PRESCRIPTIVE SOIL NAIL DESIGN FOR CONCRETE AND MASONRY RETAINING WALLS

GEO REPORT No. 165

B.L.S. Lui & Y.K. Shiu

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
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Prepared by:

Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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PREFACE

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

The Geotechnical Engineering Office also produces documents specifically for publication. These include guidance documents and results of comprehensive reviews. These publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

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

FOREWORD

Since the publication of GEO Report No. 56 "Application of Prescriptive Measures to Soil Cut Slopes" in October 1996, there has been continuous development to improve the guidelines and extend the scope of application of prescriptive measures. Initiated under Goal 2 of the GEO 2001-2005 Five-year Strategic Plan, a study has been carried out to develop prescriptive measures for retaining walls.

This report documents the findings of the study and gives a methodology for assessing whether a retaining wall meets the current geotechnical standard or not. This report also presents guidelines on prescriptive design using soil nails as upgrading works or preventive maintenance works for cut slopes with a toe wall, and concrete or masonry retaining walls.

The study was carried out by Ms B.L.S. Lui under the supervision of Mr Y.K. Shiu. A number of GEO colleagues have provided useful information and comments. All contributions are gratefully acknowledged.

W.K. Pun
Chief Geotechnical Engineer/Special Projects

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ABSTRACT

A study has been carried out to develop prescriptive measures for upgrading of concrete retaining walls and masonry retaining walls using soil nails. As part of the study, past design cases involving analytical design of soil nails for upgrading about 80 cut slopes with a toe wall, and concrete or masonry retaining walls have been reviewed for deriving the prescriptive design guidelines.

This report documents the findings of the study. It is shown that the prescriptive design approach and the standard layout of soil nails for soil cut slopes as recommended in the second edition of GEO Report No. 56 can be applied to cut slopes with a toe wall, but an additional length of soil nail is required for accommodating the nail length passing through the retaining wall and fill material. Similar prescriptive soil nail design guidelines have been developed for concrete and masonry retaining walls. The guidelines may be used for upgrading works or preventive maintenance works. A chart has also been devised to assist designers in determining whether a concrete or masonry retaining wall is substandard or not.

Typical details of soil nail heads and wall facing for use in conjunction with the prescriptive soil nails are given in the report. Areas of soil nail detailing and construction requiring special attention were also discussed.

CONTENTS

1. INTRODUCTION

In February 1995, the Geotechnical Engineering Office (GEO) of the Civil Engineering Department (CED) commenced the first phase of a systematic study of prescriptive measures for the design of soil cut slopes. The findings and recommendations of the study were incorporated in the first edition of GEO Report No. 56 (Wong & Pang, 1996). The second phase of the study extended the scope of application of prescriptive measures to upgrading of substandard masonry retaining walls by reinforced concrete skin walls. The findings and recommendations of the second phase study were incorporated in the second edition of GEO Report No. 56 (Wong et al, 1999).

In early 2003, a study was initiated under Goal 2 of the GEO 2001-2005 Five-year Strategic Plan to develop prescriptive measures for upgrading of concrete retaining walls. It was later considered practical to further extend the application of prescriptive measures to upgrading of masonry retaining walls and cut slopes with a toe wall using soil nailing.

This report documents a review of past design cases involving analytical design of soil nails for upgrading concrete or masonry retaining walls. It also proposes prescriptive design guidelines for using soil nails as upgrading works or preventive maintenance works for retaining walls.

2. REVIEW OF PAST DESIGN CASES

2.1 Past Design Cases

As defined in GEO Circular No. 15 (GEO, 2003a),

- CR features are cut slopes with a retaining wall at the crest, middle or toe of the slope, whereas

- R features are retaining walls supporting a slope or a platform with a surface sloping at < 15° (fill or natural ground).

A review of 80 CR and R features which were upgraded using soil nails has been carried out. The designs examined included upgrading works for government slopes and retaining walls under the Landslip Preventive Measures Programme as well as designs of upgrading works for private slopes and retaining walls. Among these 80 features, only 29 features were found suitable for use in deriving prescriptive design guidelines. These primarily are cases where:

(a) the features were upgraded solely using soil nails without a concrete skin wall or without taking into account the beneficial effect provided by a concrete skin wall;

(b) no adverse geological and hydrogeological conditions were encountered;

(c) the increase in factor of safety resulted from upgrading

works for the features was within the range suitable for deriving prescriptive design guidelines; and

(d) detailed design information was available for a meaningful evaluation.

As more than one cross-section have been analysed in a number of features, a total number of 42 suitable data sets were available. Details of the data sets and the derivation of prescriptive design guidelines are contained in Appendix A.

2.2 Analytical Design Methods

The upgrading works of the 29 features reviewed were all designed using the analytical approach. They were designed to the safety standards recommended in the Geotechnical Manual for Slopes (GCO, 1984). The designs were all based on detailed ground investigations in which dimensions of the retaining walls and nature of the retained ground were determined. Soil parameters were determined from laboratory testing on samples retrieved from ground investigations.

3. PRESCRIPTIVE DESIGN GUIDELINES

3.1 Scope of Application

The design guidelines given in this report are applicable to those CR features, concrete retaining walls and masonry retaining walls which satisfy the qualifying criteria listed below. Where not all the qualifying criteria are satisfied, the prescriptive measures can be used as preventive maintenance works.

(a) Feature Type:

(i) For concrete retaining wall, it should be a mass concrete wall, or a reinforced concrete (RC) wall in L-shaped, inverted L-shaped or inverted T-shaped as illustrated in Figure 1.

(ii) For masonry retaining wall, it should have condition no worse than wall condition Class B and observed state of wall deformation Class (2) as defined respectively in Tables 6 and 7 of GEO Report No. 56 (Wong et al, 1999). The two tables are reproduced as Tables 1 and 2 respectively in this report.

(iii) For CR feature, it should be a soil cut slope with a concrete or masonry retaining wall at the toe.

(b) Wall geometry and ground profile:

(i) CR features: Feature heights not exceeding those

stipulated in Table 3, and ground gradient α (over a horizontal distance of four times the wall thickness) $\leq$ 10° (see Figures 2 and 3).

(ii) R features: 3 m $\leq$ Feature Heights $\leq$ 8 m, α (over a horizontal distance of four times the wall thickness) $\leq$ 10° and gradient of retained ground $\beta \leq 15°$ (see Figures 4 and 5).

(c) The fill behind and above the wall should be of limited volume as defined by the following criteria:

(i) CR features (Figure 2 for mass concrete/masonry retaining wall and Figure 3 for RC retaining wall):

- Maximum vertical height of fill, f_t, measured from the wall top, should not be more than 5 m; and

- Maximum depth of the fill, f_w , measured horizontally from the wall top should not be more than 3 m.

(ii) R features (Figure 4 for mass concrete/masonry retaining wall and Figure 5 for RC retaining wall):

- $f_w \leq H_r$

(d) There should not be any observable or recorded adverse geological conditions and adverse discontinuities as listed in Table 3.

