nailed cut slopes designed analytically under the LPM Programme and in private developments were reviewed. Based on the findings, the scope of application of prescriptive measures as upgrading works to soil cut slopes was extended, and design guidelines were suitably revised (Pun et al, 2000).

Another study was initiated in 1999 to develop a prescriptive approach involving the use of reinforced concrete skin walls for upgrading existing masonry retaining walls. The prescriptive approach was formulated based on a review of past cases of skin wall design for upgrading existing masonry retaining walls (Wong & Pun, 1999).

In 1999, all the then prevailing guidelines on the application of prescriptive measures were consolidated in the second edition of GEO Report No. 56 : Application of Prescriptive Measures to Slopes and Retaining Walls (Wong et al, 1999). In response to the rising expectations of the public in respect of slope appearance, guidelines for prescriptive use of vegetation cover on soil cut slopes to improve slope appearance were also given in the Report.

In 2003, a study was carried out to review the use of prescriptive measures on rock cut slopes and the findings were documented in GEO Report No. 161 : Guidelines on the Use of Prescriptive Measures for Rock Cut Slopes (Yu et al, 2005). The use of prescriptive approach in rock slope stabilisation works has been widely applied in local practice for many years. The guidelines developed in 2003 were aimed at rationalising the design practice and providing detailed technical guidance on the use of different items of prescriptive measures on rock cut slopes. In the course of developing the guidelines, more than 100 rock slopes upgraded under the LPM Programme were reviewed.

Another study was carried out in 2004 to extend the application of prescriptive soil nails to concrete retaining walls, masonry retaining walls and soil cut slopes with toe walls. Prescriptive soil nail design guidelines were derived based on the review and analysis of some past cases in which soil nails designed by conventional analytical approach were used to upgrade concrete retaining walls, masonry retaining walls and soil cut slopes with toe walls. The guidelines are given in GEO Report No. 165 : Prescriptive Soil Nail Design for Concrete and Masonry Retaining Walls (Lui & Shiu, 2005).

In 2007, prescriptive measures involving surface protection, surface drainage and subsurface drainage were rationalised for use on fill slopes and retaining walls, with due regard to the findings of systematic landslide studies undertaken by the GEO since 1997.

2.3 AREAS OF APPLICATION

Prescriptive measures have basically been developed for use under two categories of slope improvement works, namely preventive maintenance works as defined in Geoguide 5 : Guide to Slope Maintenance (GEO, 2003) and upgrading works. Some of the prescriptive measures can also be applied as repair works to landslides.

The application of prescriptive measures as upgrading works should generally be limited to slope features which have not experienced any major failure (i.e. with a volume of detached or displaced groundmass $\geq 50\ m^3$, or where a fatality has occurred), or multiple minor failures (i.e. with a volume of detached or displaced groundmass $< 50\ m^3$). Where there are major or multiple minor failures on the slope feature or at adjacent areas, the causes of the failures should first be established and understood. Prescriptive measures may be applied to the slope feature as upgrading works only if it can be established that all qualifying criteria in geometry, engineering and geology, etc. are met (see Chapter 5 for details of the qualifying criteria).

Prescriptive measures may not be applicable for upgrading retaining walls with sizeable wall trees that are well anchored to the wall by their roots. In this case, the dead weight of wall trees, together with the effect arising from wind loading on the wall trees, may adversely affect the stability of the retaining wall. Designers should exercise due engineering judgement in determining whether detailed analyses are warranted to evaluate the effects of wall trees, taking into account the degree of anchorage of the tree roots.

If a slope feature that had been designed and checked to comply with the required geotechnical standards fails, then the prescriptive approach may not be applicable and the slope feature should be investigated to determine the necessary upgrading works.

2.4 MERITS AND LIMITATIONS OF PRESCRIPTIVE MEASURES

Prescriptive measures provide an effective and efficient approach for prescribing improvement works to slope features. The following are the advantages of using prescriptive measures over conventional analytical approach:

(a) Technical benefits in enhancing safety and reducing the risk of failure, by incorporating simple, standardised and suitably conservative items of works to deal with uncertainties in design that are difficult to quantify, and using experience based knowledge to supplement analytical design.

(b) Savings in time and human resources, by eliminating detailed ground investigations and design analyses. The savings can be significant, particularly in a safety screening and improvement works programme in which a large number of slopes have to be dealt with by limited available staff resources.

There are, however, some inherent limitations if the prescriptive measures are used alone. These include the following:

(a) The items to be prescribed are at best limited to application to situations within the bounds of past experience.

(b) The approach may result in more failures than design by detailed ground investigation and analysis, particularly for slopes affected by adverse geological and groundwater conditions that are not anticipated at the design stage.

Provided that designers acknowledge and work within these limitations, prescriptive measures can be adopted as effective slope improvement works. Guidance given in this document is aimed at minimising landslide risk associated with the above limitations.

The merits and limitations of the prescriptive measures listed above are not exhaustive. Designers should compare design options based on prescriptive approach and those based on conventional analytical approach in option assessments, and exercise due engineering judgement to select the best engineering solution for the problem at hand.

2.5 TYPES OF PRESCRIPTIVE MEASURES

Prescriptive measures for slope features may broadly be classified into the following three types according to the design objectives:

(a) Type 1: surface protection, local trimming and drainage – This type of measures aims at improving surface protection, surface drainage and local stability.

(b) Type 2: subsurface drainage – This type of measures aims at improving subsurface drainage and providing contingency subsurface drainage measures.

(c) Type 3: structural support – This type of measures aims at providing support to improve overall feature stability. Several items of works have been developed, including:

(i) soil nails for soil cut slopes,

(ii) soil nails for soil cut slopes with toe walls,

(iii) soil nails for concrete or masonry retaining walls,

(iv) skin walls for masonry retaining walls,

(v) concrete buttresses for rock cut slopes, and

(vi) rock dowels for rock cut slopes.

The three types of prescriptive measures may be applied in combination to different types of slope features. A schematic diagram depicting some typical prescriptive measures is shown in Figure 2.1.

2.6 SELECTION OF PRESCRIPTIVE MEASURES

In selecting the appropriate types and items of prescriptive measures, designers should take due account of the nature of the slope-forming materials, geological conditions, groundwater conditions, nature and locations of services, surface water pathways, performance history of the slope, consequence in the event of failure, site constraints, together with the type and level of improvement required. Designers should also exercise engineering judgement when prescribing the measures recommended in this document, or in applying other measures as deemed appropriate in order to suit the actual site conditions.

The common applications of different types of prescriptive measures to various types of slope features are summarised in Table 2.1.

Table 2.1 Common Applications of Different Types of Prescriptive Measures

<table>
<tr><th rowspan="2">Types of Slope Features</th><th colspan="3">Types of Improvement Works</th></tr>
<tr><th>Preventive Maintenance Works</th><th>Upgrading Works(1)</th><th>Repair Works to Landslides</th></tr>
<tr><td>Soil cut slopes(2)</td><td rowspan="3">Generally Types 1 and/or 2, sometimes Type 3</td><td>Type 3, generally supplemented by Types 1 and/or 2</td><td rowspan="2">Generally Types 1 and/or 2, sometimes Type 3</td></tr>
<tr><td>Rock cut slopes</td><td>Generally Types 1, 2 and 3 used in combination</td></tr>
<tr><td>Retaining walls</td><td>Type 3, generally supplemented by Types 1 and/or 2</td><td rowspan="2">Generally Types 1 and/or 2</td></tr>
<tr><td>Fill slopes</td><td>Generally Types 1 and/or 2</td><td>See Note (3)</td></tr>
</table>

Notes:
(1) Slope features should satisfy the qualifying criteria given in Chapter 5 for the application of Type 3 prescriptive measures as upgrading works.
(2) Soil cut slopes include those slope features with toe walls.
(3) Fill slopes can be upgraded by the prescriptive approach of surface recompaction and subsurface drainage provisions following the guidance given in the Geotechnical Manual for Slopes (GCO, 1984), Works Bureau Technical Circular No. 13/99 (Works Bureau, 1999), GEO Technical Guidance Note No. 7 (GEO, 2007a), GEO Report No. 225 (Fugro Scott Wilson Joint Venture, 2008) and Pun & Urciuoli (2008). Types 1 and/or 2 prescriptive measures may also be used in conjunction with surface recompaction.

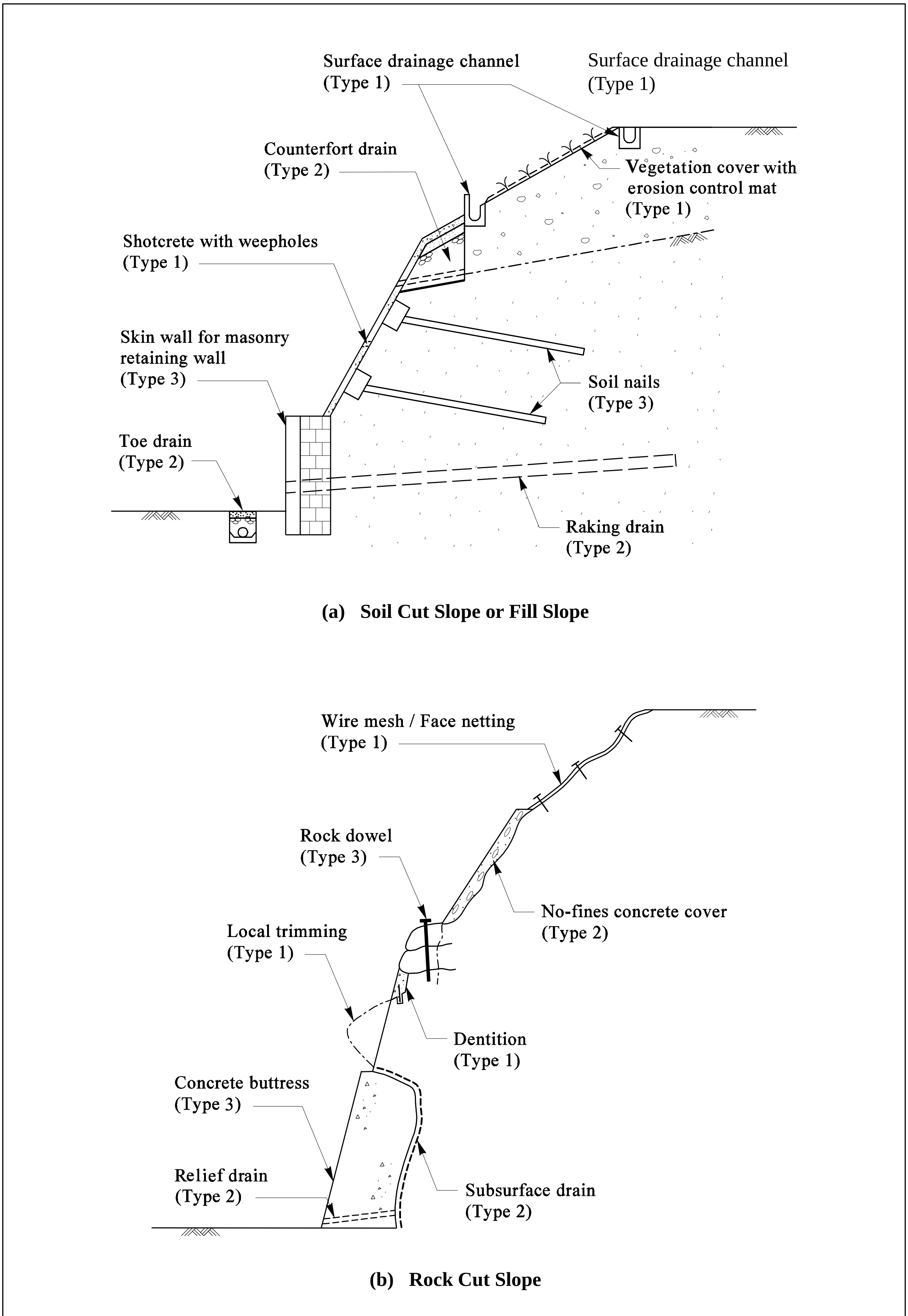


Figure 2.1 Schematic Diagram of Typical Prescriptive Measures for Man-made Slope Features

Types 1 and 2 prescriptive measures improve the surface protection and drainage condition of slope features. In essence, these are preventive maintenance works which will help reduce the rate of slope deterioration. As such, no qualifying criteria are needed. Given that the surface protection and drainage provisions on many old slopes are deficient or do not exist, designers should apply Types 1 and 2 prescriptive measures as preventive maintenance works to any types of existing slope features wherever practical.

Type 1 and/or 2 prescriptive measures can also be used as part of the repair works to landslides, in particular during the time shortly after landslide occurrence when the priority is to remove immediate danger in order to protect life and property. Although Type 3 prescriptive measures are not commonly needed as emergency repair works to landslides, their use cannot be precluded in certain circumstances. Considerations should be given to the scale and mechanism of failure, the consequence of further landslides, and the effectiveness of the prescriptive measures in respect of the recovery of the emergency situation, and each case should be treated on its own merits.

Some items of prescriptive measures need to be installed into the ground. Designers will need to check the land status. Should the proposed prescriptive measures need to be extended into the adjoining land, designers should seek the agreement of the land owner as necessary before implementation of the works.

2.7 RECOMMENDED PROCEDURES FOR APPLICATION

The recommended procedures for application of prescriptive measures to man-made slope features are given in the following paragraphs:

(a) Undertake a thorough desk study and site reconnaissance in accordance with Geoguide 2 : Guide to Site Investigation (GCO, 1987) to determine whether there is sufficient information on the ground and groundwater conditions to facilitate the checking of the qualifying criteria for application of prescriptive measures. For rock slopes, data on discontinuities should be collected and assessed. It is recommended that for preventive maintenance works and upgrading works, an Engineer Inspection (EI) in accordance with Geoguide 5 : Guide to Slope Maintenance (GEO, 2003) should be carried out to identify areas requiring attention prior to specifying the types and items of prescriptive measures.

(b) Collect relevant information to construct a preliminary geological model of the site as part of the desk study. It should also include a review of the available records on previous landslides, services, surface water pathways, slope maintenance history, stability assessment records and existing relevant ground investigation data. The site inspection should always include checks to identify whether any exposed or buried water-carrying services are present in the vicinity of the slope feature (ETWB, 2006a). If such services are present, checks should be carried out with the owner to assess whether there have been any leakages from the services, and recommendations to carry out regular checks of the services should be made.

(c) Determine the geometry of the slope feature. For slope features involving retaining walls, the wall thickness should be determined by field measurements, such as topographic survey and weephole probing. Field measurement of wall geometry should still be carried out to verify the actual geometry of the wall even where as-built drawings of the wall showing the wall dimensions are available. Where the thickness of the wall is found to vary approximately linearly with wall height, the wall thickness at about the mid-height of the wall may be taken as the average wall thickness. For walls found to have a stepped back face, the average wall thickness may be taken as the weighted average of the thicknesses of all steps taking into account the step heights.

(d) Carry out minor ground investigation if the available information is insufficient for the checking of qualifying criteria with confidence. Simple investigation techniques are often adequate, such as surface strippings on existing hard surface cover to expose the slope material; trial pits at wall toe to reveal the foundation and check the likelihood of the presence of a high permanent groundwater level; trial pits and GCO probing behind the wall to assess wall thickness, fill extent and the nature of the retained ground. Engineering judgement needs to be exercised regarding the likely transient rise in groundwater level during rainfall based on the results of the desk study, site inspection and ground investigation.

(e) Review whether the slope feature satisfies the qualifying criteria for application of prescriptive measures as upgrading works (Chapter 5). A review of the qualifying criteria is not required if the prescriptive measures are to be used as preventive maintenance works.

(f) Identify potential problems that may affect the stability of the slope feature based on the desk study, site inspection and ground investigation. For slope features with past failures, designers should seek to establish the probable causes of the failures prior to specifying prescriptive measures.

(g) Determine the design objectives and required items of prescriptive measures with reference to Chapters 3, 4 and 5. Refer to the typical details of the relevant items of prescriptive measures and follow the necessary procedures in prescribing particular modules of works items. Then specify the key dimensions for each of the items and the extent of application to the slope feature in order to suit the actual site conditions.

(h) Complete Part A of the "Record Sheets for Prescriptive Measures on Man-made Slope Features" (Sheet 1, Figure 2.2) in all cases of using prescriptive measures.

(i) Carry out construction reviews during various stages of construction (see Section 2.8 for qualification requirements of personnel and Section 6.7 for the coverage of construction reviews).

(j) Confirm that the qualifying criteria for application of the prescriptive measures are met. Review the suitability and adequacy of the specified prescriptive measures based on judgement and make suitable amendments as appropriate.

(k) Complete Part B of the "Record Sheets for Prescriptive Measures on Man-made Slope Features" (Sheet 2, Figure 2.2), giving sufficient documentary evidence on verification that the slope feature satisfied the qualifying criteria. Where prescriptive measures are to be used as preventive maintenance works, record the recommended works in the "Record Sheets for Engineer Inspections for Maintenance" (see Appendix F of Geoguide 5 (GEO, 2003)) as well.

2.8 QUALIFICATION REQUIREMENTS OF PERSONNEL

Prescriptive measures for slope features should be designed by a geotechnical engineer professionally qualified and experienced in Hong Kong (such as Registered Professional Engineer (Geotechnical)), as should the construction review. The design should also be reviewed independently by a geotechnical engineer professionally qualified and experienced in Hong Kong. Input by qualified and experienced geotechnical professionals in designing and reviewing prescriptive measures is crucial, as substantial professional judgement is required in the verification of the qualifying criteria (e.g. adverse geological features, etc.), selection of appropriate items of works and design review during the construction stage. All of the above require geotechnical expertise and experience. Assistance from an experienced engineering geologist should be sought by the responsible geotechnical professional on a need basis.

In designing prescriptive measures for rock slopes, an alternative to a professionally qualified geotechnical engineer is a professionally qualified engineering geologist (such as Chartered Geologist) with sufficient and relevant experience in rock slope stabilisation works in Hong Kong.