(e) There should not be any observable or recorded adverse groundwater conditions as listed in Table 3.

(f) In the case of upgrading of CR features, the increase in factor of safety (ΔFOS) against overall slope instability to be achieved should be less than 0.5.

3.2 Recommended Procedures for Prescriptive Soil Nail Design for CR Features

Prescriptive design of soil nails for a CR feature should be carried out by following the steps below:

(a) Undertake a thorough desk study and site reconnaissance in accordance with Geoguide 2 (GCO, 1987) to determine whether there is sufficient information on the ground and groundwater conditions for the assessment of the qualifying criteria listed in Section 3.1 above.

(b) Determine the slope geometry and wall thickness by field measurement, such as topographic survey and weephole probing.

(c) If the existing information is insufficient for assessing the qualifying criteria with confidence, there will be a need to carry out additional ground investigation (GI). For example, trial pits and GCO probing are useful in revealing the extent of fill and likelihood of the presence of a high permanent groundwater level. Engineering judgement has to be made on the likely permanent and transient rise in groundwater level based on the results of the desk study, site reconnaissance and GI.

(d) Check whether the feature satisfies the qualifying criteria given in Section 3.1 for the use of prescriptive measures as upgrading works. Checking for the qualifying criteria is not required if the prescriptive measures are used as preventive maintenance works.

(e) Determine the maximum effective height, H_e, and the range of ΔFOS against overall slope instability to be achieved as per Section A.6 of GEO Report No. 56.

(f) Determine from Table 4 the number of rows, spacings and length, L_s, of soil nails. For those soil nails to be installed through a retaining wall, the total length of soil nail, L, should be determined by the following equation:

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

where L_{free} = Length of the portion of soil nail within the retaining wall and the fill behind (m)

L_s = Length of the portion of soil nail in material behind the retaining wall and the fill (m)

L_{free} can be taken as 2 m or alternatively, determined by the designer based on detailed information on the wall thickness and the extent of fill behind the wall.

Typical patterns of soil nailing are shown in Figure 6. The soil nail layout derived from prescriptive design based on a consideration of the maximum effective feature height may be applied to the whole feature. Alternatively, the feature may be split into different sections, with the soil nail layout for each section designed by the use of the maximum effective height for the respective section.

(g) Prescribe details of the soil nail head and wall facing

following the guidelines given in Section 3.4 below.

(h) Complete Sheet 1 of the "Record Sheets for Prescriptive Applications" (Figure 13) for the prescriptive design and complete Sheet 2 of the form after design verification during construction in accordance with the guidance provided in paragraphs (f), (g) and (h) of Section 4.2.3 of GEO Report No. 56.

3.3 Recommended Procedures for Prescriptive Soil Nail Design for R Features

Prescriptive design of soil nails for a R feature should be carried out by following the steps below:

(a) Undertake a thorough desk study and site reconnaissance in accordance with Geoguide 2 (GCO, 1987) to determine whether there is sufficient information on the ground and groundwater conditions for the assessment of the qualifying criteria listed in Section 3.1 above.

(b) Determine the wall thickness and profile of the ground in front of and behind the wall by field measurement, such as topographic survey and weephole probing.

(c) If the existing information is insufficient for assessing the qualifying criteria with confidence, there will be a need to carry out additional GI such as trial pits and GCO probing in revealing the extent of fill and likelihood of the presence of a high permanent groundwater level. Engineering judgement has to be made on the likely permanent and transient rise in groundwater level based on the results of the desk study, site reconnaissance and GI.

(d) Check whether the feature satisfies the qualifying criteria given in Section 3.1 for the use of prescriptive measures as upgrading works. Checking for the qualifying criteria is not required if the prescriptive measures are used as preventive maintenance works.

(e) Determine the maximum effective height, H_e, and whether the feature should be designed to the "new" wall standard or "existing" wall standard following the guidelines given in the Geotechnical Manual for Slopes (GCO, 1984).

(f) Determine whether the feature is substandard. One way of doing it is to compare the measured retaining wall thickness with the minimum wall thickness required to satisfy the current geotechnical standards given in Figure 7 according

to the respective wall standard to be achieved. (The details of derivation of the minimum wall thickness are given in Appendix B.) If the measured retaining wall thickness is equal to or greater than the minimum thickness required, the wall can be considered as up to the respective geotechnical standard and no upgrading works are necessary. The chart in Figure 7 is applicable to mass 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 detailed GI. In these cases, the designer should decide if it is more cost effective to assume the wall to be substandard and proceed with prescriptive design of upgrading works or to carry out a stability assessment with detailed GI.

(g) Where soil nailing is required, determine from Table 5 the number of rows, spacings and lengths, L_s , of soil nails. The total length of the soil nail, L, should be determined by the following equation:

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

where L_{free} = Length of the portion of soil nail within the retaining wall and the fill behind (m)

L_s = Length of the portion of soil nail in material behind the retaining wall and the fill (m)

L_{free} can be taken as the retained height of the wall, H_r, or alternatively determined by the designer based on detailed information on the wall thickness and the extent of fill behind the wall.

Typical patterns of soil nailing are shown in Figure 8. The soil nail layout derived from prescriptive design based on a consideration of the maximum effective feature height may be applied to the whole feature. Alternatively, the feature may be split into different sections, with the soil nail layout for each section designed by the use of the maximum effective height for the respective section.

(h) Prescribe details of the soil nail head and wall facing following the guidelines given in Section 3.4 below.

(i) Complete Sheet 1 of the “Record Sheets for Prescriptive Applications” (Figure 13) for the prescriptive design and complete Sheet 2 of the form after design verification during construction in accordance with the guidance provided in paragraphs (f), (g) and (h) of Section 4.2.3 of GEO Report No. 56.

3.4 Soil Nail Head and Wall Facing Details

3.4.1 Masonry Retaining Wall

Typical details of the soil nail heads and wall facing for soil nails in a masonry retaining wall are shown on Figures 10 to 12. The following factors should be considered in the choice of types of soil nail head and wall facing:

(a) Slenderness Ratio of the wall, defined as H_r/T_w (see Figures 2 and 4),

(b) condition of the wall,

(c) availability of space in front of the wall, and

(d) aesthetic consideration.

For dry packed masonry retaining walls and other walls with a Slenderness Ratio equal to or greater than 5, a skin wall should be constructed over the whole masonry wall face.

3.4.2 Concrete Retaining Wall

Concrete retaining walls generally have better structural integrity than masonry retaining walls. The following types of nail head and facing, with typical details shown on Figures 9 to 11, may be used:

- Skin wall
- Tie beams on existing wall surface
- Soil nail heads on existing wall surface

Similar to masonry wall, in deciding on the type of soil nail head and facing, due consideration should be given on the final appearance of the feature and available space in front of the wall.

3.5 Personnel for Prescriptive Design

Prescriptive design should be specified by qualified personnel, as recommended in Section 5 of GEO Report No. 56.