Part A - Prescriptive Measures on Man-made Slope Features

Slope Feature Ref. No. ______________________	Location (Address) ______________________________

Slope Feature Geometry			Qualifying Criteria	
Slope feature height:		(m)	1. Within consequence and geometry limits	☐ Correct
Upslope gradient:		(degrees)	2. Slope-forming material confirmed on site as acceptable	☐ Correct
Slope part –	Slope height:	(m)	3. No adverse geological conditions	☐ Correct
	Slope gradient:	(degrees)	4. No adverse groundwater conditions	☐ Correct
Wall part –	Wall height:	(m)		

Consequence Category		Records of Engineer Inspection
Facility Group affected:	1 / 2 / 3 / 4 / 5 *	Records of Engineer Inspection available: Yes / No *
Consequence-to-life Category:	1 / 2 / 3 *	If Yes, dates of inspection:
Economic Consequence Category:	A / B / C *	HKGS Geology Map Sheet No.:

Records of Landslides

Date of Landslide	Scar Height (m)	Failure Volume (m^3)	Principal Causes of Failure	Incident No.
1.________________	______________	________________	________________________	________________
2.________________	______________	________________	________________________	________________
3.________________	______________	________________	________________________	________________

Type of Improvement Works

☐ Preventive maintenance works ☐ Upgrading works ☐ Repair works to landslides

Types of Measures	Design Objectives	Prescriptive Measures Recommended
☐ Type 1	☐ Improve surface protection ☐ Improve surface drainage ☐ Improve local stability	☐ 1.1 Surface cover for soil slopes ☐ 1.2 Wire mesh/Face netting for rock slopes ☐ 1.3 Surface protection for retaining walls ☐ 1.4 Surface drainage channels ☐ 1.5 Local trimming/filling ☐ 1.6 Dentition
☐ Type 2	☐ Improve subsurface drainage ☐ Contingency subsurface drainage provisions	☐ 2.1 Raking drains ☐ 2.2 Toe drains ☐ 2.3 Counterfort drains ☐ 2.4 Relief drains ☐ 2.5 Drainage for hard surface cover ☐ 2.6 No-fines concrete cover
☐ Type 3	☐ Provide structural support	☐ 3.1 Soil nails for soil cut slopes (Range of ΔFOS: I^+ / I / II / III *) ☐ 3.2 Soil nails for soil cut slopes with toe walls (Range of ΔFOS: I^+ / I / II / III *) ☐ 3.3 Soil nails for concrete or masonry retaining walls ('existing' / 'new' * wall standard) ☐ 3.4 Skin walls for masonry retaining walls ☐ 3.5 Concrete buttresses for rock cut slopes ☐ 3.6 Rock dowels for rock cut slopes
☐ Others (please specify) ________________________________		☐ Other measures (please specify) ________________________________

Attachments:
☐ Site location plan ☐ Photographs ☐ Records of Engineer Inspections
☐ Plan, sketches/drawings showing locations/layout/key dimensions of proposed prescriptive measures

Designed by: Post:	Signature: Date:	Reviewed by: Post:	Signature: Date:

'*'Delete where appropriate

Figure 2.2 Record Sheets for Prescriptive Measures on Man-made Slope Features (Sheet 1 of 2)

Part B - Design Amendments and Site Inspection Records					
Design Amendments[1]	Reasons for Amendments	Designed by (name & post)	Signature (+ date)	Reviewed by (name & post)	Signature (+ date)

Post-construction Review recommended: ☐ Yes ☐ No

If Yes, give actions to be taken (e.g. site inspections after heavy rainstorms to check adequacy of surface or subsurface drainage measures). ____

____

Notes:
(1) Sketches/drawings showing the design amendments should be attached.
(2) Sketches, notes and photographs which record the observations made during site inspections prior to and during construction of prescriptive measures, as well as documentary evidence to verify that the slope feature satisfied the qualifying criteria, should also be attached. These should be marked clearly as 'Site Inspection Records'.

Works commenced on	Works completed on	Works certified by (Name & Post)	Signature and Date
____________	____________	____________	____________

Figure 2.2 Record Sheets for Prescriptive Measures on Man-made Slope Features (Sheet 2 of 2)

For preventive maintenance works to slope features that involve only surface protection and surface drainage prescriptive measures, the prescriptive design and construction review may also be carried out by a professionally qualified civil engineer competent in site formation and drainage works. It is preferable, and often more cost-effective, to have the same professional engineer who undertakes the Engineer Inspection of the slope feature to also design the prescriptive measures as part of the preventive maintenance recommendations.

Regular reviews should be carried out during construction. The professional engineer who undertakes the construction reviews should be familiar with all the information collected in the desk study and site reconnaissance, as well as the assumptions made in prescribing the measures. The preferred arrangement is for the same professional engineer who designed the prescriptive measures items to carry out the construction reviews (see also Section 6.7).

2.9 STATUS OF SLOPE FEATURES IMPROVED BY PRESCRIPTIVE MEASURES

Where Type 3 prescriptive measures have been applied to a slope feature as upgrading works in accordance with the recommendations of this document, the slope feature can be taken to have been upgraded to the required safety standards.

Where prescriptive measures have been applied to a slope feature as preventive maintenance works, or repair works to landslides, in accordance with the recommendations of this document, the subject slope feature should not be taken to have been upgraded to the required safety standards.

3. TYPE 1 PRESCRIPTIVE MEASURES

3.1 GENERAL

This Chapter provides specific guidance on the application of Type 1 prescriptive measures to slope features. Type 1 prescriptive measures are aimed at improving surface protection, surface drainage and local stability of slope features. Type 1 prescriptive measures will contribute to reduce the rate of deterioration of a slope feature and improve its stability, in particular the margin of safety against local and shallow failures. The need for these prescriptive measures should be considered in all cases of man-made slope features.

Table 3.1 shows a summary of the Type 1 prescriptive measures items and the associated design objectives. The application of the items should be specified by designers to best suit the slope feature type and actual site conditions.

Table 3.1 Items of Type 1 Prescriptive Measures

Type of Measures	Design Objectives	Item No.	Items
Type 1	Improve surface protection	1.1	Surface cover for soil slopes
		1.2	Wire mesh/Face netting for rock slopes
		1.3	Surface protection for retaining walls
	Improve surface drainage	1.4	Surface drainage channels
	Improve local stability	1.5	Local trimming/filling
		1.6	Dentition

3.2 TYPE 1 PRESCRIPTIVE MEASURES

3.2.1 Surface Protection

(1) *Surface Cover for Soil Slopes*. A slope surface cover is necessary to prevent undue surface infiltration and protect the soil slopes against erosion by surface runoff. Where the existing slope surface cover is deficient, a new one should be provided depending on the susceptibility of the slope to surface infiltration and erosion.

A vegetation cover may be used to provide surface protection to soil slopes. Since the slope will be prone to surface erosion if the vegetation is not well established, the provision of appropriate erosion control measures and suitable types of vegetation is essential to the proper performance of the vegetation cover. Recommended measures for the prescriptive use of vegetation cover for soil slopes of different gradients are given in Table 3.2. Such measures are appropriate for both soil cut slopes and fill slopes, which have an inadequately developed vegetation cover or a defective chunam cover which no longer serves as a relatively impermeable cover effectively.

Table 3.2 Prescriptive Use of Vegetation Cover for Soil Slopes

Slope Gradients	Erosion Control Measures	Types of Suitable Vegetation
Slope gradient ≤ 35°	Temporary degradable erosion control mat(3)	Creepers, herbaceous plants, grass, shrubs and/or trees
35° < slope gradient ≤ 45°	Long-term non-degradable erosion control mat(3)	Creepers, herbaceous plants, grass, shrubs and/or trees
45° < slope gradient ≤ 55°(2)	Long-term non-degradable erosion control mat(3) and wire mesh	Creepers, herbaceous plants, grass and/or shrubs

Notes:
(1) The measures given in this Table are based on known successful experience in Hong Kong. Other measures as given in GEO Publication No. 1/2000 (GEO, 2000a) may be used where considered appropriate.
(2) For soil cut slopes steeper than 55°, designers may adopt similar suite of erosion control measures as slopes with gradients between 45° and 55° but close monitoring of vegetation growth and its performance on erosion control during maintenance is recommended.
(3) Fixing details for erosion control mats should comply with the manufacturer's instructions.

The prescriptive use of vegetation cover for soil slopes should be in conjunction with other suitable items of prescriptive measures as recommended in this document. For the area below and adjacent to downslope drainage channels with convergent surface water flow, consideration should be given to providing an impermeable, erosion-resistant surface protective cover, e.g. apron slabs of 0.5 m to 1 m in width on both sides of the channels, to further strengthen the surface protection of the vegetated soil slope.

Shotcrete, or any other kinds of hard slope facings, may provide a hard surface cover for soil slopes to prevent surface infiltration and protect the slopes against surface erosion. Designers' attention is drawn to the need to strike a suitable balance between slope safety and slope appearance. The government policy on slope appearance is that any existing vegetation on a slope should be maintained as far as possible (Works Bureau, 1993 & 2000).

Prior to adopting a shotcrete facing where this is deemed appropriate, any landslide debris or loose materials on the slope surface should be removed to ensure proper contact between the shotcrete and the slope. Applying shotcrete directly onto a slope surface with active seepage must be avoided. A hard surface cover is generally not necessary for the less weathered portion (PW50/90 zone or better, as defined in Geoguide 3 : Guide to Rock and Soil Descriptions (GCO, 1988)) of a slope formed in weathered rock.

Where considered appropriate by designers, a vegetation cover may be used to replace an existing hard surface cover (e.g. shotcrete) of a soil cut slope of consequence-to-life Category 3 as defined in the Geotechnical Manual for Slopes (GCO, 1984), Works Bureau

Technical Circular No. 13/99 : Geotechnical Manual for Slopes - Guidance on Interpretation and Updating (Works Bureau, 1999), and GEO Technical Guidance Note No. 15 : Guidelines for Classification of Consequence-to-Life Category for Slope Features (GEO, 2007b). However, for soil cut slopes of consequence-to-life Categories 1 and 2, the replacement of the hard surface cover by vegetation cover should be done only where soil nailing works are also carried out to upgrade the slope at the same time. For such cases, the soil nails should be designed, either by means of the conventional analytical approach or the prescriptive approach, to upgrade the slope to meet the required safety standards for a 'new' slope.

In assessing whether an existing hard surface cover can be replaced by a vegetation cover, account should be taken of the average and local slope gradients, size of the upslope catchment and likelihood of the presence of concentrated surface water flow, signs of seepage from slope surface, records of past failure of the slope of concern as well as the adjoining areas, likelihood of casualty should a failure occur, etc. Consideration should be given to the potential socio-economic impact should failure occur.

(2) *Wire Mesh/Face Netting for Rock Slopes*. Apart from local zones of closely-fractured rock mass which may warrant shotcreting, rock slopes generally do not require a hard surface cover. Wire mesh (sometimes referred to as face netting) may be fixed to a rock face to prevent small rockfalls, or hung loosely over a slope to guide rocks to the slope toe. The lower end of the mesh should be no more than about 0.6 m above the slope toe in order to prevent rock blocks from falling and bouncing onto the facility (e.g. road) at the slope toe. These measures are generally effective for retaining moderately to highly fractured rock blocks with dimensions up to about 0.6 m to 1 m, but they may not be suitable for retaining highly to completely weathered materials.

The likely volume/extent of rock mass to be retained and the minimum typical block size of the rock face would govern the choice of wire mesh. Galvanised and PVC coated double-twisted hexagonal wire mesh (e.g. 2.2 mm diameter wire with 80 mm x 60 mm openings) would be suitable for use on steep cut faces to control rockfalls with dimensions of less than about 0.6 m. For larger rock blocks, consideration may be given to the use of more robust forms of face netting, such as cable nets or ring nets (Muhunthan et al, 2005), as judged appropriate by the designers.

The upper edge of the wire mesh should be placed close to the potential rockfall source so that the blocks will have little momentum when they impact on the mesh. The mesh should be anchored in accordance with the latest version of CEDD Standard Drawing No. C2205 : Fixing of Wire Mesh to Rock Face. The mesh should be anchored at intermediate points by U-hooks or similar at a spacing of about 3 m. Such spacing will generally permit the detached rock blocks to work their way down to the slope toe rather than accumulating behind the mesh. Near the bottom of the slope, U-hooks with an extension connector should be provided at the lowest row so that they can be loosened and removed from the anchored end to enable the mesh to be lifted for removal of the detached rock blocks.

For roadside slopes with unprotected steep rock faces of consequence-to-life Category 1, the provision of wire mesh is strongly recommended for protection against minor rockfalls. Nevertheless, judgement should be exercised in identifying cases where wire mesh is not warranted, e.g. presence of massive, very tightly-jointed and not adversely jointed rock where there is no credible minor rockfall potential, near the tapering ends of big rock cuts where the reduced height and setback from the carriageway would mean any minor rockfalls would not reach the road, mixed rock/soil slopes where wire mesh is only warranted on the 'hard-rock' portion with credible rockfall potential, etc.

(3) *Surface Protection for Retaining Walls*. Surface protection works to retaining walls include sealing of cracks on the surfaces of concrete walls, sealing of cracked mortar joints or missing pointing on masonry walls, and repairing of defective joint sealant on concrete walls. Loose or dislocated blocks of pointed masonry walls should be fixed with cement mortar. Where there are concerns regarding surface infiltration at the crest of a retaining wall, the crest area should be paved.

3.2.2 Surface Drainage

Poor surface drainage provisions, such as inadequate number of drainage channels, undersized drainage channels and poor channel layout and detailing, are major causes of landslides including washouts, particularly local failures. Where the existing provisions are deficient, new or additional surface drainage channels with an adequate layout and proper detailing should be provided to improve the hydraulic capacity of the drainage system and minimise the risk of blockage.

A review of all potential surface water pathways that could affect the slope feature should be carried out prior to the design of prescriptive surface drainage measures. Potential convergent surface water flow should be diverted away from the slope feature where possible or should be directed downslope, preferably with no change in the flow direction, by means of drains with adequate capacity.

Consideration should be given to providing an upstand for the crest drainage channel of a slope feature to minimise possible uncontrolled spillage of surface water, and increasing the channel gradient and size. Details of the upstand are shown in the latest version of CEDD Standard Drawing No. C2509 : Shotcrete to Upslope Area and Crest Channel with Upstand. However, the possibility of local ponding behind the upstand at the crest channel should be considered. Where an upstand is provided, the gradient along the alignment of the channel should exceed 1 in 10. Similar details may be adopted for the berm channels, except that the height of the upstand may be reduced.

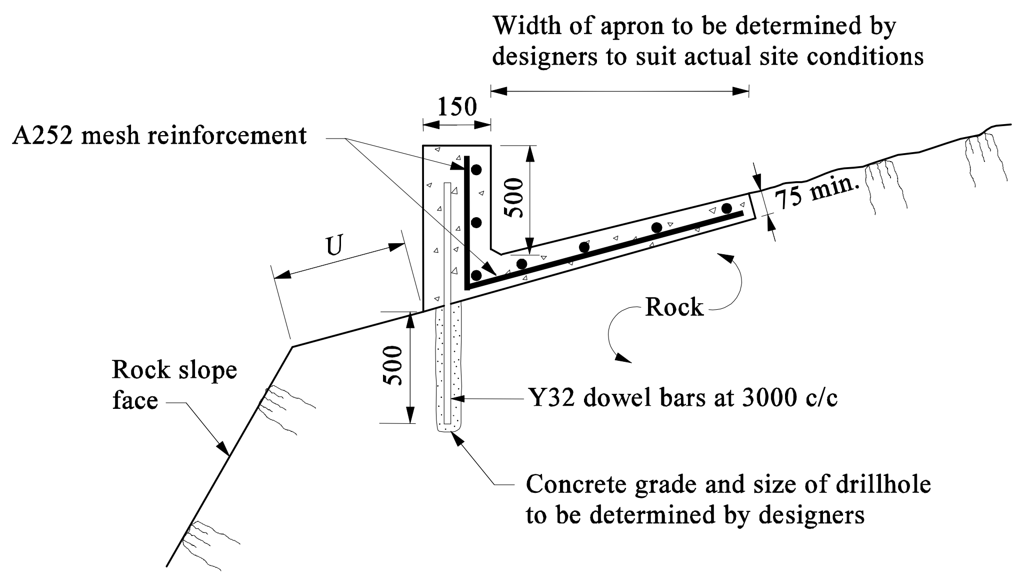
Special attention should be given to the layout and detailing of the surface drainage system to ensure adequate flow capacity and containment of flow within the channels, together with adequate discharge capacity at the downstream side. For instance, abrupt changes in the flow directions, which can be conducive to spilling or overflow along the channels, should be avoided. Environmental factors, such as potential sources of concentrated flow of surface water which may adversely affect slope stability, should be dealt with properly. Further discussions on the role of environmental factors in slope instability are given by Au & Suen (1991a & b).

Junctions of surface drainage channels should be properly detailed to avoid excessive turbulence and splashing. A smooth transition of alignment should be provided at the junction of berm channels and down channels where practicable in order to improve the hydraulics of surface water flow. Baffle walls, or catchpits, should be provided at junctions of channels, if deemed necessary, to minimise spilling or overflow. Baffle walls may be preferred as catchpits could be susceptible to blockage (e.g. by erosion debris or dead vegetation).

Unless herringbone drains are provided, downslope drainage channels should preferably be spaced at a horizontal distance not exceeding 15 m. With the provision of herringbone drains, an upper limit of about 30 m should be adopted where practicable, integrating with the locations of existing manholes, catchpits, etc.

In the case of a rock slope, excavations in rock for the construction of drainage channels will be tedious. Alternative typical details of the crest flat drainage channel are shown in Figure 3.1. For a steeply inclined rock face, the size of catchment for the rock face itself is generally small. Half-round channels may be used on berms to minimise excavations in rock. If the amount of surface runoff on the rock face is not large, berm channels which require excavations in rock may be omitted. However, the berms should still be paved with concrete to prevent water ingress into any open rock joints. The use of stepped channels on steep rock slopes may result in spillage of water. Site-specific designed downpipes are an alternative to stepped channels.

More guidance on the improvement and design of surface drainage is given in GCO (1984), Ho et al (2003), GEO (2006) and Hui et al (2007).



Notes:
(1) Dimensions in millimetres unless stated otherwise.
(2) Dimension *U* to be determined by designers to suit actual site conditions.
(3) Slope crest channel with upstand should have a minimum gradient of 1:10.
(4) The concrete channel should be cast against insitu ground in order to avoid the use of external formwork.

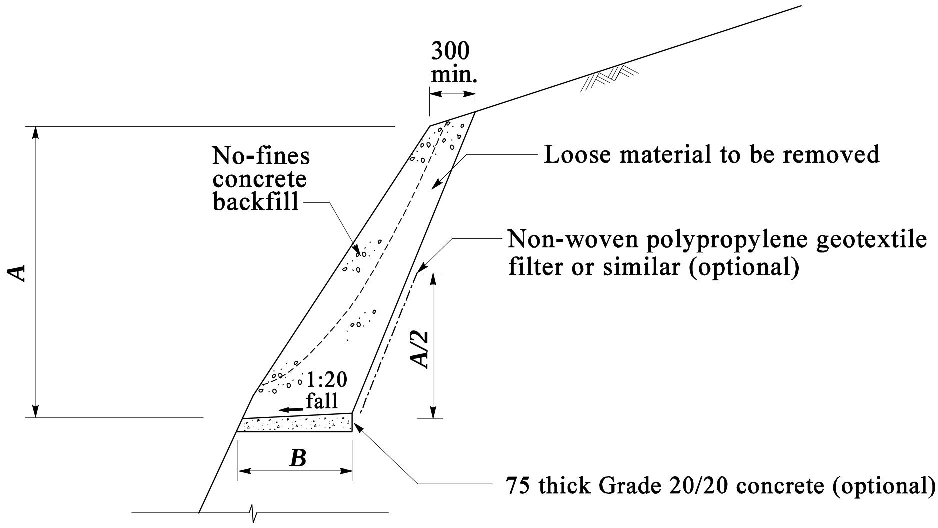
Figure 3.1 Alternative Flat Drainage Channel Details to Minimise Excavation in Rock

3.2.3 Local Stability

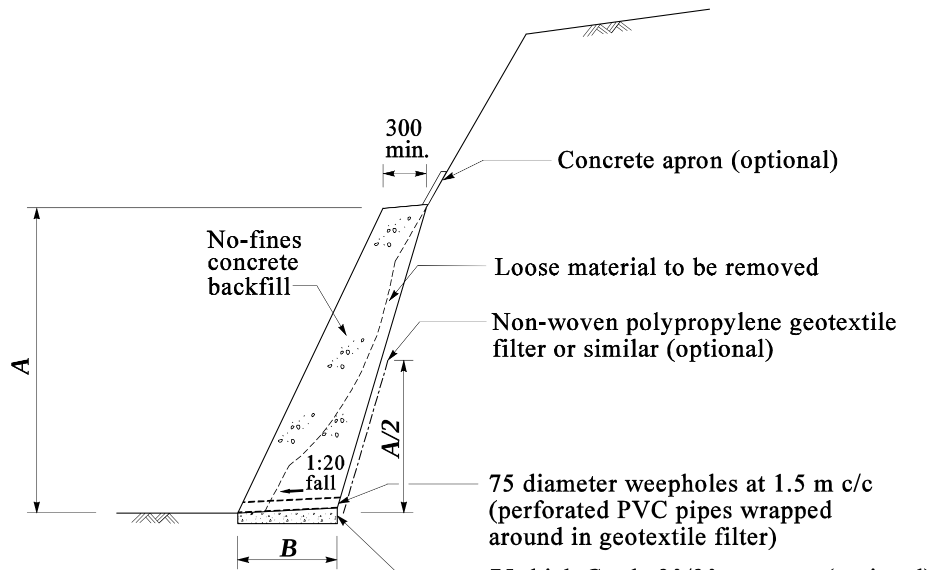
(1) *Local Trimming/Filling*. Locally over-steepened areas or depressions (e.g. landslide scars) may be trimmed or filled with no-fines concrete (Figure 3.2) to restore the slope profile in order to avoid local instability from developing. In particular, local failure of a portion of a rock slope may form an overhang on the face which will constitute a hazard.

Loose rocks may be removed by hand-held scaling bars. However, removal should only be done where it is certain that the new face will be stable and there is no risk of undermining the upper part of the rock slope. Designers should re-examine and re-assess the stability of the rock face following local trimming and scaling of certain loose rocks. Removal of loose rocks on the slope face may not be effective where the rock is highly fractured. Other measures such as use of wire mesh may be considered in such cases.

(2) *Dentition*. In the case of rock slopes, dentition can be used to backfill slots resulting from trimming of bands of soft materials, or to support an overhang formed on the rock face. Typical details of dentition works are shown in the latest version of CEDD Standard Drawing No. C2204 : Typical Rock Face Dentition. A grout pipe may be provided for subsequent grouting to ensure good contact between the overhang and the supporting concrete dentition.



(a) At Upper Part of Slope



(b) At Lower Part of Slope or on Berm

Notes:

(1) Dimensions in millimetres unless stated otherwise.

(2) For $A < 1.5$ m , $B = 0.3$ m minimum. For $A \geq 1.5$ m, $B = 0.5$ m minimum.

(3) The geotextile filter behind the no-fines concrete block may be extended further upslope to cover seepage/potential seepage areas as specified by designers.

(4) Where it is deemed necessary to improve the stability of the no-fines concrete block, hot dip galvanised high yield deformed bars, typically 2 m long, 25 mm in diameter grouted in 50 mm diameter holes at spacing not exceeding 2 m in both vertical and horizontal directions, may be provided to tie the no-fines concrete block to the slope.

Figure 3.2 No-fines Concrete Backfill to Local Areas

4. TYPE 2 PRESCRIPTIVE MEASURES

4.1 GENERAL

This Chapter provides specific guidance on the application of Type 2 prescriptive measures to slope features. Type 2 prescriptive measures are aimed at improving subsurface drainage. Type 2 prescriptive measures will contribute to prevent the build-up of water pressure behind hard surface covers of slopes or structural facings of retaining walls, as well as to lower the groundwater level behind the slope features. The need for these prescriptive measures should be considered in all cases of man-made slope features.

Table 4.1 shows a summary of the Type 2 prescriptive measures items and the associated design objectives. The application of the items should be specified by designers to best suit the type of slope feature and actual site conditions.

Table 4.1 Items of Type 2 Prescriptive Measures

Type of Measures	Design Objectives	Item No.	Items
Type 2	Improve subsurface drainage	2.1	Raking drains
		2.2	Toe drains
		2.3	Counterfort drains
		2.4	Relief drains
		2.5	Drainage for hard surface cover
		2.6	No-fines concrete cover

4.2 TYPE 2 PRESCRIPTIVE MEASURES

4.2.1 Subsurface Drainage

Where the build-up of groundwater pressure is likely to be so rapid that drainage from the slope surface alone may not be adequate to avoid failure, subsurface drainage provisions should be provided.

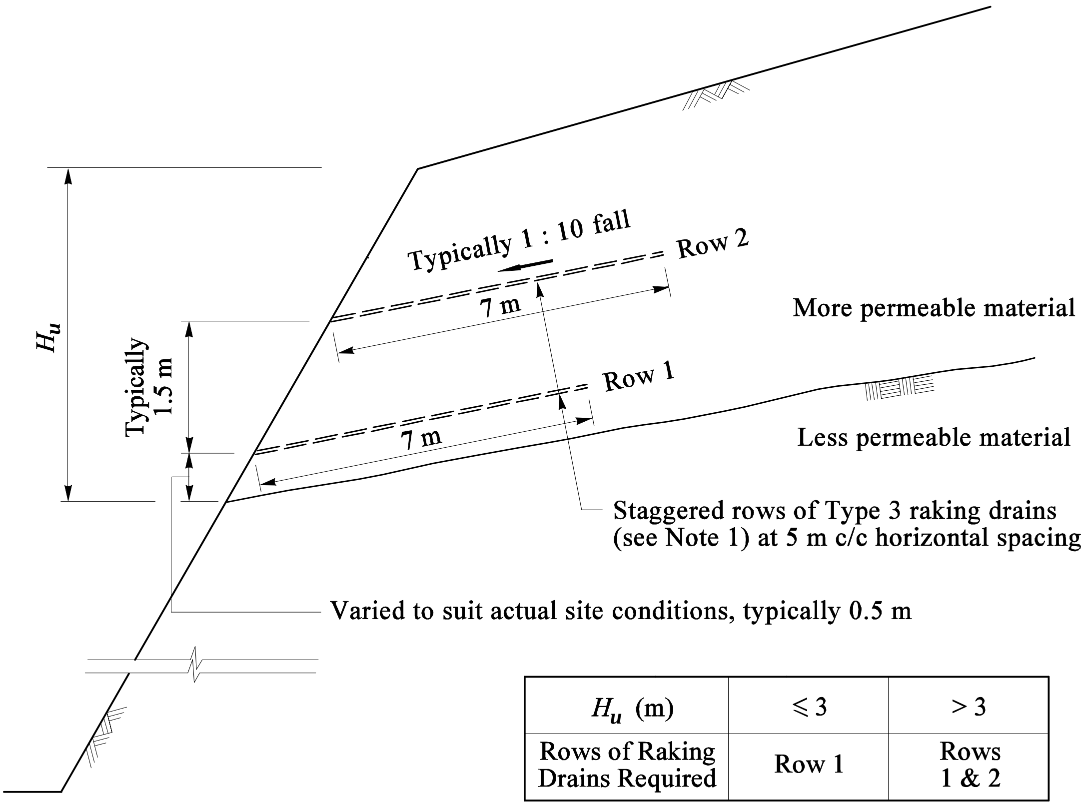
(1) *Raking Drains*. Raking drains can be effective in lowering the groundwater level and relieving the groundwater pressure at depth. Three items of prescriptive measures may be used:

(a) At the upper part of a slope feature (Figure 4.1) – this is to control the development of a potential perched water table in a more permeable soil stratum overlying a less permeable stratum.

(b) At the lower part of a slope feature (Figure 4.2) – this is to control the transient rise of the main groundwater level during/following rainfalls.

(c) At specific seepage or potential seepage areas – this is to facilitate drainage and relieve the water pressures at specific locations where persistent seepage or preferential flowpaths are present.

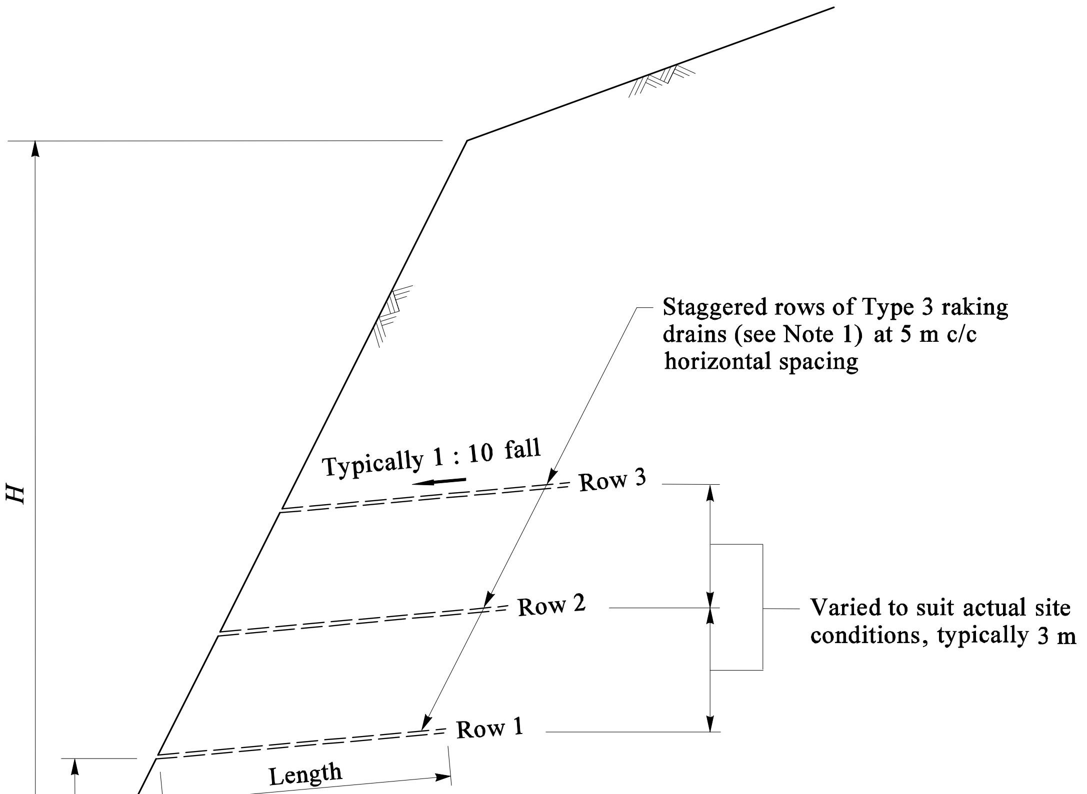
Raking drains may also be prescribed as contingency measures to cater for uncertainties in the groundwater conditions and possible adverse effects of subsurface seepage (e.g. from leaking services) on slope stability.



H_u (m)	⩽ 3	> 3
Rows of Raking Drains Required	Row 1	Rows 1 & 2

Notes:
(1) For details of raking drains, see the latest version of CEDD Standard Drawing No. C2403 : Typical Arrangement of Raking Drains.
(2) The spacing of the raking drains is nominal and may be varied to suit actual site conditions as determined by designers.

Figure 4.1 Raking Drains at Upper Part of Slope



H (m)	⩽ 7	7 - 15	> 15
Rows of Raking Drains Required	Row 1	Rows 1 & 2	Rows 1, 2 & 3
Length (m)	5	7	10

Notes: (1) For details of raking drains, see the latest version of CEDD Standard Drawing No. C2403 : Typical Arrangement of Raking Drains.
(2) The spacing of the raking drains is nominal and may be varied to suit actual site conditions as determined by designers.

Figure 4.2 Raking Drains at Lower Part of Slope

If raking drains are used in conjunction with soil nails on a slope feature, the drains should be oriented and/or lengthened to intercept any groundwater behind the soil-nailed zone as deemed appropriate by designers. The raking drains should be installed after all the soil nails at elevations higher than the raking drains have been grouted.

Further technical guidance on the construction, maintenance and performance of raking drains can be found in GCO (1984), Lam et al (1989) and Martin et al (1995).

(2) *Toe Drains*. For slope features affected by high groundwater level, construction of toe drains (Figure 4.3) provides an effective means of lowering the groundwater level close to the lower part of the slope face. These may be used in combination with other Type 2 prescriptive measures to facilitate subsurface drainage, or as contingency provisions.

(3) *Counterfort Drains*. For slope features which are liable to a rapid build-up of groundwater pressures, such as development of a perched water table in a relatively thin surface mantle of loose colluvium overlying weathered rock (e.g. Pun & Li, 1993; Wong & Ho, 1995), the use of raking drains alone may not necessarily provide sufficient drainage capacity to quickly relieve the transient groundwater pressures to avoid failure. In such cases, counterfort drains (Figure 4.4) could be used, either on their own or in combination with raking drains.

To be more effective, counterfort drains should be extended into the underlying less permeable ground. If this cannot be achieved, raking drains should be provided to intercept any groundwater flow beneath the counterfort drains. Particular care should be taken to ensure that the watertightness of the 'impermeable' membrane at the base of the drain is achieved in construction.

With regard to construction safety considerations, the use of counterfort drains exceeding 2.5 m in depth is not recommended. It is advisable that, before commencement of the works, some trial pits should be excavated over the crest of the slope feature to confirm the subsoil conditions and the suitability of using these items of prescriptive measures.

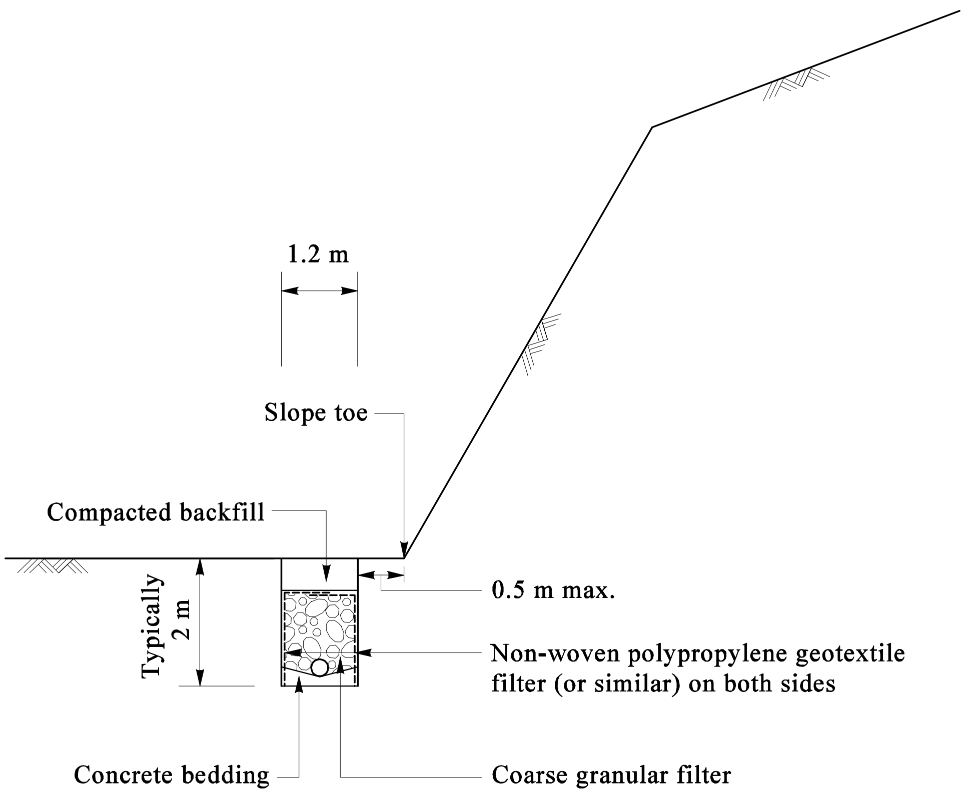
(4) *Relief Drains*. Where there are signs of potential seepage sources (e.g. rock joints with signs of seepage) behind a hard surface cover, relief drains should be provided as shown in the latest version of CEDD Standard Drawing No. C2404 : Relief Drain Details. It is important to avoid sliding instability at the interface between the rock and the geosynthetic material by providing proper anchorage by the use of nails or plaster. The drainage material should be covered by an impermeable fabric with a hole cut through to insert a PVC flange and pipe for drainage.

(5) *Drainage for Hard Surface Cover*. Inadequate drainage behind hard surface cover (e.g. shotcrete) can be a contributory cause of failure on slopes with subsurface seepage flow. Geosynthetic composite drainage material can be installed behind the hard surface cover, together with the provision of a no-fines concrete toe (Figure 4.5) or relief drains (Figure 4.6) in order to minimise the build-up of water pressure. This is particularly important at locations where preferential flowpaths, such as soil pipes, erosion channels or holes left behind by rotted tree roots or burrowing animals, exist in the ground behind the hard surface cover.

It is important to avoid sliding failure at the interface of the soil and geosynthetic composite drainage material by providing proper anchorage and ensuring that there are no significant gaps at the interface which may result in erosion. The spacing of the geosynthetic composite drainage material as shown in Figures 4.5 and 4.6 may be adjusted on site to suit the locations of seepage and preferential flowpaths, provided that the overall area of the surface covered by the drainage material is within about one-third of the area of the hard surface cover.

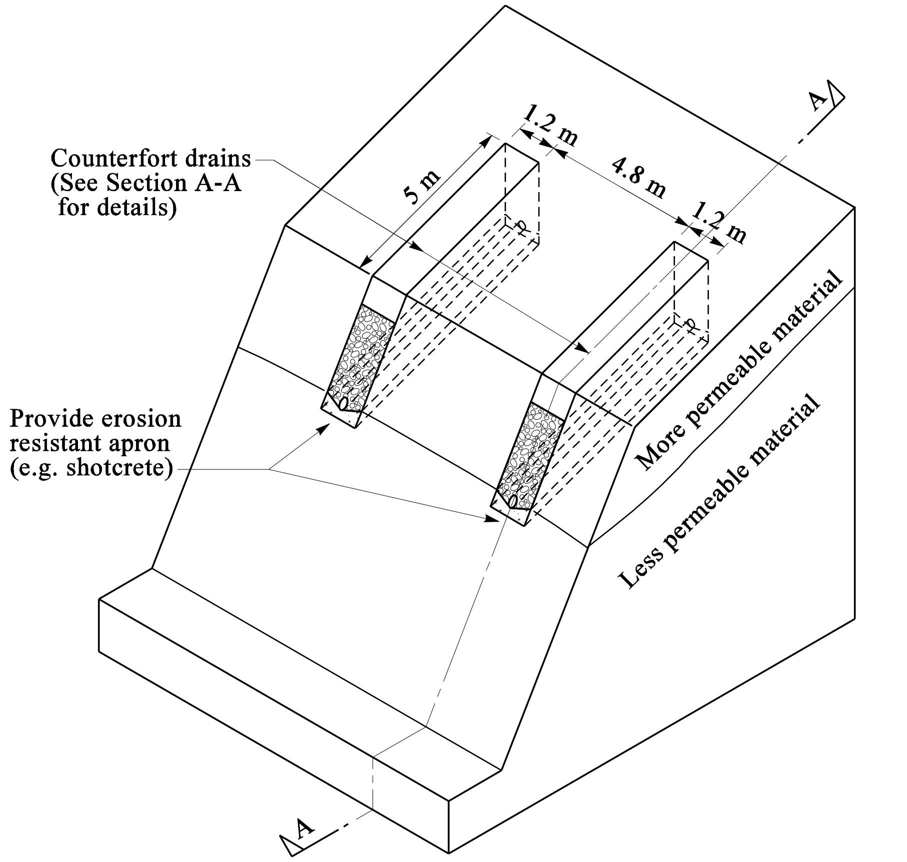
It should be noted that geosynthetic composite drainage material has a limited drainage capacity but it is suitable for relieving groundwater pressures in the soil close to the hard surface cover. Where a larger drainage capacity is required, the use of a no-fines concrete cover (see Item (6) below) should be considered. Installation of geosynthetic composite drainage material may be difficult if the slope surface is irregular, e.g. at landslide scars. In such cases, the use of no-fines concrete may be more convenient.

Where the existing provisions are deficient, new or additional weepholes should be provided for slopes with hard surface cover and for retaining walls. Where skin walls are constructed on existing retaining walls, the existing weepholes should be extended through any new skin walls.