3.6 Design and Construction Considerations

When applying the prescriptive measures recommended in this report, designers should pay attention to the following design and construction aspects:

(a) Aesthetics

GEO (2000) gives guidelines on landscape treatment to man-made slopes and retaining walls. 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.

(b) Space in front of retaining wall

If exposed tie beams or exposed soil nail heads are provided on a retaining wall overlooking a footpath, the lowest row of soil nails should be placed high enough to avoid affecting pedestrians.

(c) Drainage

Existing weepholes should be extended through any new skin wall. Prescriptive raking drains should be provided to control the rise of groundwater level as needed. Raking drains should be installed after all the soil nails at levels higher than the raking drains have been grouted. Details of prescriptive raking drains are given in Section A.5.3 of GEO Report No. 56.

(d) Safety precautions for drilling through reinforced concrete wall

Before drilling works in a reinforced concrete wall is carried out, safety precautions should be implemented to avoid damaging steel bars in the reinforced concrete wall, such as using metal detector to determine locations of steel bars.

(e) Settlement

For soil nails to be installed in a retaining wall with fill material behind, the likelihood of ground settlement at the wall crest and potential adverse effects on exiting utilities and other facilities should be assessed. Considerations should be given to implement measures to minimize settlement. Staggered drilling of soil nails and provision of casings in drillholes are examples of the means of minimizing settlement.

(f) Grout loss and hole collapse

Considerations should be given to provide temporary or permanent casing in the part of drillholes within the fill material for preventing collapse of the drillholes. Records of grout volume intake should be kept.

4. STATUS OF SLOPE FEATURES IMPROVED BY PRESCRIPTIVE MEASURES

Where prescriptive measures have been applied to a feature as upgrading works in accordance with the recommendations of this report, the feature can be taken to have been upgraded to acceptable geotechnical standards.

Where prescriptive measures have been applied to a feature as preventive maintenance works in accordance with the recommendations of this report, the prescriptive measures can be taken to have improved the feature to reduce the rate of deterioration, and to have met a recommended standard of good practice for slope preventive maintenance.

The features improved by prescriptive measures should be maintained in accordance with the guidelines given in Geoguide 5 (GEO, 2003b).

5. REFERENCES

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GCO (1987). Geoguide 2 - Guide to Site Investigation. Geotechnical Control Office, Hong Kong, 353 p.

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Wong, H.N. and Pang, L.S. (1996). Application of Prescriptive Measures to Slopes and Retaining Walls. Geotechnical Engineering Office, Hong Kong, 52 p. (GEO Report No. 56, First Edition)

Wong, H.N., Pang, L.S., Wong, A.C.W., Pun, W.K. & Yu, Y.F. (1999). GEO Report No. 56, Second Edition - Application of Prescriptive Measures to Slopes and Retaining Walls. Geotechnical Engineering Office, Hong Kong, 73 p.

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Table 1 - Classification of Visible Masonry Wall Condition

Masonry Wall Condition Class	State of Distress and Wall Deformation Based on Inspection (See Note 1)
A	Minimal distress (e.g. wall fabric in good condition) and deformation.
B	Moderate distress (e.g. much mortar missing, minor dislocation of isolated masonry blocks) and/or deformation.
C	Onset of severe distress (e.g. missing or dislocation of some masonry blocks) and/or deformation.
D	Advanced stage of severe distress (e.g. missing or major dislocation of many masonry blocks) and/or deformation.

Notes:
(1) In general, the state of deformation of old masonry retaining wall can be assessed reliably by means of experience and engineering judgement. In case of doubt or in marginal cases, reference may be made to Table 2 for guidance.
(2) For walls without tie members, a conservative assessment should be made, with the overall wall visible 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 3 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 2 - Guidelines for Evaluation of the State of Masonry 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 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 to 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, engineering judgement is crucial since different walls are likely to present different degrees of difficulty in deformation determination. The proposed deformation limits shown in this Table should not be regarded as absolute.		

Table 3 - Scope of Application of Prescriptive Soil Nail Design to CR and R Features with Concrete/Masonry Retaining Walls

Types of Slope Improvement Works	Qualifying Criteria for Application			
	Consequence[1]		Geometry	Engineering and Geology
Preventive Maintenance Works	Qualifying criteria not applicable			
Upgrading Works using Prescriptive Soil Nail Design	CR Features	Groups 1 & 2 facilities affected	Feature height ≤ 10 m	- Apply only to (i) R feature with either a masonry or a concrete retaining wall judged to require improvement works or (ii) CR feature associated with an existing soil cut slope[2] with a toe masonry/concrete retaining wall judged to require improvement works. - Apply to site confirmed as comprising colluvial, residual or saprolitic soils of granitic or volcanic origin that do not contain loose or soft materials. 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. - 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- 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). - Apply only if no observable or recorded adverse groundwater conditions, i.e. no signs of a high permanent[3] groundwater table over a significant area of the slope. As a general guide, the average pore water pressure ratio, ru, for the slope should not exceed 0.1.
		Group 3 facilities affected	Feature height ≤ 13 m	
		Groups 4 & 5 facilities affected	Feature height ≤ 18 m	
	R Features		3 m ≤ Feature height ≤ 8 m	

Notes:
(1) The various groups of facilities are given in Table A1, Appendix A of GEO Report No. 56 (Wong et al, 1999).
(2) 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 overlying colluvium. Where the size of the fill body, if present, meets GEO's slope registration criteria, the fill body should be dealt with using the conventional approach.
(3) "Permanent" refers to "typical wet season water level" as described on p. 60, GCO (1984).
(4) If a feature that was designed and checked to be up to the current geotechnical standards has failed, then the prescriptive design approach may not be applicable and the feature should be investigated to determine suitable urgent repair or upgrading works.
(5) The application of prescriptive measures as upgrading works should generally be limited to features which have not experienced any major or multiple minor failures. Where there are major or multiple minor failures on the feature or at areas adjacent to the feature, the causes of the failures should first be investigated and understood. Prescriptive measures may be applied but these may be treated as upgrading works only if the investigation can confirm that all qualifying criteria (geometry, engineering and geology) are met.

Table 4 - Standard Prescriptive Soil Nail Layout for CR Features with a Toe Wall

Standard Soil Nail Layout	H_e (m)	ϕ_r (mm)	ϕ_h (mm)	A			B			C		
				N	L_s (m)	S_h (m)	N	L_s (m)	S_h (m)	N	L_s (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) L_s is the length of the portion of soil nail in material behind the retaining wall and fill.

(2) Total length of a soil nail should include the length of the portion of nail within the retaining wall and fill, L_{free} , and L_s.

(3) H_e is the maximum effective feature height (see Figures 2 and 3 for definition), ϕ_r the steel bar diameter, ϕ_h the hole diameter, S_h the horizontal spacings of soil nails and N the number of rows of soil nails.