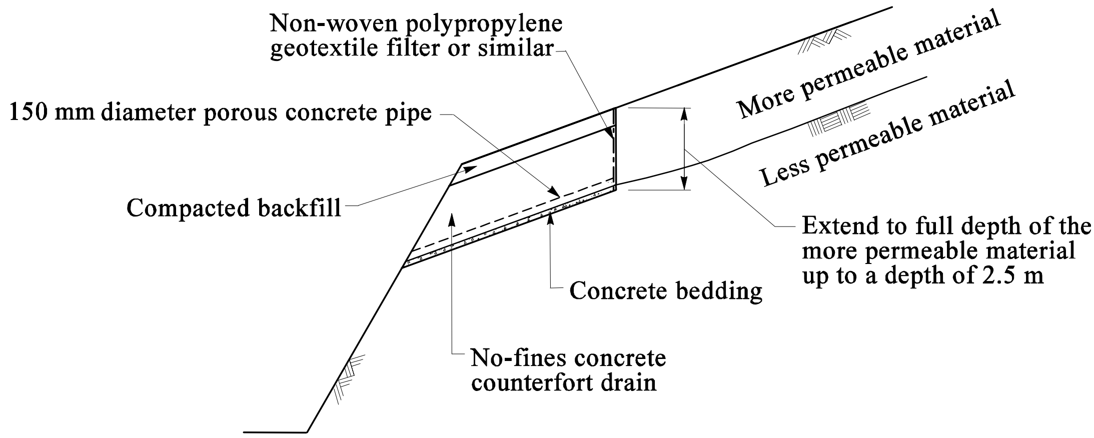


Notes:
(1) Toe drain details should be similar to that of cut-off drain given in the latest version of CEDD Standard Drawing No. C2401 : Cut-off Drain Details, except that non-woven polypropylene geotextile filter should be placed against both side walls of the trench.
(2) If required, the compacted backfill to the drains may be replaced by concrete or shotcrete in order to blend in with the surrounding hard surface.

Figure 4.3 Toe Drain



Isometric View

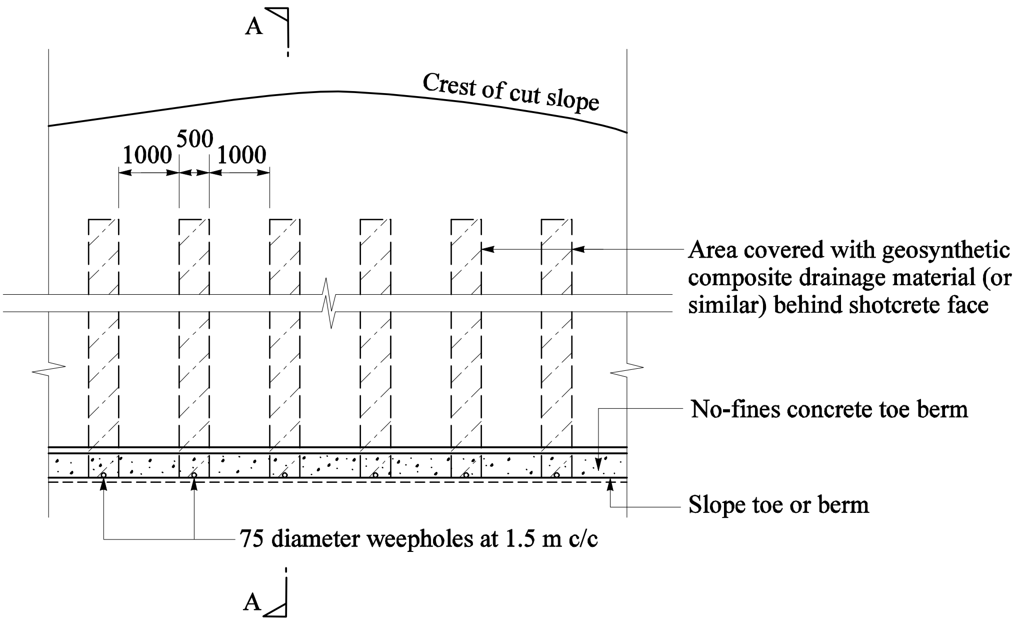


Section A-A

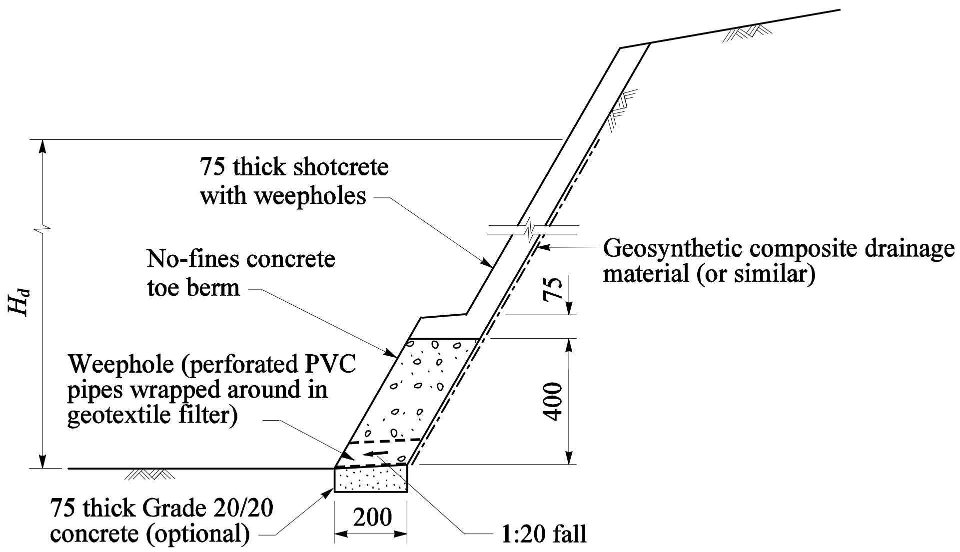
Notes: (1) Details of counterfort drain should be similar to cut-off drain given in the latest version of CEDD Standard Drawing No. C2401 : Cut-off Drain Details, except that the coarse granular filter material is to be replaced by no-fines concrete and the non-woven polypropylene geotextile filter should be placed against both side walls of the trench.

(2) If required, the compacted backfill to the drains may be replaced by concrete or shotcrete in order to blend in with the surrounding hard surface.

Figure 4.4 Counterfort Drains at Upper Part of Slope



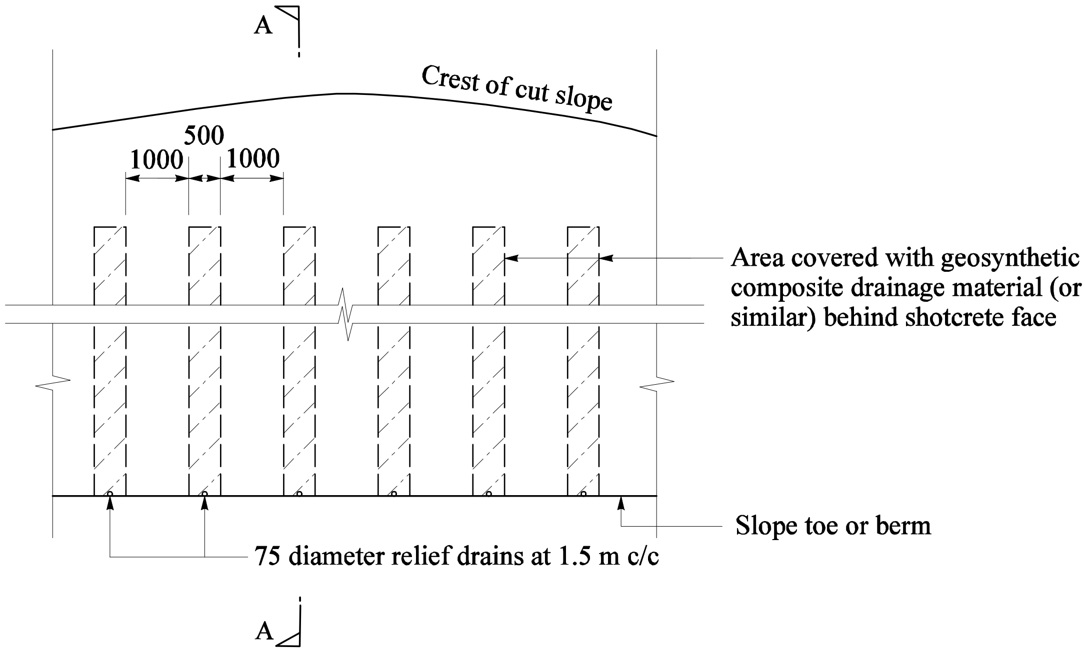
Elevation



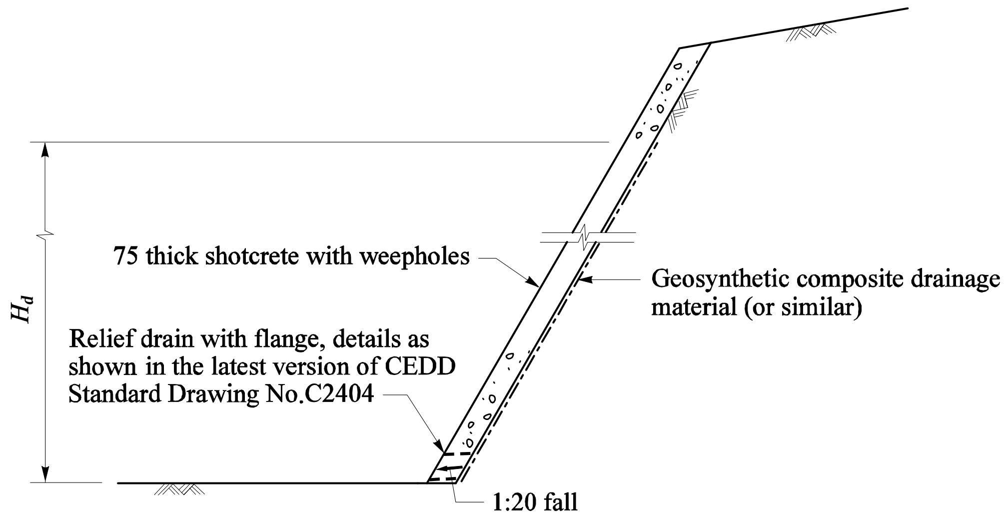
Section A-A

Notes:
(1) Dimensions in millimetres unless stated otherwise.
(2) The width and spacing of the geosynthetic composite drainage material (or similar) may be varied to suit actual site conditions, e.g. closer spacing in areas of observed or potential seepage.
(3) The height of the geosynthetic composite drainage material (or similar), H_d, to be specified by designers.
(4) Non-woven polypropylene geotextile filter should be provided between the no-fines concrete toe berm and the soil at seepage/potential seepage areas.

Figure 4.5 Drainage for Hard Surface Cover (with No-fines Concrete Toe)



Elevation



Section A-A

Notes:

(1) Dimensions in millimetres unless stated otherwise.

(2) The width and spacing of the geosynthetic composite drainage material (or similar) may be varied to suit actual site conditions, e.g. closer spacing in areas of observed or potential seepage.

(3) The height of the geosynthetic composite drainage material (or similar), H_d, to be specified by designers.

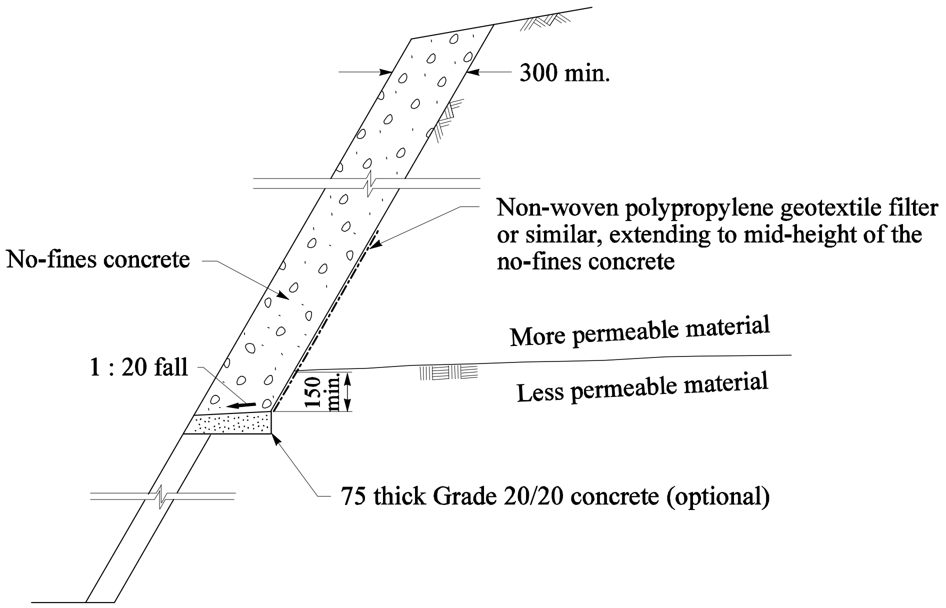
(4) If $H_d > 5$ m, relief drains should also be provided at mid-height of the geosynthetic composite drainage material (or similar).

Figure 4.6 Drainage for Hard Surface Cover (with Relief Drains)

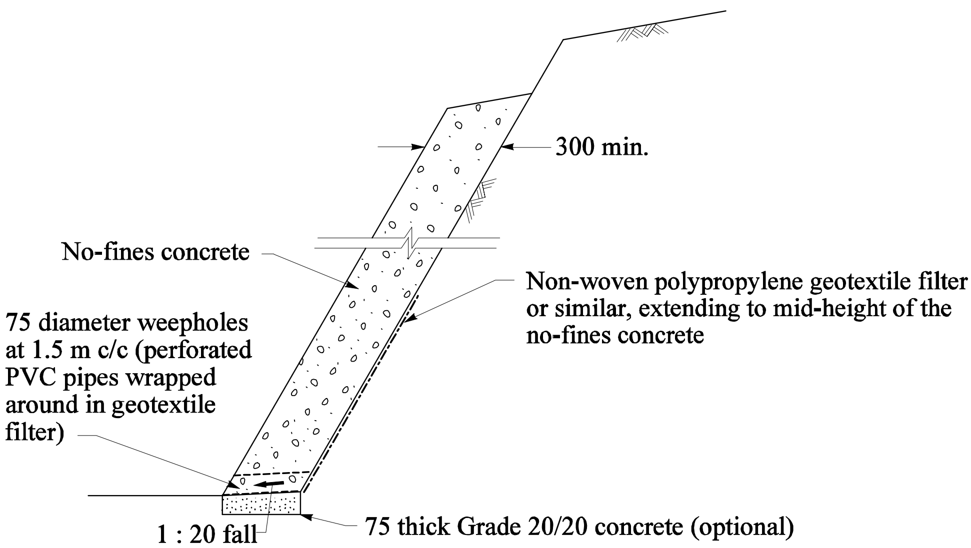
(6) *No-fines Concrete Cover*. No-fines concrete has good drainage capacity and its dead weight offers some stabilisation effects. It can conveniently be built against irregular ground profile to give a uniform surface, and if used properly in conjunction with a geotextile filter or geosynthetic composite drainage material, it is effective in controlling slope surface instability and erosion (Figure 4.7).

Loose material on the slope surface should be removed before placing the no-fines concrete. Care should be exercised during placement of no-fines concrete to avoid damaging and blocking the geotextile filter or geosynthetic composite drainage material, which is required to prevent internal soil erosion. If necessary, an additional protective layer of geotextile filter or sand bags may be placed over the geotextile filter or geosynthetic composite drainage material to protect it from damage during casting of the no-fines concrete.

The no-fines concrete cover should be founded on firm ground to ensure stability. Benching of the concrete into the slope should be considered to improve the stability, especially on steep slopes. Galvanised steel dowel bars may also be used to tie the no-fines concrete block and geotextile filter (or geosynthetic composite drainage material) to the slope.



(a) At Upper Part of Slope



(b) At Lower Part of Slope or on Berm

Notes:
(1) Dimensions in millimetres unless stated otherwise.
(2) Where it is deemed necessary to improve the stability of the no-fines concrete block, hot dip galvanised high yield deformed bars, typically 2 m long, 25 mm in diameter grouted in 50 mm diameter holes at spacing not exceeding 2 m in both vertical and horizontal directions, may be provided to tie the no-fines concrete cover to the slope.

Figure 4.7 No-fines Concrete Cover

5. TYPE 3 PRESCRIPTIVE MEASURES

5.1 GENERAL

This Chapter provides specific guidance on the application of Type 3 prescriptive measures to slope features. Type 3 prescriptive measures are aimed at improving the stability of a slope feature by providing structural support in the form of soil nails, skin walls, concrete buttresses or rock dowels where appropriate. The guidance given is not applicable to newly-formed slope features.

Table 5.1 shows a summary of Type 3 prescriptive measures items and the associated areas of application. The type, extent and details of application of the items should be specified by designers to suit the actual site conditions.

Table 5.1 Items of Type 3 Prescriptive Measures

Type of Measures	Areas of Application	Item No.	Items
Type 3	Soil cut slopes	3.1	Soil nails
	Soil cut slopes with toe walls	3.2	Soil nails
	Concrete or masonry retaining walls	3.3	Soil nails
	Masonry retaining walls	3.4	Skin walls
	Rock cut slopes	3.5	Concrete buttresses
	Rock cut slopes	3.6	Rock dowels

5.2 PRESCRIPTIVE SOIL NAILS FOR SOIL CUT SLOPES

5.2.1 Qualifying Criteria

Soil nails have been used in upgrading a vast number of substandard soil cut slopes in Hong Kong with a good track record in terms of slope performance (Pun & Urciuoli, 2008). Prescriptive soil nail layouts have been standardised based on a review of past designs. Soil cut slopes are deemed to satisfy the required safety standards with the prescriptive soil nails applied as upgrading works, provided that the slopes satisfy the qualifying criteria given in Table 5.2. In the case where not all the qualifying criteria are satisfied, the prescriptive measures may be used as preventive maintenance works.

Table 5.2 Qualifying Criteria for Application of Prescriptive Soil Nails to Soil Cut Slopes

<table>
<tr><th rowspan="2">Types of Slope Improvement Works</th><th colspan="3">Qualifying Criteria for Application</th></tr>
<tr><th>Facility Group Affected[1]</th><th>Geometry</th><th>Engineering and Geology</th></tr>
<tr><td>Preventive maintenance works</td><td colspan="3">(Qualifying criteria not applicable)</td></tr>
<tr><td rowspan="5">Upgrading works</td><td>Group 1</td><td rowspan="2">Slope feature height, $H \leq 10$ m</td><td rowspan="10">1. Apply only to existing soil cut slopes[3] judged to require improvement works.

2. Apply to slopes confirmed on site as comprising colluvial, residual or saprolitic soils of granitic or volcanic origin that do not contain loose or soft materials. Also apply to slopes comprising other materials with similar shear strength properties, with the exception of alluvial and marine deposits and sedimentary rocks containing argillaceous layers.

3. Apply only if no observable or recorded adverse geological material (e.g. significantly kaolinised granite and volcanics, weathered dykes, and sedimentary layers within volcanic formations) and adverse discontinuities (e.g. adversely-oriented, persistent, clay-infilled or silt-infilled discontinuities, pre-existing shear surfaces or zones, and well-developed discontinuities that are slickensided or heavily coated with dark minerals or kaolinite).

4. Apply only if no observable or recorded adverse groundwater condition, i.e. no signs of a high permanent[4] groundwater table over a significant area of the slope. As a general guide, the average pore water pressure ratio, r_u, should not exceed 0.1.</td></tr>
<tr><td>Group 2</td></tr>
<tr><td>Group 3</td><td>Slope feature height, $H \leq 13$ m</td></tr>
<tr><td>Group 4</td><td rowspan="2">Slope feature height, $H \leq 18$ m</td></tr>
<tr><td>Group 5</td></tr>
<tr><td rowspan="5">Repair works to landslides[2]</td><td>Group 1</td><td rowspan="2">Height of landslide scar ≤ 10 m and landslide volume ≤ 100 m^3</td></tr>
<tr><td>Group 2</td></tr>
<tr><td>Group 3</td><td>Height of landslide scar ≤ 15 m and landslide volume ≤ 200 m^3</td></tr>
<tr><td>Group 4</td><td rowspan="2">Height of landslide scar ≤ 20 m and landslide volume ≤ 400 m^3</td></tr>
<tr><td>Group 5</td></tr>
</table>

Notes:
(1) The various facility groups are given in GEO Technical Guidance Note No. 15 (GEO, 2007b).
(2) When specifying prescriptive soil nails for emergency repair works to landslides, considerations should be given to the scale and mechanism of slope failure, the potential consequence of further landslides, and the effectiveness of the prescriptive measures in respect of the recovery of the emergency situation.
(3) Soil cut slopes include cuttings in a weathered rock mass in the Residual Soil, PW0/30 and/or PW30/50 zone as defined in Geoguide 3 (GCO, 1988), with or without any overlying colluvium. Where substandard fill (or loose or soft colluvium) is present and where the size of the fill body (or colluvium mass) meets GEO's slope registration criteria, the fill body (or colluvium mass) should be dealt with using the conventional analytical approach.
(4) 'Permanent' refers to 'typical wet season water level' as described in the Geotechnical Manual for Slopes (GCO, 1984).
(5) These qualifying criteria are also applicable to the application of prescriptive soil nails to soil cut slopes with toe walls mentioned in Section 5.3.