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

(5) Soil nails should be evenly spaced over the feature face. If the height of retaining wall at the slope toe is less than the vertical spacing of soil nails, at least one row of soil nails should be installed through the retaining wall.

(6) 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 feature, soil nails should be provided at vertical and horizontal spacings similar to that at the critical section. Alternatively, different soil nail layouts according to the maximum H_e of that part of the feature may be adopted.

(7) 'A', 'B' and 'C' refer to factor of safety increase in the ranges 0.3 to 0.5, 0.1 to less than 0.3, and less than 0.1 respectively.

(8) If, in the process of drilling, rock is encountered 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), the designer may exercise professional judgement to reduce the nail length L_s .

(9) The designer should check the land status to see whether the nails encroach into adjoining land and if so whether this is acceptable to the land owner.

(10) The parts of the feature with a height less than 2 m do not usually require reinforcement by soil nails**.**

(11) The vertical spacing (S_v) of soil nails should not be less than 1.5 m, see Figure 6.

Table 5 - Standard Prescriptive Soil Nail Layout for R Features of Concrete/Masonry Retaining Wall

Standard Soil Nail Layout	H_e (m)	ϕ_r (mm)	ϕ_h (mm)	New Wall Standard			Existing Wall Standard		
				N	L_s (m)	S_h (m)	N	L_s (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) L_s is the length of the portion of soil nail in material behind the retaining wall and fill.

(2) Total length of a soil nail should include the length of the portion of soil nail in retaining wall and fill, L_{free} , and L_s.

(3) H_e is the maximum effective feature height (see Figures 4 and 5 for definition), ϕ_r the steel bar diameter, ϕ_h the hole diameter, S_h the horizontal spacings of soil nails, and N the number of rows of soil nails.

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

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

(6) 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 feature, soil nails should be provided at vertical and horizontal spacings similar to that at the critical section. Alternatively, different soil nail layouts according to the maximum H_e of that part of the feature may be adopted.

(7) New and existing wall standards refer to the standards of upgrading retaining wall in accordance with the conditions listed in the Geotechnical Manual for Slopes (GCO, 1984).

(8) If, in the process of drilling, rock is encountered 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), the designer may exercise professional judgement to reduce the nail length L_s.

(9) The designer should check the land status to see whether the nails encroach into adjoining land and if so whether this is acceptable to the land owner.

(10) The parts of the feature with a height less than 2 m do not usually require reinforcement by soil nails.

(11) The vertical spacing (S_v) of soil nails should not be less than 1.5 m, see Figure 8.

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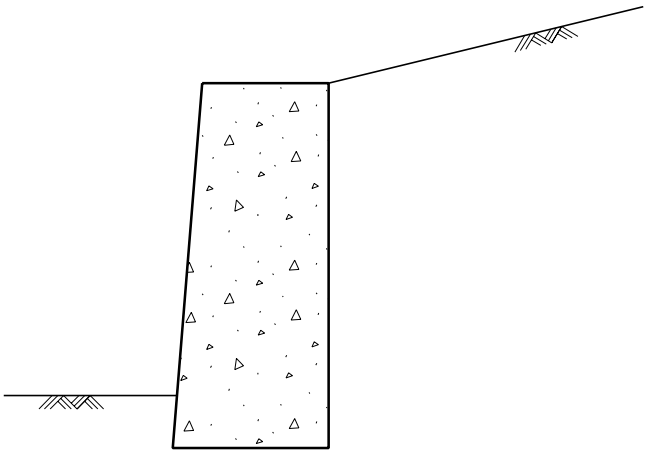
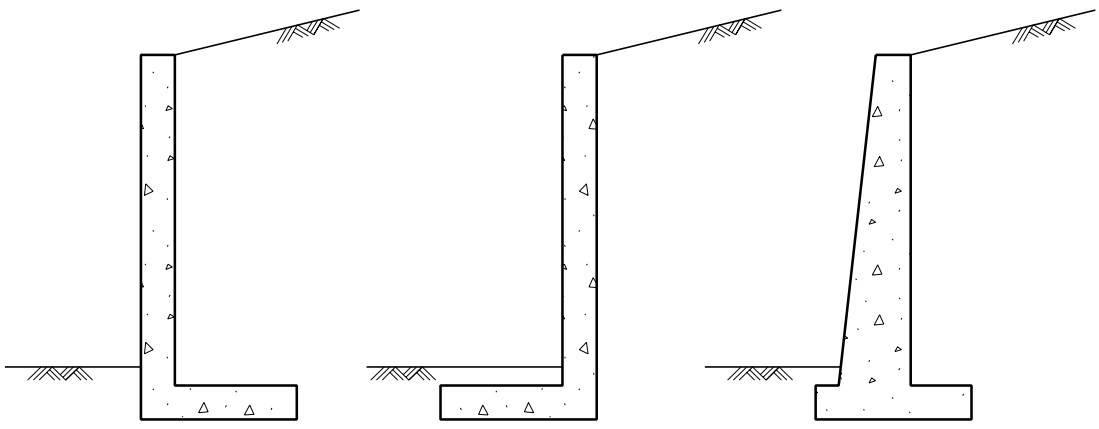
LIST OF FIGURES

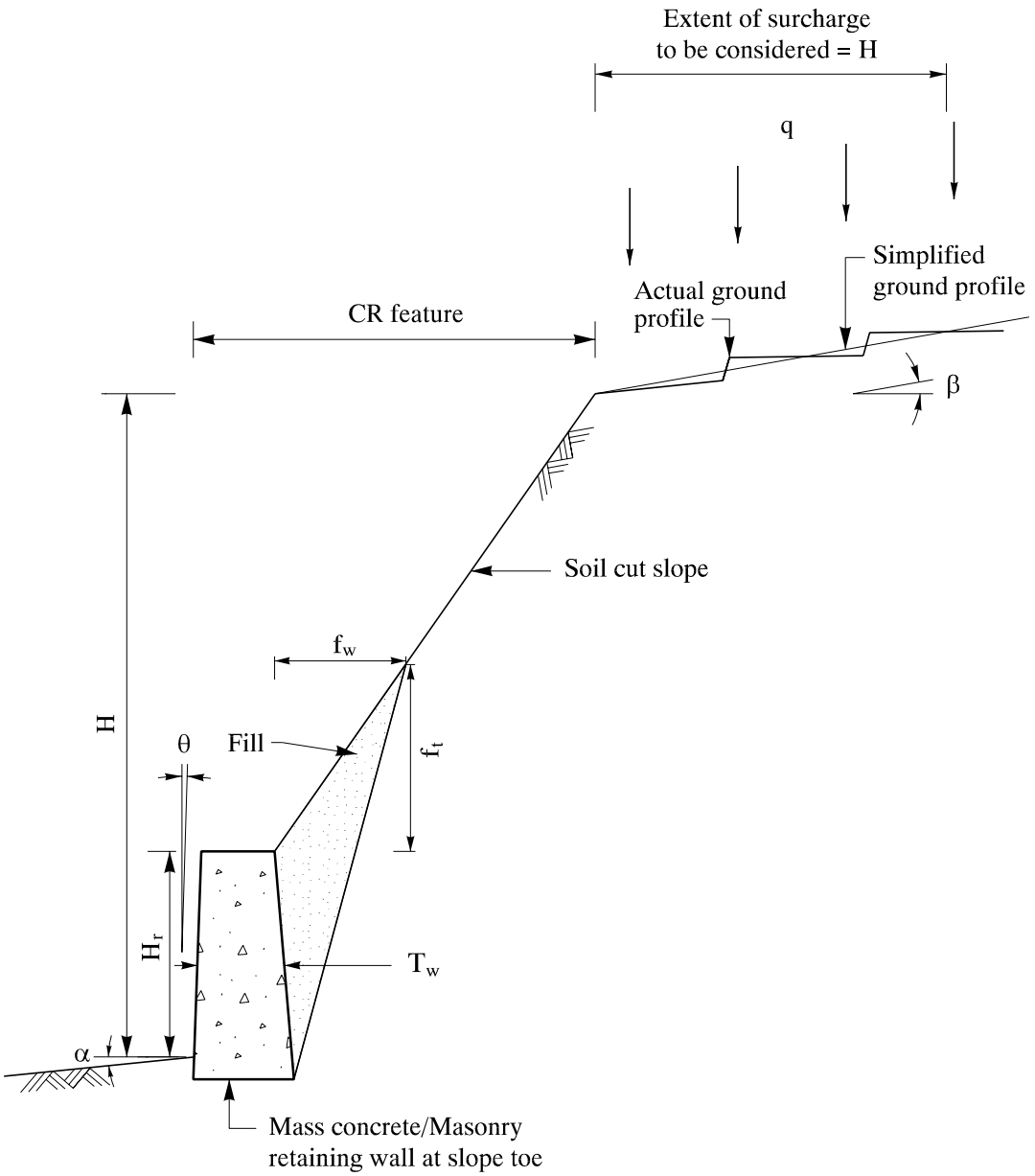


(a) Gravity Retaining Wall: Mass Concrete Retaining Wall



(b) Reinforced Concrete (R.C.) Retaining Wall: L-, Inverted L-, or Inverted T-shaped Retaining Wall (with or without key)

Figure 1 - Types of Concrete Retaining Walls within the Scope of Application of Prescriptive Measures



Legend:

α	Gradient of ground in front of wall	β	Gradient of retained ground
q	Design surcharge	θ	Wall face angle
f_w	Depth of fill layer from retaining wall top	f_t	Vertical thickness of fill layer above retaining wall
H_r	Height of retained ground		
H	Height of feature from toe to crest	T_w	Average thickness of retaining wall
H_e	Effective Height where $H_e = H*(1+0.35\tan\beta) + q/20$		

Figure 2 - Simplified Geometry of CR Feature with a Mass Concrete/Masonry Retaining Wall and the Adjacent Ground

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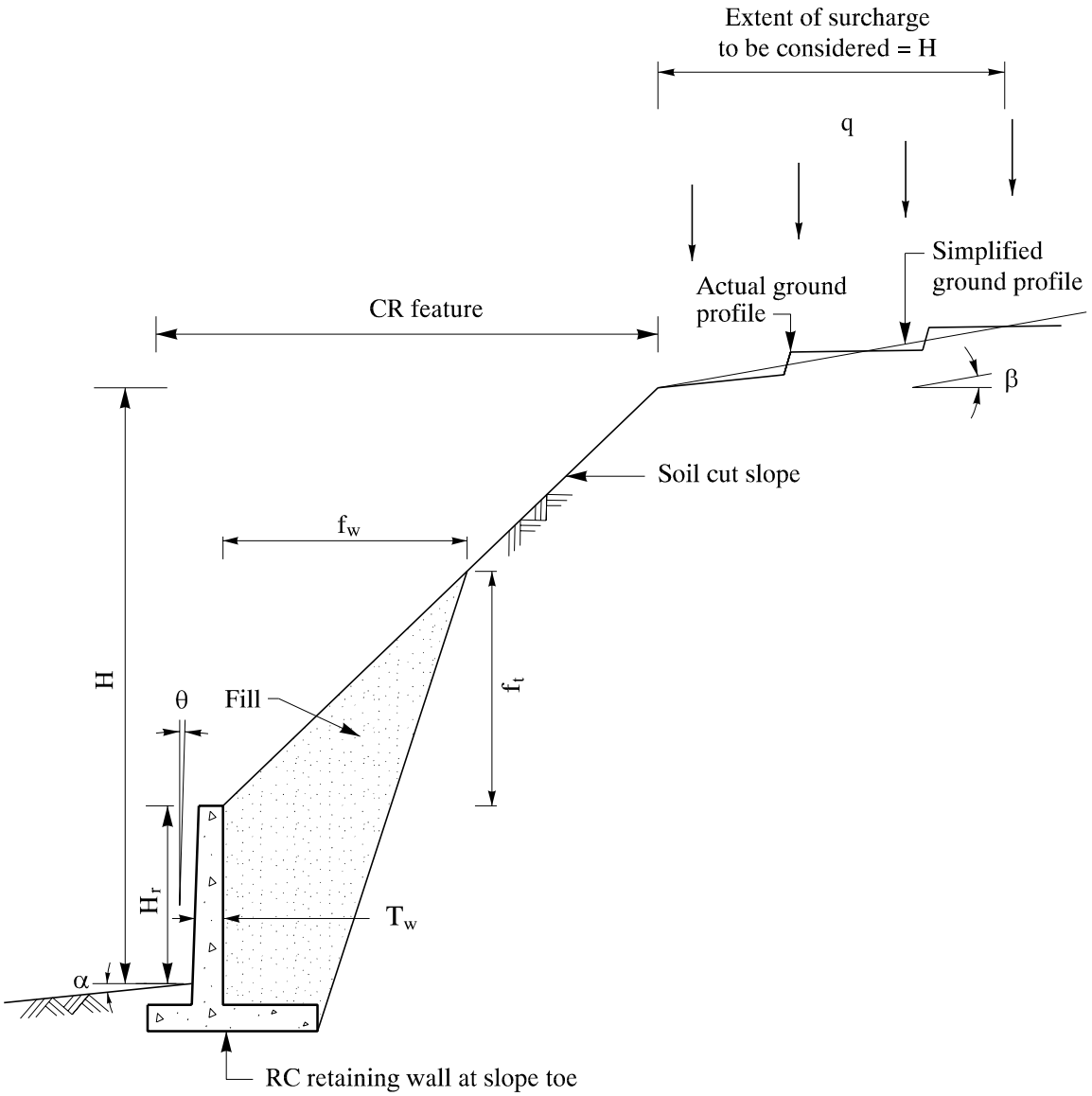

Legend:

α	Gradient of ground in front of wall	β	Gradient of retained ground
q	Design surcharge	θ	Wall face angle
f_w	Depth of fill layer from retaining wall top	f_t	Vertical thickness of fill layer above retaining wall
H_r	Height of retained ground		
H	Height of feature from toe to crest	T_w	Average thickness of retaining wall

Figure 3 - Simplified Geometry of CR Feature with a RC Retaining Wall and the Adjacent Ground

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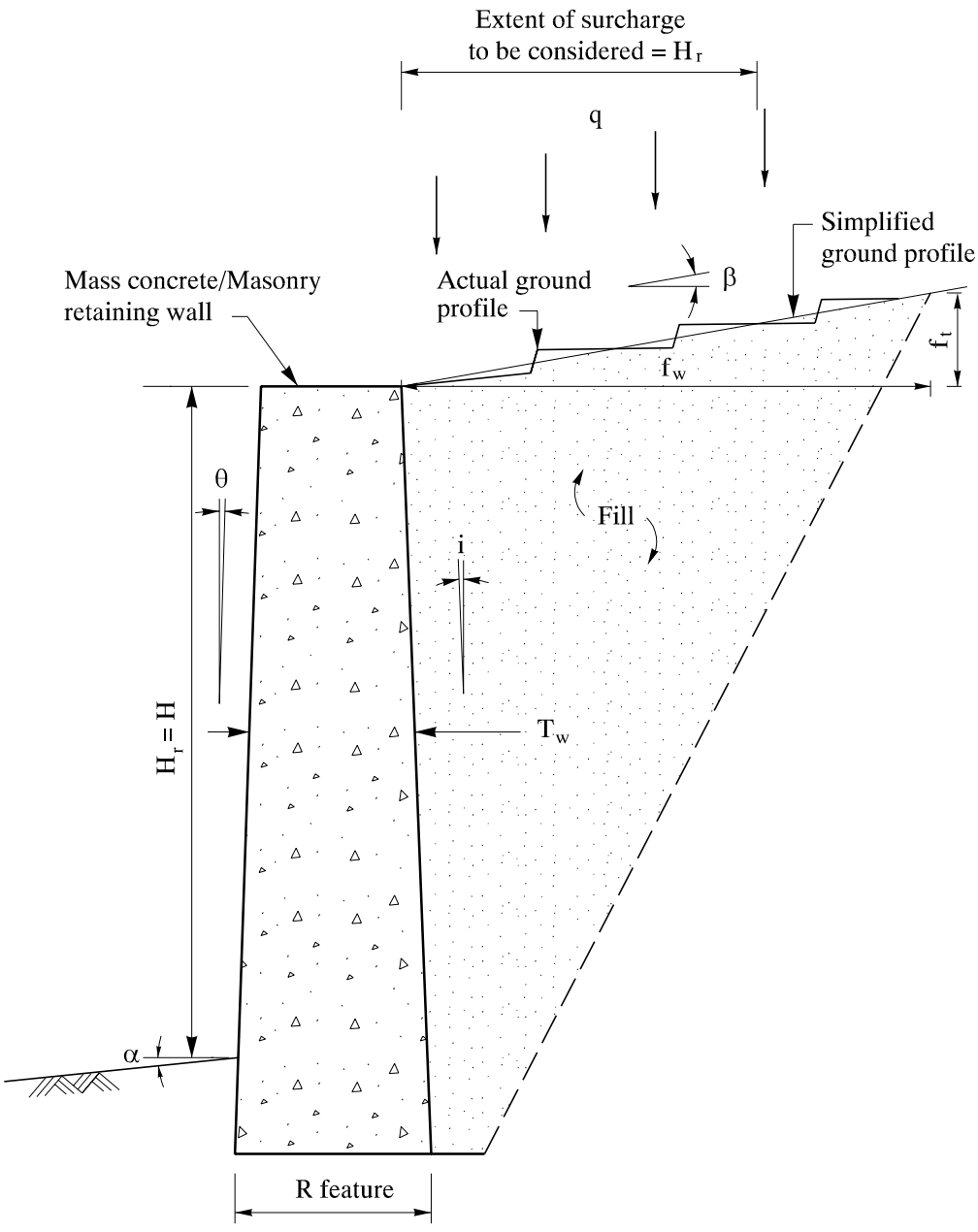

Legend:

α	Gradient of ground in front of wall	β	Gradient of retained ground
q	Design surcharge	θ	Wall face angle
f_w	Depth of fill layer from retaining wall top	f_t	Vertical thickness of fill layer above retaining wall
H_r	Height of retained ground		
H	Height of feature from toe to crest	T_w	Average thickness of retaining wall
H_e	Effective Height where $H_e = H*(1+0.35\tan\beta) + q/20$	i	Wall face angle

Figure 4 - Simplified Geometry of R Feature with a Mass Concrete/Masonry Retaining Wall and the Adjacent Ground

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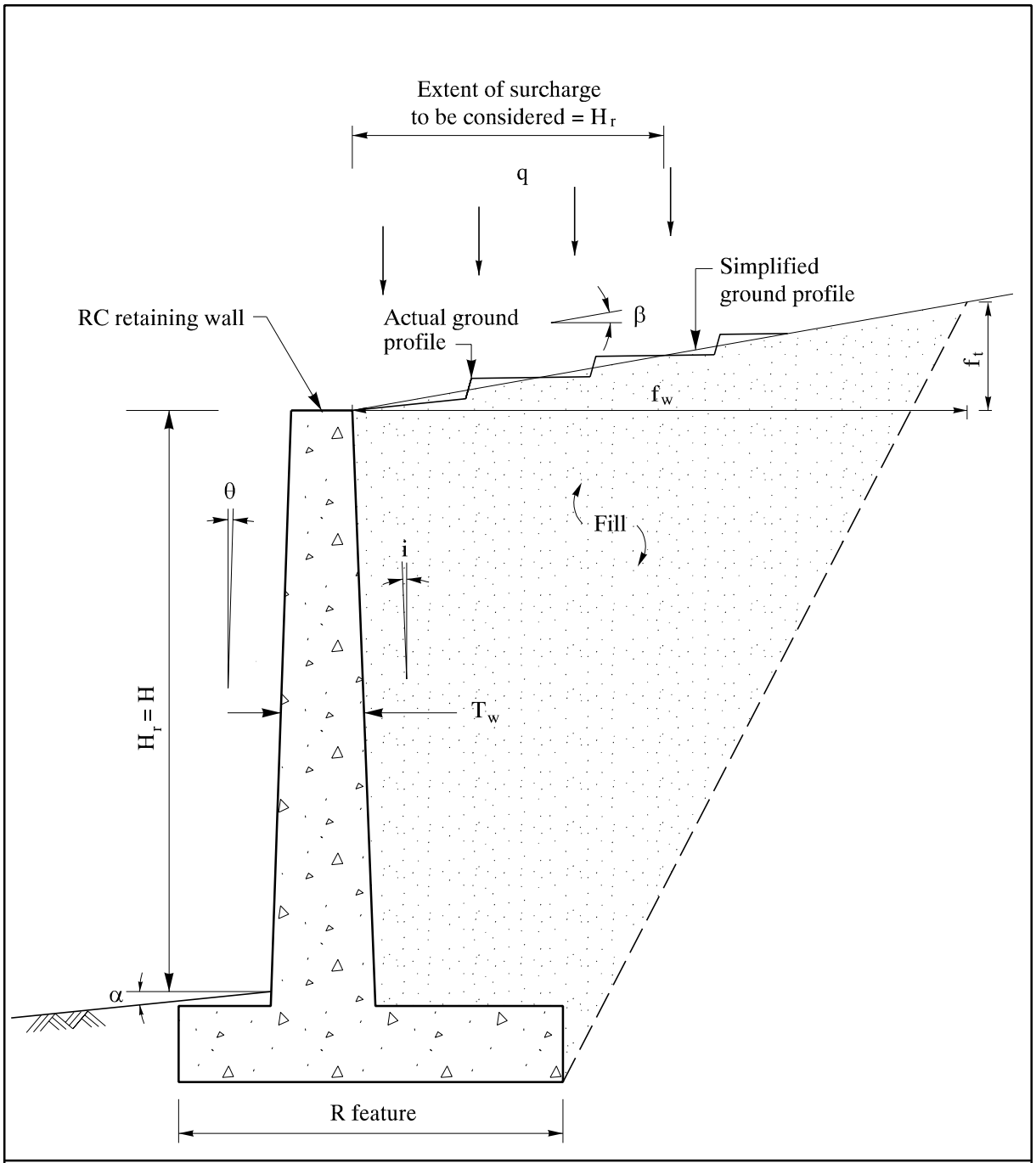