5.2.2 Soil Nail Layout

Prescriptive soil nail design should be carried out in accordance with the following steps:

(a) Determine the required range of increase in factor of safety (ΔFOS) for the slope, viz:

(i) range I for a large ΔFOS ($0.3 < \Delta FOS \leq 0.5$),

(ii) range II for a moderate ΔFOS ($0.1 < \Delta FOS \leq 0.3$), and

(iii) range III for a small ΔFOS ($0 < \Delta FOS \leq 0.1$).

The required range of ΔFOS should be determined by designers based on professional judgement and the guidance given in Table 5.3. If the required ΔFOS exceeds 0.5, the slope is outside the bounds of previous experience and hence is beyond the scope of application of prescriptive soil nails.

(b) Determine the standard soil nail layout from Table 5.4, based on the required range of ΔFOS and the maximum effective height of slope feature, H_e, using the following equation:

$$H_e = H\,(1 + 0.35 \tan \beta) + q / 20 \quad \text{.................(5.1)}$$

where H = slope feature height, i.e. the maximum height of slope feature from toe to crest (m)

β = gradient of terrain above slope feature (degree)

q = surcharge loading at slope crest expressed as an equivalent uniform pressure (kPa)

Figure 5.1 shows the prescriptive soil nailing to a soil cut slope. The soil nail layout, derived from prescriptive design based on the consideration of the maximum effective height of the slope, may be applied to the entire slope. Alternatively, the slope may be split into different sections where there is a large variation in height along the slope, with the soil nail layout for each section designed according to the maximum effective height for the respective sections. This would enhance the cost-effectiveness of the prescriptive designs, especially for large soil cut slopes.

Table 5.3 Stability Enhancement for Application of Prescriptive Soil Nails to Soil Cut Slopes

'New' Slope Standard[(1)]

Failure consequence category[(2)]	Consequence-to-life								
	Category 1			Category 2			Category 3		
	Economic Consequence								
	Category A			Category B			Category C		
Observed or recorded past instability[(3)]	Ma	Mi	No	Ma	Mi	No	Ma	Mi	No
Required range of ΔFOS[(4)]	I^+	I	I	I	II	II	II	II	III

'Existing' Slope Standard[(1)]

Failure consequence category	Consequence-to-life								
	Category 1			Category 2			Category 3		
Observed or recorded past instability[(3)]	Ma	Mi	No	Ma	Mi	No	Ma	Mi	No
Required range of ΔFOS[(4)]	I	II	II	II	II	III	II	III	III

Notes:

(1) The conditions for designating a slope as a 'new' slope or as an 'existing' slope are stipulated in the Geotechnical Manual for Slopes (GCO, 1984) and Works Bureau Technical Circular No. 13/99 (Works Bureau, 1999).

(2) Reference should be made to GCO (1984), Works Bureau (1999), and GEO Technical Guidance Note No. 15 (GEO, 2007b) for the classification of consequence-to-life and economic consequence categories of slope features. The choice of the required range of increase in factor of safety (ΔFOS) should be based on the higher consequence of either consequence-to-life category or economic consequence category, if the slope does not satisfy the conditions for an 'existing' slope.

(3) Past instability includes both recorded and observed failures. 'Ma', 'Mi' and 'No' refer to slopes with major (i.e. failure volume ≥ 50 m^3, or where a fatality has occurred), minor (i.e. failure volume < 50 m^3) and no past instability respectively.

(4) 'I', 'II', and 'III' refer to the following ranges of ΔFOS: $0.3 < \Delta FOS \leq 0.5$, $0.1 < \Delta FOS \leq 0.3$ and $0 < \Delta FOS \leq 0.1$, respectively. 'I^+' is similar to 'I' except that Type 2 prescriptive measures (e.g. raking drains) must be adopted as contingency provisions.

(5) Slopes that require a ΔFOS of over 0.5 are beyond the scope of application of prescriptive measures.

Table 5.4 Standard Prescriptive Soil Nail Layouts for Soil Cut Slopes

Standard Soil Nail Layouts	H_e (m)	ϕ_r (mm)	ϕ_h (mm)	I			II			III		
				N	L (m)	S_h (m)	N	L (m)	S_h (m)	N	L (m)	S_h (m)
(a)	3	25	100	2	4	1.5	2	4	1.5	2	4	1.5
(b)	4	25	100	2	5	1.5	2	5	1.5	2	5	1.5
(c)	5	25	100	3	6	1.5	3	6	1.5	3	6	2.0
(d)	6	25	100	4	8	1.5	3	8	1.5	3	7	1.5
(e)	7	25	100	4	9	1.5	4	8	1.5	3	7	1.5
(f)	8	25	100	5	9	1.5	4	8	1.5	3	8	1.5
(g)	9	25	100	5	10	1.5	4	9	1.5	4	8	1.5
(h)	10	25	100	6	10	1.5	4	10	1.5	4	9	1.5
(i)	12	32	100	6	11	1.5	5	10	1.5	5	10	2.0
(j)	14	32	100	6	12	1.5	5	11	1.5	6	10	2.0
(k)	16	32	100	7	12	1.5	7	12	2.0	6	11	2.0
(l)	18	32	100	8	13	1.5	8	12	2.0	7	12	2.0
(m)	20	32	100	10	14	2.0	9	12	2.0	8	12	2.0
(n)	22	32	100	11	14	2.0	10	12	2.0	8	12	2.0
(o)	24	32	100	12	14	2.0	10	12	2.0	8	12	2.0
(p)	25	32	100	12	15	2.0	10	12	2.0	8	12	2.0

Notes:

(1) H_e is the maximum effective height of slope feature, ϕ_r the soil nail diameter, ϕ_h the drillhole diameter, S_h the horizontal spacing of soil nails, and L the length of soil nails.

(2) For H_e between any of the two consecutive values in the above table, the soil nail layout corresponding to the higher H_e value should be adopted.

(3) N is the number of soil nails per vertical column required at the critical section, i.e. the section with the maximum effective height, H_e. At other parts of the slope, soil nails should be provided at vertical and horizontal spacing similar to that at the critical section. Alternatively, different soil nail layouts according to the H_e of that part of the slope may be adopted.

(4) The vertical spacing (S_v) of soil nails, as defined in Figure 5.1, should not be less than 1.5 m. If necessary, designers may adjust N and S_h to achieve the required minimum S_v value. In so doing, the adjusted layout should maintain the same soil nail density as that of the layout given in this Table, with $S_h \geq 1.0$ m. Where the designers opt for a specific S_v value (e.g. 2 m) to suit site constraints or other considerations, the soil nail layout may be adjusted by maintaining the same soil nail density as that given in this Table, with $S_h \geq 1.0$ m.

(5) Soil nails should be evenly spaced over the slope face.

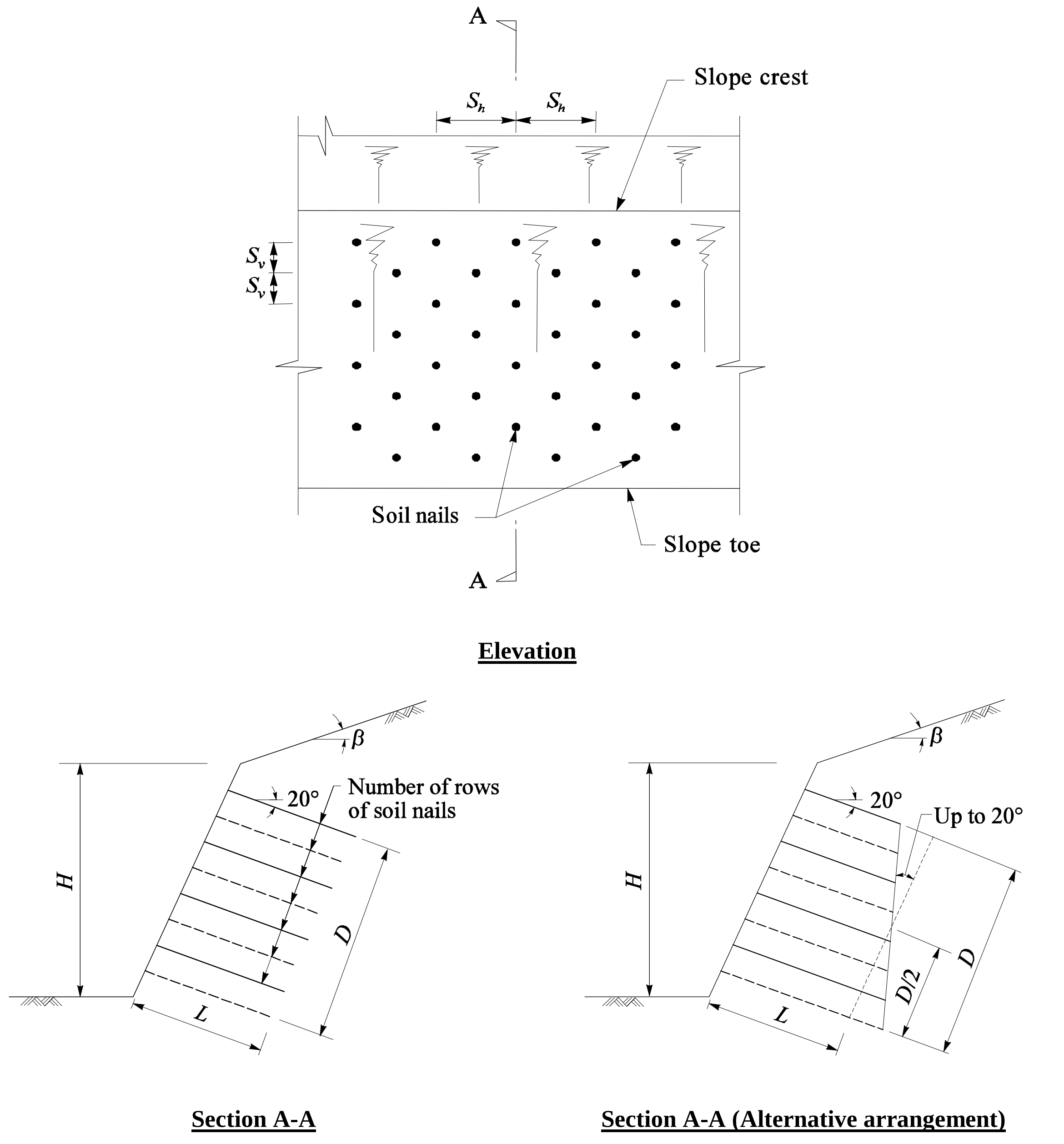
(6) Steel reinforcement for soil nails shall be of Type 2 high yield deformed bars.

(7) 'I', 'II' and 'III' refer to the following ranges of ΔFOS: $0.3 < \Delta FOS \leq 0.5$, $0.1 < \Delta FOS \leq 0.3$ and $0 < \Delta FOS \leq 0.1$, respectively.

(8) If rock is encountered in the process of drilling such that part of the soil nails will be installed in rock (e.g. installation through a PW50/90 zone or better, see Geoguide 3 (GCO, 1988)), designers may exercise professional judgement to reduce the soil nail length.

(9) Designers should check the land status to establish whether the soil nails would encroach into the adjoining land and, if so, whether this is acceptable to the land owner.

(10) Slope sections that are lower than 2 m in height do not usually require reinforcement by soil nails.



Notes:
(1) L = Length of soil nail; H = Slope feature height; D = Depth of soil-nailed zone; β = Gradient of terrain above slope feature.
(2) N, L, S_h, S_v and other dimensions for the soil nails are given in Table 5.4 based on the type of soil nail layout as specified by designers.
(3) The alternative soil nail arrangement may be adopted as appropriate to suit actual site conditions.

Figure 5.1 Prescriptive Soil Nails on a Soil Cut Slope

5.2.3 Soil Nail Head and Facing

Soil nail heads have to be provided in conjunction with the prescriptive soil nails. Sizes of prescriptive soil nail heads are given in Table 5.5. Typical details of soil nail heads for use on slopes with vegetation cover are shown in the latest version of CEDD Standard Drawing No. C2106/2 : Soil Nail Head Details, and Nos. C2106/4 and C2106/5 : Details of Recessed Soil Nail Head. Typical details of soil nail heads for a gently inclined slope given in Figure 5.6 of Geoguide 7 : Guide to Soil Nail Design and Construction (GEO, 2008) may be used as appropriate.

For vegetated slopes steeper than 45°, a wire mesh structurally connected to the soil nail heads should be provided. The structural connection of the wire mesh to the soil nail heads is shown in the latest version of CEDD Standard Drawings Nos. C2511/1 and C2511/2 : Fixing Details for Erosion Control Mat and Wire Mesh with Soil Nails. The wire mesh should be continuous and span across soil nail heads.

Typical details of a soil nail head for use on slopes with hard surface cover are shown in the latest version of CEDD Standard Drawing No. C2106/3 : Soil Nail Head Details for Sprayed Concrete Slope Surface.

For soil cut slopes steeper than 65°, reinforced concrete tie beams embedded in the slope, instead of isolated soil nail heads, should be used. Typical details of the tie beams for use on slopes with prescriptive soil nails are shown in the latest version CEDD Standard Drawing No. C2525 : Details of Embedded Tie Beam for Steep Cut Slopes.

Table 5.5 Sizing of Prescriptive Soil Nail Heads

Geology	**Square Soil Nail Head Size (mm x mm)**	
	Slope gradient < 55°	55° ≤ slope gradient ≤ 65°
Highly decomposed granitic or volcanic rock.	600 x 600	600 x 600
Other soils including colluvial, residual or completely decomposed materials of granitic and volcanic origin, and weathered sedimentary rocks.	800 x 800	600 x 600

Notes: (1) The minimum thickness of the soil nail head should be 250 mm.
(2) For slope gradients greater than 65°, embedded tie beams instead of isolated soil nail heads should be used (Shiu & Chang, 2005).

5.2.4 Corrosion Protection

Corrosion protection measures have to be designed for the steel reinforcement of prescriptive soil nails. As normally no ground investigation and hence no soil aggressivity testing is carried out for sites to be applied with prescriptive soil nails, the aggressivity of the soil at the site should be classified based on an assessment of the site setting, development history, as well as the nature and extent of utilities affecting the site in accordance with the guidance given in Section 4.3.2 of Geoguide 7 (GEO, 2008). The design of corrosion protection measures should follow the guidance given in Section 5.5 of Geoguide 7. Guidance on the possible use of materials other than steel reinforcement for corrosion protection is given in Section 5.12.4 of Geoguide 7, which may be considered based on the concept of ‘life-cycle costing’.

5.3 PRESCRIPTIVE SOIL NAILS FOR SOIL CUT SLOPES WITH TOE WALLS

5.3.1 Qualifying Criteria

Soil nail layouts for soil cut slopes with toe walls have been standardised based on a review of past designs. Soil cut slopes with toe walls are deemed to satisfy the required safety standards with the prescriptive soil nails applied as upgrading works, provided that the slopes satisfy the qualifying criteria given in Table 5.2 and the additional qualifying criteria in Table 5.6. In the case where not all the qualifying criteria are satisfied, the prescriptive measures may be used as preventive maintenance works.

Table 5.6 Additional Qualifying Criteria for Application of Prescriptive Soil Nails to Soil Cut Slopes with Toe Walls as Upgrading Works

Subjects	Qualifying Criteria for Application
Slope and wall type	1. The slope feature should be a soil cut slope with a concrete or masonry retaining wall at the toe. 2. For concrete toe wall, it should be a mass concrete wall, or a reinforced concrete wall of L-shaped, inverted L-shaped or inverted T-shaped as shown in Figure 5.2. 3. For masonry toe wall, it should be of a condition no worse than wall condition Class B and no worse than observed state of wall deformation No. (2) as defined in Tables 5.7 and 5.8 respectively.
Terrain profile	Gradient of terrain in front of slope feature, α (averaged over a horizontal distance of four times the wall thickness) should not be greater than 10°.
Extent of fill material	1. Maximum vertical height of fill, f_t, as measured from the wall crest, should not be more than 5 m. 2. Maximum thickness of the fill, f_w, as measured horizontally from the top of wall back face, should not be more than 3 m.

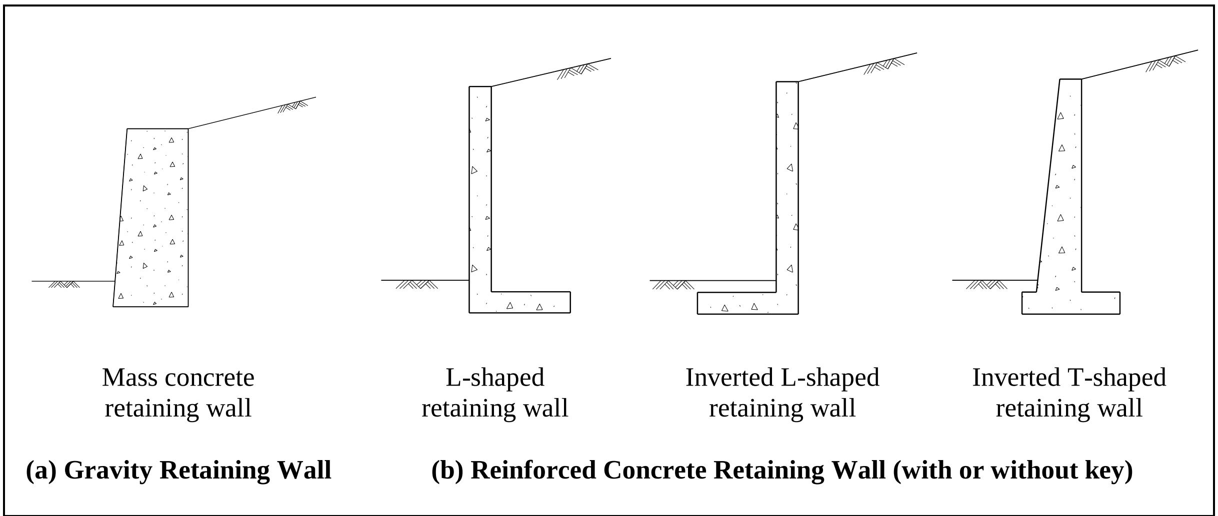


Figure 5.2 Types of Concrete Retaining Walls covered by the Scope of Application of Prescriptive Soil Nails

Table 5.7 Classification of Condition of Masonry Retaining Walls

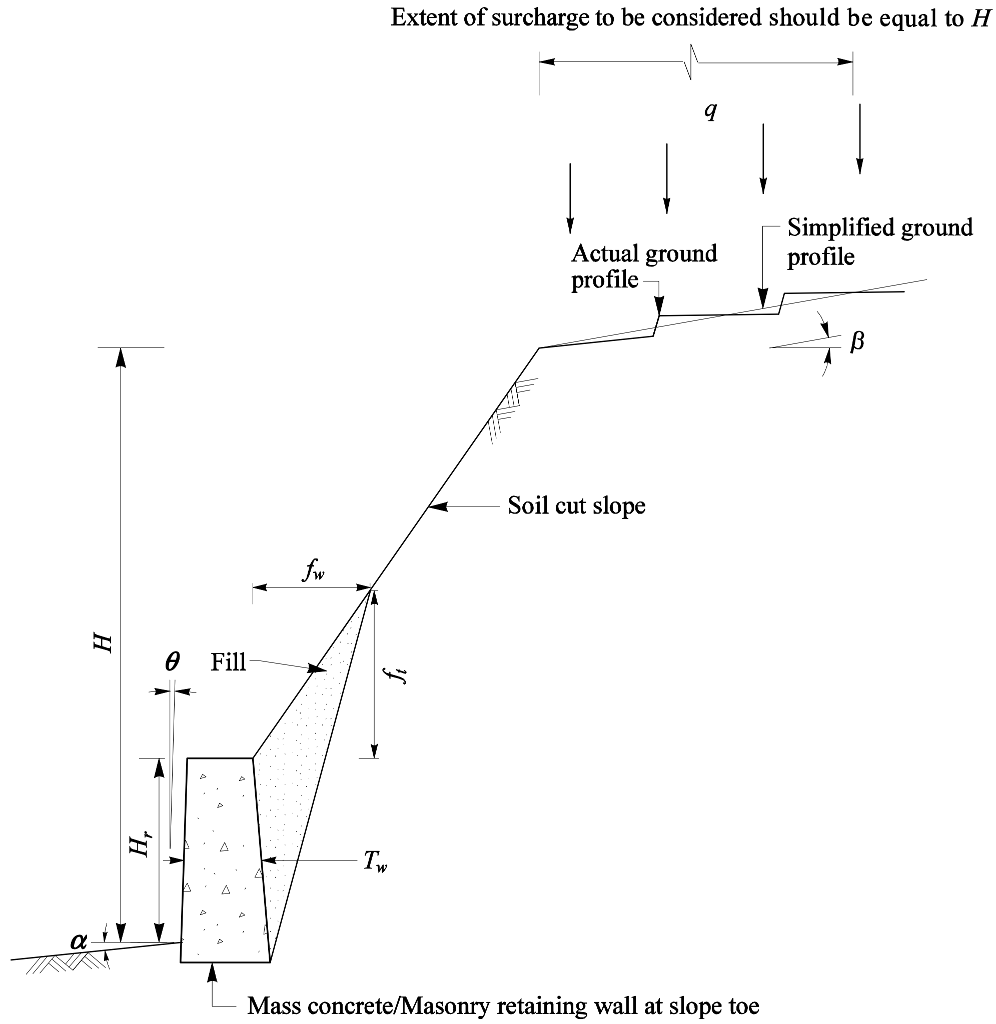
Masonry Retaining Wall Condition Class	State of Distress and Wall Deformation Based on Inspection[1]
A	Minimal distress and deformation.
B	Moderate distress and/or deformation.
C	Onset of severe distress and/or deformation.
D	Advanced stage of severe distress and/or deformation.

Notes:
(1) In general, the state of distress and deformation of old masonry retaining walls can be assessed reliably by means of experience and engineering judgement. Reference may be made to Table 5.8 and GEO Circular No. 33 (GEO, 2004) for guidance.
(2) For walls without tie members, a conservative assessment should be made, with the overall wall condition downgraded by one class, where appropriate.
(3) If the condition of the wall is known to be deteriorating, the next wall condition class appropriate to the worst possible wall condition anticipated should be chosen instead.
(4) Dry-packed random rubble walls of up to 5 m high should be assigned a wall condition Class C, irrespective of the condition and deformation profile of the wall.
(5) Dry-packed random rubble walls of more than 5 m high should be assigned a wall condition Class D, irrespective of the condition and deformation profile of the wall.

Table 5.8 Guidelines for Evaluation of the State of Masonry Retaining Wall Deformation

Observed State of Wall Deformation	Forward Movement	Bulging
(1) Minimal Deformation	Forward movement of wall as indicated by: (a) long continuous movement cracks at wall crest sub-parallel to wall, total width at any section < 0.1% of wall height, *h*, or (b) sub-vertical through cracks in return wall of total width at each level < 0.1%*h*, where *h* is height of measurement point from ground surface level in front of toe	Negligible bulging of wall
(2) Moderate Deformation	Forward movement as (1) except crack width totalling between 0.1%*h* and 0.2%*h*	Minor bulging of wall face noticeable to naked eye
(3) Onset of Severe Deformation	Forward movement as (1) except crack width totalling between 0.2%*h* and 0.6%*h*	Bulged profile of wall face sufficient to touch a vertical line drawn through wall toe, or maximum bulging of wall approaching or equal to 75 mm
(4) Advanced Stage of Severe Deformation	Forward movement as (1) except crack width totalling a value > 0.6%*h*	Bulging as (3) but protruding beyond a vertical line drawn through toe, or maximum bulging of wall > 75 mm

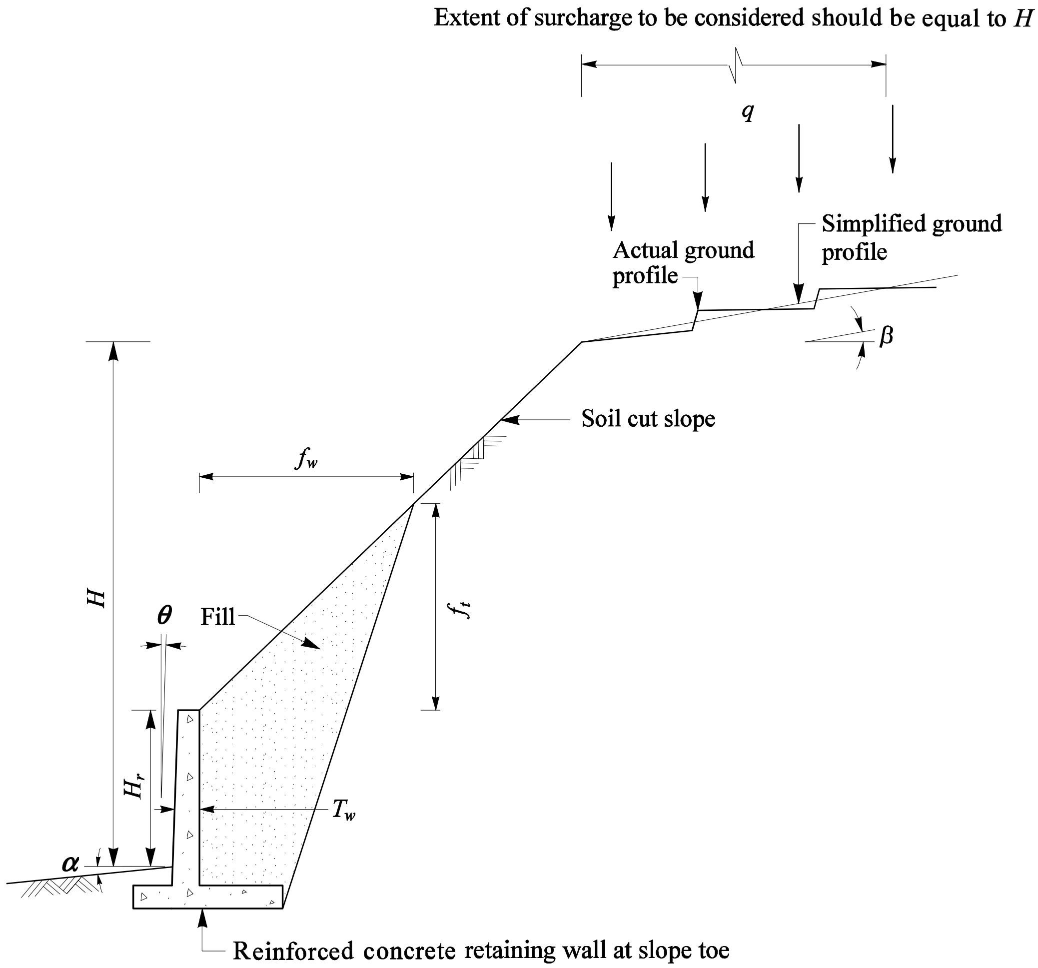
Note: When using this table, the application of sound engineering judgement is crucial since different walls are likely to present differing degrees of difficulty in the assessment of wall deformation. The proposed deformation limits shown in this table should not be regarded as absolute values.



Legend:

α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
q	Design surcharge
θ	Wall face angle
f_t	Vertical thickness of fill layer above retaining wall crest
f_w	Depth of fill layer measured from top of wall back face
H	Slope feature height
H_e	Maximum effective height of slope feature, where $H_e = H\,(1+0.35\tan\beta) + q/20$
H_r	Height of retained ground
T_w	Average thickness of retaining wall

Figure 5.3 Simplified Geometry of a Slope Feature Incorporating a Soil Cut and a Mass Concrete or Masonry Retaining Wall at Toe



Legend:

α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
q	Design surcharge
θ	Wall face angle
f_t	Vertical thickness of fill layer above retaining wall crest
f_w	Depth of fill layer measured from top of wall back face
H	Slope feature height
H_e	Maximum effective height of slope feature, where $H_e = H\,(1+0.35\tan\beta) + q/20$
H_r	Height of retained ground
T_w	Average thickness of retaining wall

Figure 5.4 Simplified Geometry of a Slope Feature Incorporating a Soil Cut and a Reinforced Concrete Retaining Wall at Toe

5.3.2 Soil Nail Layout

Prescriptive soil nail design should be carried out in accordance with the following steps:

(a) Determine the maximum effective height of slope feature, H_e (see Equation (5.1) in Section 5.2.2).

(b) Determine the required range of ΔFOS, viz.:

(i) range I for a large ΔFOS ($0.3 < \Delta FOS \leq 0.5$),

(ii) range II for a moderate ΔFOS ($0.1 < \Delta FOS \leq 0.3$), and

(iii) range III for a small ΔFOS ($0 < \Delta FOS \leq 0.1$).

The required range of ΔFOS should be determined by designers based on professional judgement and the guidance given in Table 5.3. If the required ΔFOS exceeds 0.5, the slope feature is outside the bounds of previous experience and hence is beyond the scope of application of prescriptive soil nails.

(c) Determine the total length of soil nails, L_{total}, as follows (see Figure 5.5):

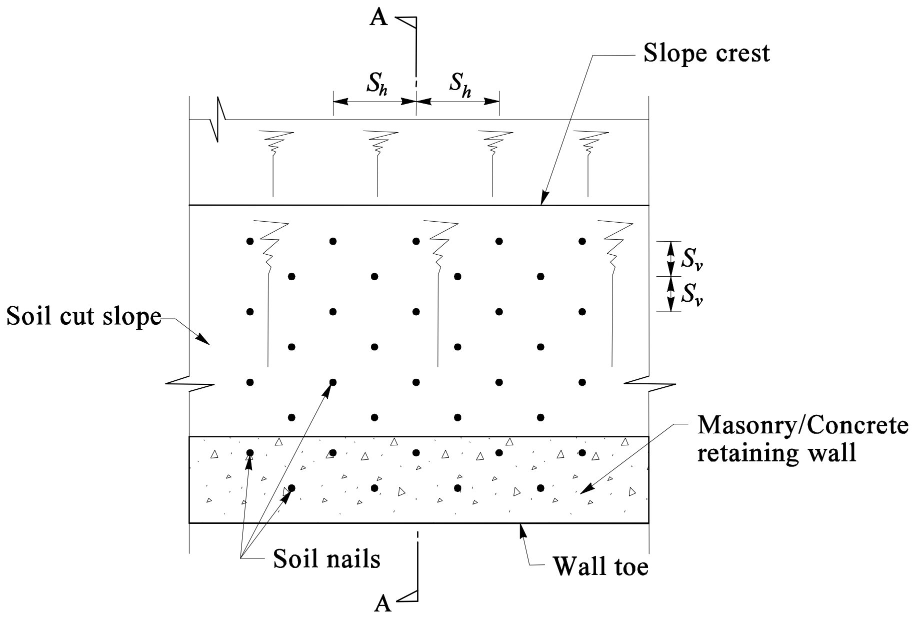
$$L_{total} = L + L_{free}$$

where L = Length of the portion of soil nail in material behind wall backfill (m)

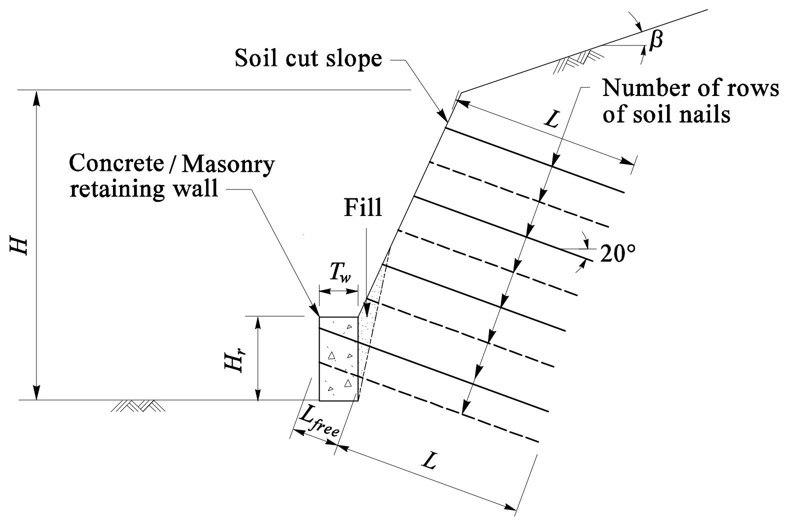
L_{free} = Length of the portion of soil nail within the retaining wall and wall backfill (m).

Determine from Table 5.4 the number of rows, spacings and the lengths of soil nails, L. L_{free} can be taken as 2 m or alternatively determined by designers based on detailed information on the wall thickness and the extent of fill behind and above the wall. For those soil nails to be installed on the cut slope part above the toe wall and fill material, L_{free} should be taken as zero.

A typical pattern of prescriptive soil nailing to a soil cut slope with toe wall is shown in Figure 5.5. The soil nail layout, derived from prescriptive design based on the consideration of the maximum effective height of the slope feature, may be applied to the entire slope feature. Alternatively, the slope feature may be split into different sections, with the soil nail layout for each section designed according to the maximum effective height for the respective sections. This would enhance the cost-effectiveness of the prescriptive designs.



Elevation



Section A-A

Notes:

(1) L = Length of the portion of soil nail in material behind wall backfill; L_{free} = Length of the portion of the soil nail within the retaining wall and wall backfill; H = Slope feature height; H_r = Height of retained ground; T_w = Average retaining wall thickness; β = Gradient of terrain above slope feature.

(2) N, L, S_v, S_h and other dimensions for the soil nails are given in Table 5.4 based on the type of soil nail layout specified by designers.

(3) If the height of the toe wall is less than the vertical spacing of soil nails, at least one row of soil nails should be installed through the toe wall.

(4) If tie beams and/or tie columns are provided, the soil nails may not necessarily be staggered.

Figure 5.5 Prescriptive Soil Nails on a Soil Cut Slope with Toe Wall

5.3.3 Soil Nail Head and Facing

Guidance on the design of soil nail head and/or wall facing is given in Sections 5.2.3 and 5.4.3 respectively.

5.3.4 Corrosion Protection

Guidance on the design of corrosion protection measures for steel reinforcement of prescriptive soil nails is given in Section 5.2.4.

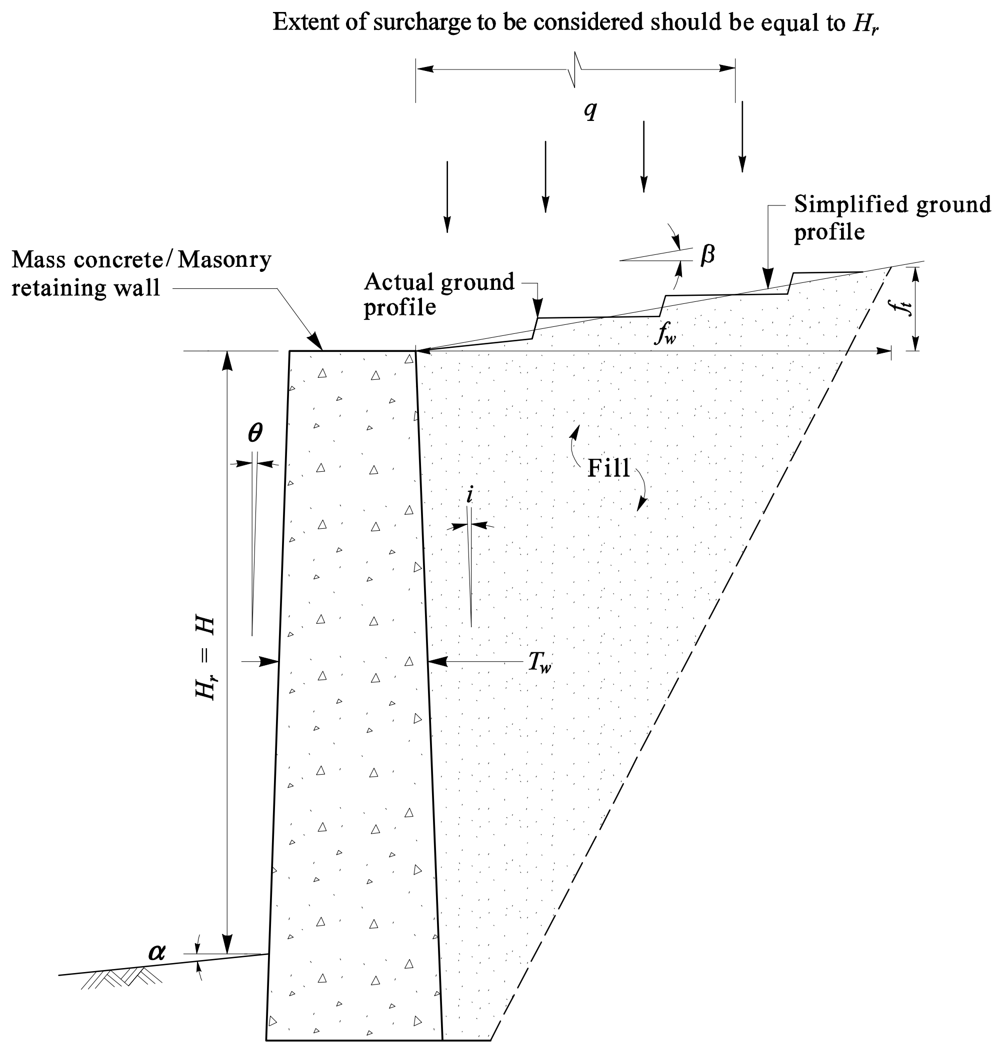
5.4 PRESCRIPTIVE SOIL NAILS FOR CONCRETE OR MASONRY RETAINING WALLS

5.4.1 Qualifying Criteria

Soil nail layouts for retaining walls have been standardised based on a review of past designs. Retaining walls are deemed to satisfy the required safety standards with the prescriptive soil nails applied as upgrading works, provided that the retaining walls satisfy the qualifying criteria given in Table 5.9. In the case where not all the qualifying criteria are satisfied, the prescriptive measures may be used as preventive maintenance works.

Table 5.9 Qualifying Criteria for Application of Prescriptive Soil Nails to Concrete or Masonry Retaining Walls as Upgrading Works

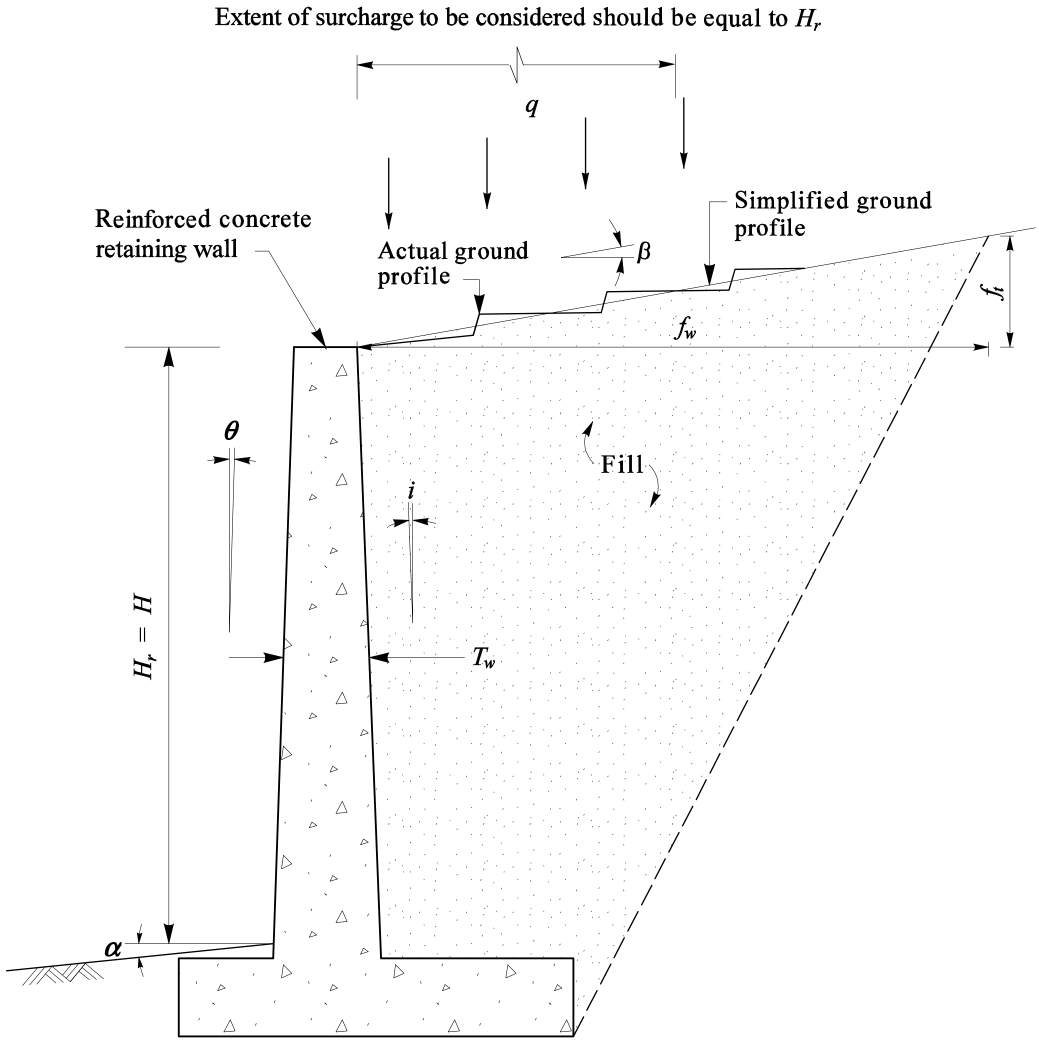
Subjects	Qualifying Criteria for Application
Geometry	Slope feature height, $H \leq 8$ m
Engineering and geology	1. Apply only to either concrete or masonry retaining walls judged to require improvement works. 2. Apply to sites comprising colluvial, residual or saprolitic soils of granitic or volcanic origin. Also apply to sites comprising other materials with similar shear strength properties, with the exception of alluvial and marine deposits and sedimentary rocks containing argillaceous layers. 3. Criteria 3 and 4 under the column of "Engineering and Geology" in Table 5.2 are also applicable.
Wall type	1. For concrete retaining wall, it should be a mass concrete wall, a reinforced concrete wall of L-shaped, inverted L-shaped or inverted T-shaped, as shown in Figure 5.2. 2. For masonry retaining wall, it should be of a condition no worse than wall condition Class B and no worse than observed state of wall deformation No. (2) as defined in Tables 5.7 and 5.8 respectively.
Terrain profile	1. Gradient of terrain in front of slope feature, α (averaged over a horizontal distance of four times the wall thickness) should not be greater than 10°. 2. Gradient of terrain above slope feature, β should not be greater than 15°.
Extent of fill material	Maximum thickness of fill, f_w as measured horizontally from the top of wall back face should not be more than the height of retained ground, H_r.



Legend:

α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
q	Design surcharge
θ	Wall face angle
f_t	Vertical thickness of fill layer above retaining wall crest
f_w	Depth of fill layer measured from top of wall back face
H	Slope feature height
H_e	Maximum effective height of slope feature, where $H_e = H\ (1+0.35\tan\beta) + q/20$
H_r	Height of retained ground
i	Wall back angle
T_w	Average thickness of retaining wall

Figure 5.6 Simplified Geometry of a Mass Concrete or Masonry Retaining Wall Feature



Legend:

α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
q	Design surcharge
θ	Wall face angle
f_t	Vertical thickness of fill layer above retaining wall crest
f_w	Depth of fill layer measured from top of wall back face
H	Slope feature height
H_e	Maximum effective height of slope feature, where $H_e = H (1+0.35\tan\beta) + q/20$
H_r	Height of retained ground
i	Wall back angle
T_w	Average thickness of retaining wall

Figure 5.7 Simplified Geometry of a Reinforced Concrete Retaining Wall Feature

5.4.2 Soil Nail Layout

Prescriptive soil nail design should be carried out in accordance with the following steps:

(a) Determine the maximum effective height of slope feature, H_e (see Equation (5.1) in Section 5.2.2).

(b) Determine whether the feature should be designed to the 'new' wall standard or 'existing' wall standard in accordance with the guidelines given in the Geotechnical Manual for Slope (GCO, 1984) and Works Bureau Technical Circular No. 13/99 : Geotechnical Manual for Slopes - Guidance on Interpretation and Updating (Works Bureau, 1999).

(c) Determine whether the feature is substandard. A way of doing it is to compare the measured wall thickness with the minimum wall thickness required to satisfy the current geotechnical standards given in Figure 5.8 according to the respective wall standard to be achieved.

If the measured retaining wall thickness is equal to or greater than the minimum required thickness, the wall can be considered as being up to the respective geotechnical standard and no upgrading works are necessary. The chart in Figure 5.8 is applicable to both concrete retaining walls and masonry retaining walls.

For reinforced concrete retaining walls, it is hard to determine whether the wall is substandard or not in the absence of a detailed ground investigation. In such cases, designers should decide whether it would be more cost effective to assume the wall to be substandard and proceed with prescriptive design of upgrading works, or whether it would be more appropriate to carry out a stability assessment with detailed ground investigation.

(d) Determine the total length of soil nails, L_{total}, as follows (see Figure 5.5):

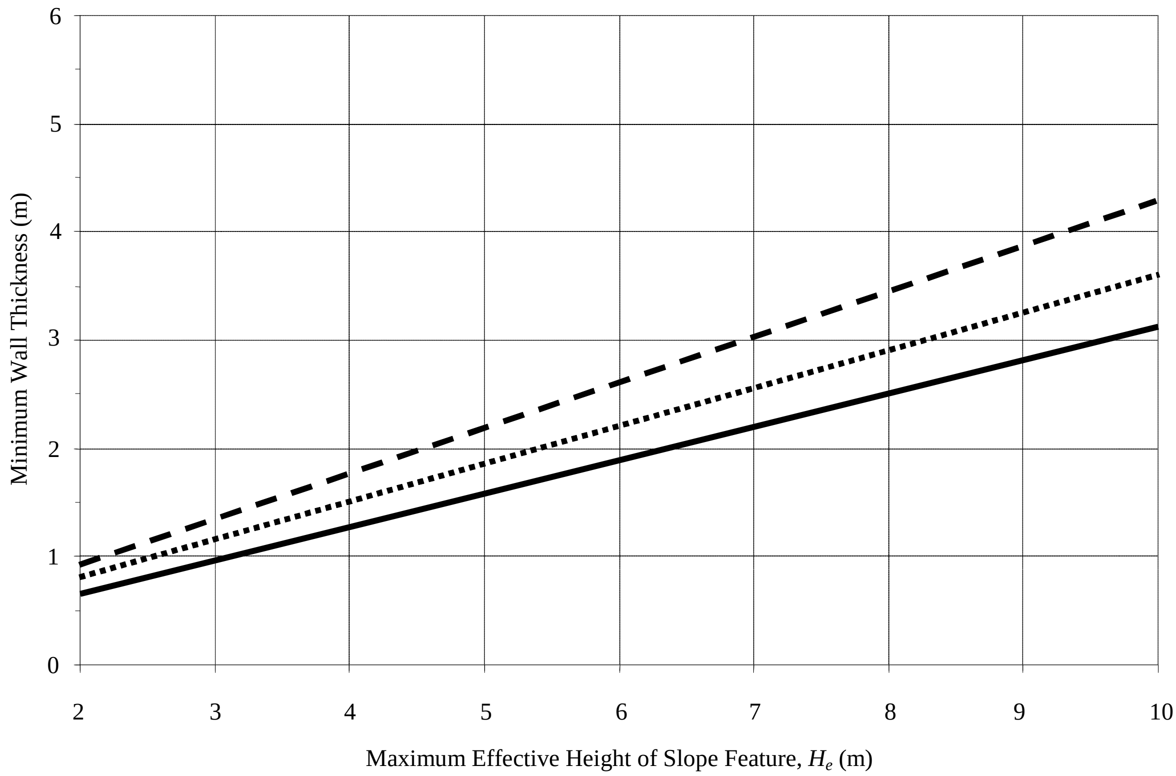
$$L_{total} = L + L_{free}$$

where L = Length of the portion of soil nail in material behind wall backfill (m)

L_{free} = Length of the portion of soil nail within the retaining wall and wall backfill (m).

Determine from Table 5.10 the number of rows, spacings and lengths of the soil nails, L. L_{free} can be taken as the height of retained ground, H_r, or alternatively it may be determined by designers based on detailed information on the wall thickness and extent of fill behind the wall.

A typical pattern of prescriptive soil nailing to a retaining wall is shown in Figure 5.9. The soil nail layout, derived from prescriptive design based on the consideration of the maximum effective height of the slope feature, may be applied to the entire slope feature. Alternatively, the feature may be split into different sections, with the soil nail layout for each section designed according to the maximum effective height for the respective sections.



Legend:

———	Concrete retaining wall ('existing' wall standard)
- - - -	Concrete retaining wall ('new' wall standard)
— —	Masonry retaining wall ('existing' and 'new' wall standards)

Note: This chart is only applicable to concrete or masonry retaining walls that satisfy the qualifying criteria listed in Table 5.9, and situations where the surcharge behind the feature does not exceed 10 kPa.

Figure 5.8 Minimum Required Thickness of Concrete or Masonry Retaining Walls where No Type 3 Prescriptive Measures are Needed

Table 5.10 Standard Prescriptive Soil Nail Layouts for Concrete or Masonry Retaining Walls

Standard Soil Nail Layouts	H_e (m)	ϕ_r (mm)	ϕ_h (mm)	'New' Wall Standard[(1)]			'Existing' Wall Standard[(1)]		
				N	L (m)	S_h (m)	N	L (m)	S_h (m)
(a)	3	25	100	2	4	1.5	2	4	1.5
(b)	4	25	100	2	5	1.5	2	5	1.5
(c)	5	25	100	3	6	1.5	3	6	1.5
(d)	6	25	100	4	8	1.5	3	8	1.5
(e)	7	25	100	4	9	1.5	4	8	1.5
(f)	8	25	100	5	9	1.5	4	8	1.5
(g)	9	25	100	5	10	1.5	4	9	1.5
(h)	10	25	100	6	10	1.5	4	10	1.5

Notes:

(1) The conditions for designating a retaining wall as a 'new' retaining wall or as an 'existing' retaining wall are stipulated in the Geotechnical Manual for Slopes (GCO, 1984) and Works Bureau Technical Circular No. 13/99 (Works Bureau, 1999).

(2) H_e is the maximum effective height of slope feature, ϕ_r the soil nail diameter, ϕ_h the drillhole diameter, S_h the horizontal spacing of soil nails, and L the length of the portion of soil nail in material behind wall backfill.

(3) Total length of a soil nail, L_{total}, should include the length of the portion of soil nail within the retaining wall and wall backfill, L_{free}, and L.

(4) For H_e between any of the two consecutive values in the above table, the soil nail layout corresponding to the higher H_e value should be adopted.

(5) N is the number of soil nails per vertical column required at the critical section, i.e. the section with the maximum effective height, H_e. At other parts of the retaining wall, soil nails should be provided at vertical and horizontal spacing similar to that at the critical section. Alternatively, different soil nail layouts according to the H_e of that part of the retaining wall may be adopted.

(6) The vertical spacing (S_v) of soil nails, as defined in Figure 5.1, should not be less than 1.5 m. If necessary, designers may adjust N and S_h to achieve the required minimum S_v value. In so doing, the adjusted layout should maintain the same soil nail density as that of the layout given in this Table, with $S_h \geq 1.0$ m. Where the designers opt for a specific S_v value (e.g. 2 m) to suit site constraints or other considerations, the soil nail layout may be adjusted by maintaining the same soil nail density as that given in this Table, with $S_h \geq 1.0$ m.

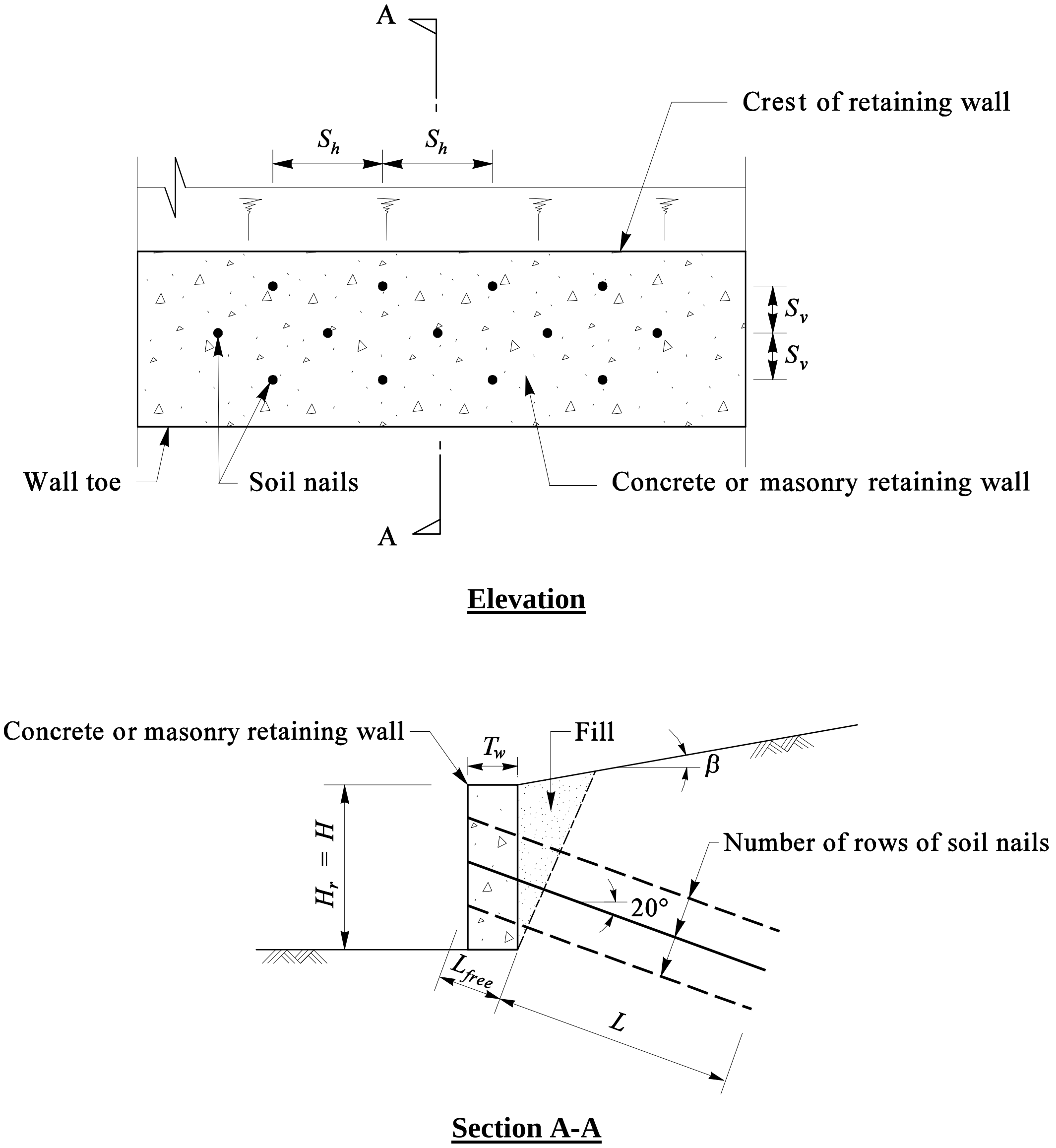
(7) Soil nails should be evenly spaced over the face of the retaining wall.

(8) Steel reinforcement for soil nails shall be of Type 2 high yield deformed bars.

(9) If rock is encountered in the process of drilling such that part of the soil nails will be installed in rock (e.g. installation through a PW50/90 zone or better, see Geoguide 3 (GCO, 1988)), designers may exercise professional judgement to reduce the soil nail length.

(10) Designers should check the land status to establish whether the soil nails would encroach into the adjoining land and, if so, whether this is acceptable to the land owner.

(11) Sections of a retaining wall that are lower than 2 m in height do not usually require reinforcement by soil nails.



Notes: (1) L = Length of the portion of soil nail in material behind the wall backfill; L_{free} = Length of the portion of the soil nail within the retaining wall and wall backfill; H = Slope feature height; H_r = Height of retained ground; T_w = Average retaining wall thickness; β = Gradient of terrain above slope feature.

(2) N, L, S_v, S_h and other dimensions for the soil nails are given in Table 5.11 based on the type of soil nail layout specified by designers.

(3) If tie beams and/or tie columns are provided, the soil nails may not necessarily be staggered.

Figure 5.9 Prescriptive Soil Nails on a Retaining Wall

5.4.3 Soil Nail Head and Facing

Skin walls, tie beams or tie columns should be provided to connect soil nails, in particular those installed in masonry retaining walls with poor wall conditions, such as dry-packed walls or walls with signs of distress. Isolated concrete soil nail heads can be used in concrete or well-constructed masonry retaining walls, because these walls generally have better structural integrity. For well-constructed masonry retaining walls, recessed soil nail heads are preferred in order to preserve the wall fabric and appearance. Due care needs to be exercised in the temporary removal of the masonry blocks to facilitate construction of recessed soil nail heads.

Typical details of a prescriptive reinforced concrete skin wall for connecting the soil nails in a concrete or masonry retaining wall together are shown in the latest version of CEDD Standard Drawing No. C2520 : Typical Details of Skin Wall with Soil Nails.

Typical details of the prescriptive exposed reinforced concrete tie beams and tie columns for connecting soil nails in a concrete or masonry retaining wall together are shown in the latest version of CEDD Standard Drawings No. C2524 : Details of Exposed Tie Beam for Retaining Wall and No. C2523 : Details of Embedded Tie Column for Masonry Retaining Wall.

Typical details of the exposed soil nail heads are shown in the latest version of CEDD Standard Drawing No. C2522 : Typical Details of Soil Nail Head on Rock or Concrete Wall Surface.

The following factors should be considered in the choice of the types of soil nail heads and facing for use on a wall face:

(a) Slenderness ratio of the wall, defined as H_e/T_w (see Figures 5.6 and 5.7) – Skin walls should be provided to reinforce existing retaining walls with high slenderness ratio. As a general guidance, a skin wall should be constructed over the entire face of a retaining wall with a slenderness ratio equal to or greater than 5.

(b) Wall condition – Skin walls should be considered to reinforce existing masonry retaining walls with poor wall condition. As a general guidance, a skin wall should be constructed over the entire face of a dry-packed masonry retaining wall, or a masonry retaining wall with condition Class B or observed state of wall deformation No. (2), as defined in Tables 5.7 and 5.8 respectively.

(c) Availability of space in front of the wall – If exposed tie beams or exposed soil nail heads are to be provided to a retaining wall overlooking a footpath, the lowest row of beams or soil nail heads should be placed at an elevation high enough to avoid pedestrians being affected.

(d) Slope appearance – GEO Publication No. 1/2000 : Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2000a) gives guidelines on landscape treatment to man-made features. If no skin wall is constructed over an existing wall face, care should be exercised to avoid staining of the surface of the existing wall due to grouting of soil nails.

5.4.4 Corrosion Protection

Guidance on the design of corrosion protection measures for steel reinforcement of prescriptive soil nails is given in Section 5.2.4.

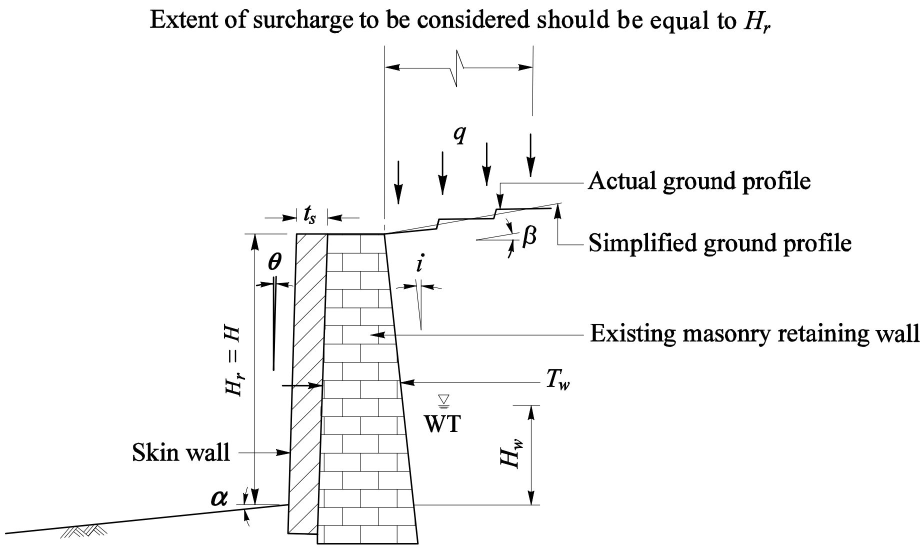
5.5 PRESCRIPTIVE SKIN WALLS FOR MASONRY RETAINING WALLS

5.5.1 Qualifying Criteria

Concrete skin walls are commonly used for upgrading masonry retaining walls. The prescriptive skin wall may be considered as upgrading works for masonry retaining walls if the qualifying criteria given in Table 5.11 are satisfied. In the case where not all of the qualifying criteria are satisfied, the skin wall may be used as preventive maintenance works.

Table 5.11 Qualifying Criteria for Application of Prescriptive Skin Walls to Masonry Retaining Walls as Upgrading Works

Subjects	Qualifying Criteria for Application
Geometry	Maximum effective height of slope feature, $H_e \leq 8$ m
Engineering and geology	1. There should not be any observable or recorded presence of weak materials such as extensive kaolin-bearing layers, ground with extensive loose fill materials, etc. 2. There should not be any observable or recorded signs of water which indicate that the groundwater level is higher than 1/3 of the height of retained ground, H_r.
Wall type	1. The wall should satisfy the conditions for 'existing' walls stipulated in the Geotechnical Manual for Slopes (GCO, 1984) and Works Bureau Technical Circular No. 13/99 (Works Bureau, 1999). 2. The wall should be of a condition no worse than wall condition Class B and no worse than observed state of wall deformation No. (2) as defined in Table 5.7 and Table 5.8 respectively.
Wall slenderness ratio, (H_e / T_w)	$H_e / T_w < 5$
Wall face angle, (θ)	$0° \leq \theta \leq 10°$
Terrain profile	1. Gradient of terrain in front of slope feature, α (averaged over a horizontal distance of four times the wall thickness) should not be greater than 10°. 2. Gradient of terrain above slope feature, β should not be greater than 10°.
Surcharge loading	1. Vertical uniform surcharge, q should not be greater than 10 kPa. 2. Total horizontal load, P should not be greater than 0.2 H_r^2, where P is in kN/m and H_r is in metres.



Wall Geometry

Legend:

α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
γ	Unit weight of soil
θ	Wall face angle
H	Slope feature height
H_e	Maximum effective height of slope feature, where $H_e = H\,(1 + 0.35 \tan \beta) + q/\gamma$
H_r	Height of retained ground
H_w	Height of design groundwater level behind the wall
i	Wall back angle
q	Design surcharge
T_w	Average thickness of masonry retaining wall
t_s	Prescriptive skin wall thickness
▽ WT	Design groundwater table

Figure 5.10 Prescriptive Skin Walls to Masonry Retaining Walls

5.5.2 Skin Wall Design

The prescriptive skin wall design should be carried out in accordance with the following steps:

(a) Compare the measured retaining wall thickness with the minimum required masonry retaining wall thickness where no works are needed using Figure 5.8. If the measured retaining wall thickness is equal to or greater than the minimum required thickness, the wall can be considered as being up to the safety standards for ‘existing’ walls recommended in the Geotechnical Manual for Slope

(GCO, 1984) and Works Bureau Technical Circular No. 13/99 : Geotechnical Manual for Slopes - Guidance on Interpretation and Updating (Works Bureau, 1999), provided that the conditions for 'existing' walls are satisfied, and no upgrading works would be required in this case.

(b) Otherwise, determine the required prescriptive skin wall thickness, t_s, using the following equation:

$$t_s = 0.056H_e + 0.22 \quad (5.2)$$

where H_e = maximum effective height of slope feature (m)

Typical skin wall details are given in the latest version of CEDD Standard Drawing No. C2521 : Typical Details of Skin Wall without Soil Nails.

5.6 PRESCRIPTIVE CONCRETE BUTTRESSES FOR ROCK CUT SLOPES

Where a rockfall has occurred leading to the formation of a cavity on the slope face, it may be necessary to construct a concrete buttress in the cavity to prevent further rockfalls. A buttress serves two functions, viz. to retain and protect areas of weak rock and to support the overhang. It may also be used to prevent local toppling failure of the rock face. Rock dowels are commonly used in conjunction with concrete buttresses to stabilise and tie the rocks together. Typical details of a concrete buttress are shown in the latest version of CEDD Standard Drawing No. C2203 : Typical Details of Concrete Buttress Type A.

The size of a concrete buttress is generally governed by geometrical considerations such that it is large enough to provide physical support to a rock block or overhang. The stability of its foundation should be considered. It should be founded on a level, clean and sound rock surface. If this surface is not at right angles to the direction of resultant force acting on the buttress, the buttress should be anchored to a solid base using dowels to prevent sliding failure. In addition, the top of the buttress should be set at a higher elevation than the top of the overhang to ensure good contact.

5.7 PRESCRIPTIVE ROCK DOWELS FOR ROCK CUT SLOPES

5.7.1 Collection and Assessment of Discontinuity Data

Stability in rock is controlled principally by discontinuities in the rock mass. The role of discontinuity data collection is primarily to aid the identification of the possible modes of failure. Rock outcrop mapping is the best field way to obtain discontinuity data. Geoguide 2 : Guide to Site Investigation (GCO, 1987) and Geoguide 3 : Guide to Rock and Soil Descriptions (GCO, 1988) describe the requirements for rock discontinuity mapping for rocks in Hong Kong.

Rock joint discontinuity data should be recorded in a proforma similar to Figure 1 of Geoguide 3 (GCO, 1988).

The degree of rock exposure is usually the controlling factor in determining the accuracy of the collected data. In the event that the rock slope face is fully exposed, there should be sufficient good quality data for rock mass discontinuity assessment. If little or no exposure is available on the slope, knowledge of the local geology may permit extrapolation from areas outside the slope. The key to this lies in the recognition of discontinuity patterns. Where extrapolation is necessary, designers should determine whether the rock mass and discontinuity pattern in the area of data collection are akin to those of the rock slope by consideration of the local geological conditions.

Where there are doubts on this, the discontinuity data should be collected from the covered rock slope direct. Techniques for investigating partially and fully covered rock faces include surface cover stripping, window opening, coring and drillhole inspection. Where stripping is used, a scanline survey may be undertaken as opposed to stripping the whole slope. Where prescriptive measures are specified without a close inspection of all the rock blocks to be treated, the actual rock block size and the measures needed should be reviewed once the conditions and dimensions of the block can be examined on site more accurately during the construction stage, particularly when the slope surface cover is removed and/or safe access for close inspection is provided.

A qualitative assessment is required to determine the potential instability problem and the likely scale of failure. If local zones of instability are observed, the prescriptive measures items given in this document can be applied. However, if there are potential global instability or large zones of potentially unstable rock blocks with a volume greater than 5 m^3, the use of these prescriptive measures items alone is not considered adequate, and suitable stabilisation measures based on analytical design should be implemented.

During the assessment, kinematic analysis could be used to facilitate judgement to be made on the stability of the slope. Where stereoplots are used, their limitations should be recognised (Hoek & Bray, 1981; Hencher, 1985). It is important that designers exercise due care when interpreting stereoplots and that correct judgement is applied. It should also be noted that assessment of discontinuity data only provides a reference for designers. The stability of an existing rock slope, particularly local stability of individual rock blocks, should always be assessed based on field inspections. Indeed, the step of discontinuity data collection may be omitted if the rock face to be treated is fully exposed, such that detailed examination of the rock face can be carried out to identify all potential instability problems.

Designers should review the overall stability of a rock slope before concentrating on stabilising small unstable rock blocks by means of prescriptive measures. Desk study, collection of relevant rock joint data and assessment of the stability of an existing rock slope through detailed visual inspection in the field should be carried out as needed.

5.7.2 Prescriptive Rock Dowels

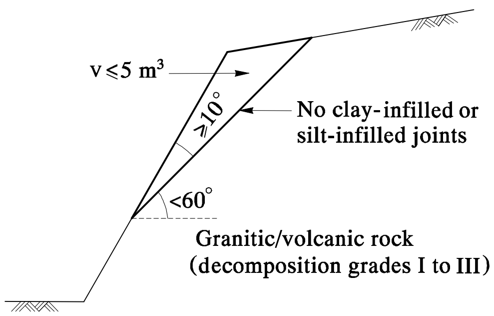
Loosening and detachment of small rock blocks on the slope face can be prevented by the installation of passive rock dowels, which are composed of reinforcing steel bars grouted into holes drilled in the underlying stable rock.

Prescriptive rock dowels can be applied as upgrading works to rock cut slopes which satisfy the qualifying criteria given in Table 5.12. In the case where not all the qualifying criteria are satisfied, the rock dowels may be used as preventive maintenance works.

Standard rock dowel design has been developed as shown in Figure 5.11 for prescriptive application. The rock block sliding angle and rock block volume should be estimated prior to using the design table to determine the number of dowels required. By reading off from the design table with the appropriate volume of potentially unstable rock block, the required number of dowels can be estimated. Typical details of a rock dowel are shown in the latest version of CEDD Standard Drawing No. C2202 : Typical Arrangement of Rock Dowel.

Table 5.12 Qualifying Criteria for Application of Prescriptive Rock Dowels to Rock Cut Slopes as Upgrading Works

Subjects	Qualifying Criteria for Application
Geometry	1. The volume of the rock block should not be greater than 5 m^3 and the rock block is not supporting any foundations of structures or surcharge. 2. The angle between the slope at the rock face and the potential sliding surface should not be smaller than 10°. 3. The angle of the rock block basal sliding surface should be smaller than 60°.
Engineering and geology	1. The rock type is granitic or volcanic and of decomposition grades I to III. 2. No daylighting clay-infilled or silt-infilled discontinuities.



Volume of Potentially Unstable Rock Block, v(m^3)	Number of Rock Dowels Required
$v \leq 1$	1
$1 < v \leq 2$	2
$2 < v \leq 3$	3
$3 < v \leq 4$	4
$4 < v \leq 5$	5

Notes:
(1) Dowel bars shall be of 32 mm in diameter (hot dip galvanised type 2 high yield steel bars to be used).
(2) Angle of dowels to be approximately perpendicular to potential sliding surface of the rock block.
(3) Dowel length = 3 x thickness of potentially unstable rock block, subject to a minimum length of 3 m and a maximum length of 6 m.
(4) The layout of the rock dowels as applied to a sliding rock block/wedge shall be at least 0.3 m from the identified periphery of the rock block/wedge in order to provide effective stabilisation.
(5) The vertical and horizontal spacing of the rock dowels shall be from a minimum of 0.3 m to an effective spacing evenly distributed to cover the sliding area of the block.

Figure 5.11 Prescriptive Rock Dowels on Rock Cut Slopes

6. OTHER CONSIDERATIONS

6.1 GENERAL

This Chapter provides guidance on other pertinent considerations in respect of the application of the prescriptive design framework.

6.2 SLOPE APPEARANCE AND LANDSCAPING

Due consideration should be given to making the appearance of a slope feature with prescriptive measures as natural as possible and minimising the potential visual impact to the existing environment. Whenever possible, vegetation should be used as the primary surface protection for slopes. General guidance on greening and landscape treatment for slope features is given in GEO Publication No. 1/2000 : Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2000a).

Guidance on selection of vegetation types (grass, shrubs, trees, creepers and/or other herbaceous plants), species and planting techniques (e.g. hydroseeding mix) can be found in GEO (2000a). Selection of vegetation type and species for area-specific or site-specific applications should be made in consultation with a landscape architect, the advice of whom could also be sought with regard to visual and ecological aspects. The party responsible for maintenance of the slope feature and the horticulture should also be consulted as appropriate. Further information on vegetation species suitable for slope greening can be found in the booklet "Tree Planting and Maintenance in Hong Kong" published by the Information Services Department (Hong Kong Government, 1991) and in GEO Technical Guidance Note No. 20 : Update of GEO Publication 1/2000 – Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (GEO, 2007c).

6.3 TREE PRESERVATION

The government policy on tree preservation is that no trees should be unnecessarily felled or pruned (ETWB, 2006b). The planning and design of prescriptive measures should take into account the need for tree preservation on slope features. Designers should ensure that the existing trees are preserved as far as possible by selecting appropriate prescriptive measures items and adjusting the layout of the works. For example, tree rings should be provided to existing trees where a hard surface cover is required. The prescriptive soil nail layout should be adjusted to locate the nails away from tree trunks and tree roots. Box-out should also be provided for existing trees where a prescriptive skin wall is used.

Trees should be properly protected during construction works. Extreme care is needed to avoid damage to major tree roots during excavation for subsurface drainage and soil nailing. Protective fencing may be used to screen construction works from areas of existing vegetation. Existing tree trunks may also be protected with the use of wooden pallets and/or hessian wrapping during construction works.

6.4 BUILDABILITY

In prescribing improvement works to slope features using prescriptive measures, due consideration should be given to assessing the buildability of the works with respect to the site conditions. In particular, designers should give due consideration to the buildability of soil nails in ensuring that the design is practical and buildable (GEO, 2008).

6.5 WORKS IN THE VICINITY OF SENSITIVE STRUCTURES

When carrying out improvement works to slope features in the vicinity of sensitive structures, such as old buildings with shallow foundations, buildings that have previously been subjected to disturbance and important underground service utilities that are vulnerable to ground movement, designers should ensure that the proposed prescriptive measures will not induce undue disturbance or excessive ground movement to the sensitive structures. Where deemed necessary, suitable preventive or mitigation measures should be implemented to minimise the potential disturbance that could be caused by the prescriptive measures. The need for condition or defects survey of the sensitive structures and setting up of an appropriate monitoring system should also be considered.

6.6 CONSTRUCTION SUPERVISION AND CONTROL

The necessary construction control for prescriptive measures is similar to that for any other form of slope works which are designed analytically. Adequate site supervision and control should be provided during the implementation of the measures. General guidance on aspects of construction control is given in Chapter 9 of the Geotechnical Manual for Slopes (GCO, 1984). Chapter 6.2 of Geoguide 7 : Guide to Soil Nail Design and Construction (GEO, 2008) also provides guidance on construction supervision and control of soil nailing works.

6.7 CONSTRUCTION REVIEW

The application of prescriptive measures does not involve detailed ground investigation and design analyses at the design stage. It is therefore of paramount importance that construction reviews are carried out during various stages of construction to examine the actual condition of the slope feature and verify the validity of the design assumptions.

Construction reviews should include site inspections and assessment of the geology, slope-forming materials and groundwater conditions, together with verification of whether the qualifying criteria for application of the prescriptive measures have been met. The reviews should also include an evaluation of the suitability and adequacy of the specified types and items of prescriptive measures, as well as recommendations on the necessary design modifications to cater for the actual site and ground conditions as revealed.

Every opportunity should be taken in inspecting any exposed slope-forming materials for adverse geological or groundwater conditions, and identifying any significant differences between the actual conditions and that assumed during the design stage. This can be done most effectively at the time when the prevailing slope surface cover has been removed, during excavation for subsurface drainage works, and during drilling for raking drains or soil nails. Where deemed necessary, geological advice may be sought from an experienced engineering geologist on the presence of any adverse geological conditions. The importance of engineering geological input during construction is emphasised in GEO Publication No. 1/2007 : Engineering Geological Practice in Hong Kong (GEO, 2007d).

The findings and recommendations of construction reviews, including sketches, drawings, notes and photographs which record the site observations and design amendments, should be properly documented as 'Site Inspection Records' in the "Record Sheets for Prescriptive Measures on Man-made Slope Features" (Figure 2.2). The record sheets, together with other information as specified in Geoguide 5 : Guide to Slope Maintenance (GEO, 2003), should be included in the Maintenance Manual.

6.8 MAINTENANCE

Regular and proper maintenance should be provided to slope features with prescriptive measures. General guidance on recommended good practice for maintenance works for slope features, including the provision of safe access, is given in Geoguide 5 (GEO, 2003).

Raking drains used as prescriptive measures should not be considered as "Special Measures" as defined in Geoguide 5, and the monitoring requirements stipulated in Section 5 of Geoguide 5 are not applicable to these drains. Regular inspections and routine maintenance of the raking drains should however be carried out.

Where water-carrying services are present which are judged to have a destabilising effect on a slope feature in the event of leakage, the guidance given in Geoguide 5 should be followed.

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GLOSSARY OF SYMBOLS

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A	Height of no-fines concrete backfill
B	Base width of no-fines concrete backfill
D	Depth of soil-nailed zone
f_t	Vertical thickness of fill layer above top of retaining wall
f_w	Depth of fill layer as measured from top of retaining wall
H	Slope feature height, i.e. the maximum height of slope feature from toe to crest
H_d	Height of geosynthetic composite drainage material (or similar)
H_e	Maximum effective height of slope feature
H_r	Height of retained ground
H_u	Height of the upper part of slope feature
H_w	Height of design groundwater level behind retaining wall
h	Height of retaining wall
i	Angle of wall back
L	Length of portion of soil nail in material behind wall backfill
L_{free}	Length of portion of soil nail within retaining wall and wall backfill
L_{total}	Total length of soil nail
N	Number of soil nails per vertical column required at the critical section
P	Total horizontal load on retaining wall
q	Surcharge loading expressed as an equivalent uniform pressure
r_u	Average pore water pressure ratio
S_h	Horizontal spacing of soil nails
S_v	Vertical spacing of soil nails
T_w	Average thickness of retaining wall
t_s	Thickness of prescriptive skin wall
U	Distance between upstand of flat drainage channel and slope crest

v	Volume of potentially unstable rock block
α	Gradient of terrain in front of slope feature
β	Gradient of terrain above slope feature
ϕ_h	Soil nail drillhole diameter
ϕ_r	Soil nail diameter
γ	Unit weight of soil
θ	Angle of wall face

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Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
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