Legend:

α	Gradient of ground in front of wall	β	Gradient of retained ground
q	Design surcharge	θ	Wall face angle
f_w	Depth of fill layer from retaining wall top	f_t	Vertical thickness of fill layer above retaining wall
H_r	Height of retained ground		
H	Height of feature from toe to crest	T_w	Average thickness of retaining wall
H_e	Effective Height where $H_e = H*(1+0.35\tan\beta) + q/20$	i	Wall face angle

Figure 5 - Simplified Geometry of R Feature with a RC Retaining Wall and the Adjacent Ground

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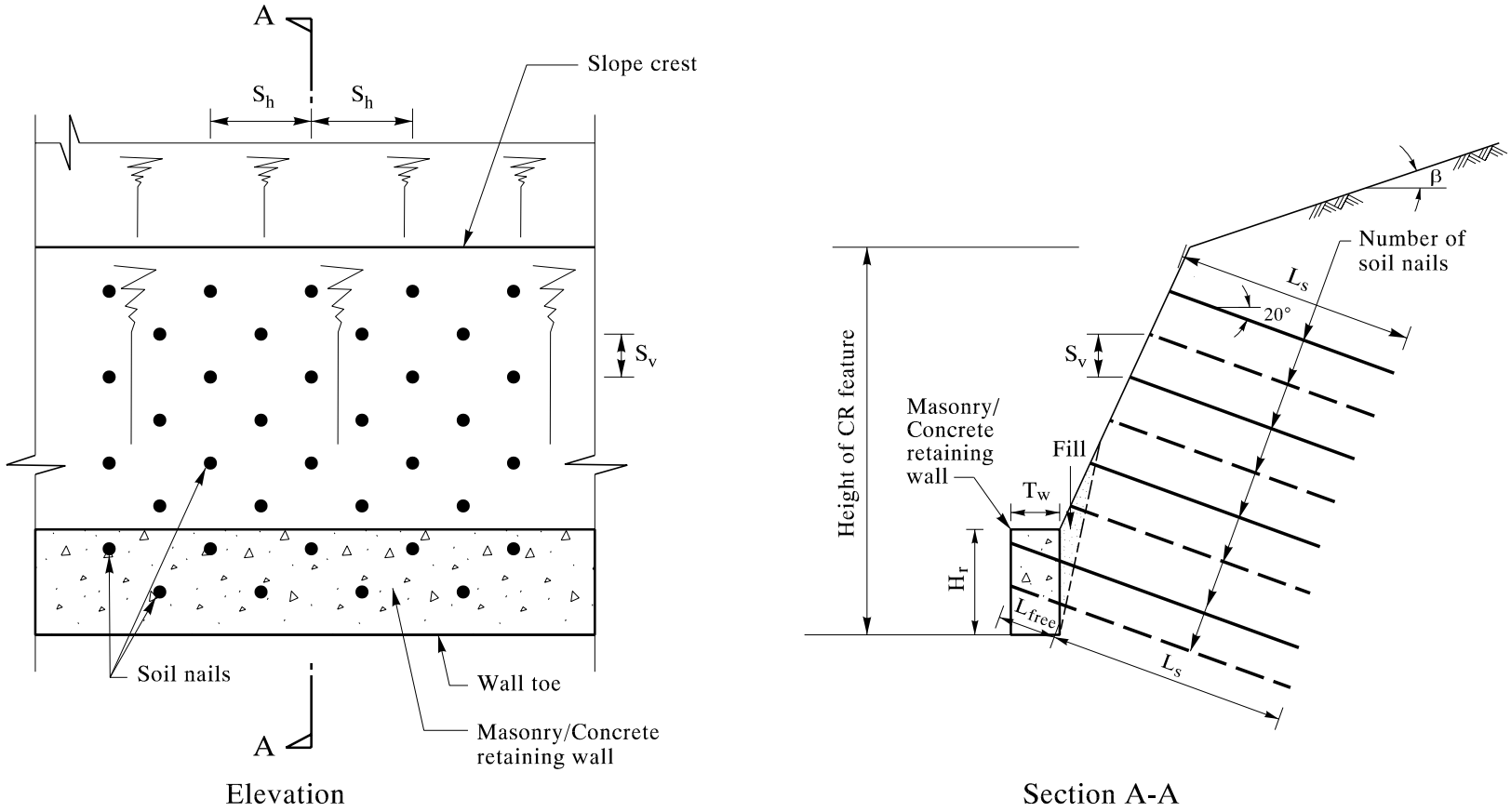


Notes:

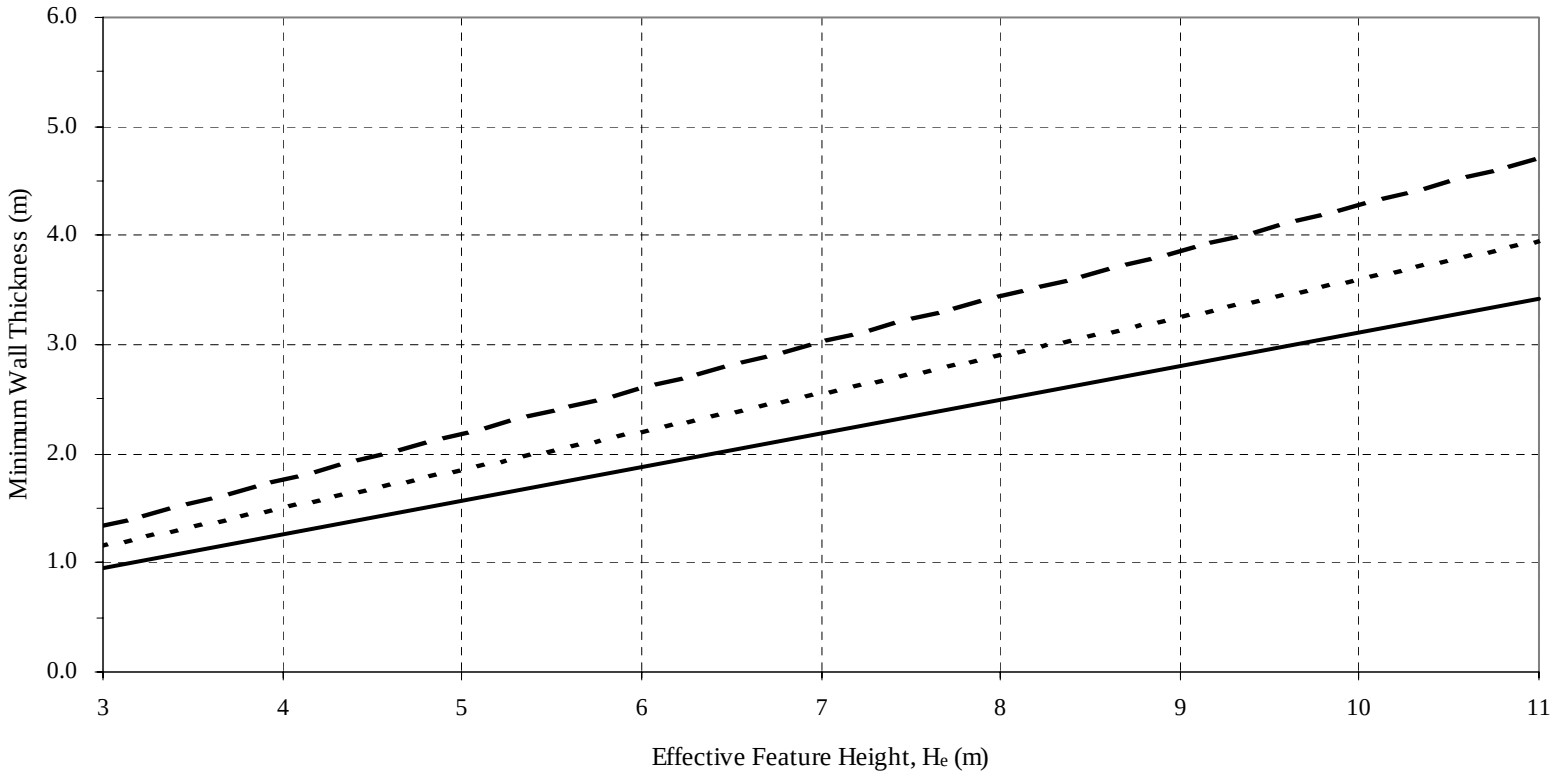
(1) L_s = Length of the portion of soil nail in material behind the retaining wall and fill; L_{free} = Length of the portion of the soil nail within the retaining wall and fill; H_r = Height of the retained ground; T_w = Average retaining wall thickness.

(2) N, S_v, S_h and other dimensions for the soil nails are given in Table 4 based on the type of soil nail layout specified by the designer.

(3) See CED Drawing Nos. C2106/1F for details of soil nails; C2106/2C and 3D for details of soil nail heads on slopes and Figures 9 to 12 for details of soil nail heads on wall and wall facing.

(4) This Figure shows the arrangement of soil nails staggered at alternative rows. Alternatively, soil nails staggered at alternative columns may be adopted by the designer as appropriate to suit site conditions.

Figure 6 - Soil Nailing to CR Feature



Legend:

Concrete wall (existing wall standard)

Concrete wall (new wall standard)

Masonry wall (existing and new wall standard)

Note: The chart is only applicable to R features with masonry/concrete retaining wall satisfying the qualifying criteria listed in Section 3.1 and Table 3, and surcharge above the feature should not more than 10kPa.

Figure 7 - Minimum Retaining Wall Thickness for R Features for No Works

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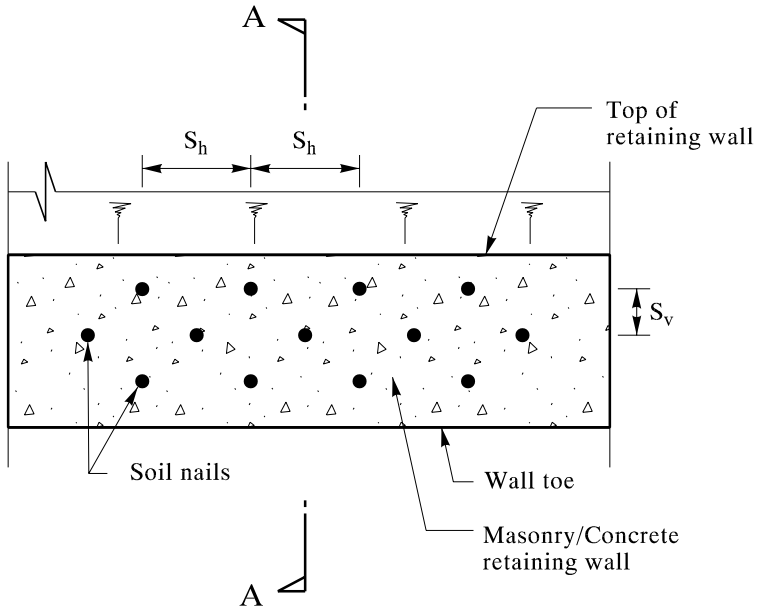
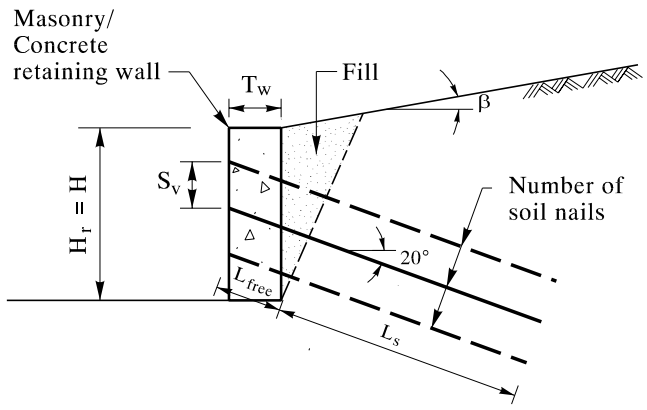


Elevation



Section A-A

Notes:

(1) L_s = Length of the portion of soil nail in material behind the retaining wall and fill; L_{free} = Length of the portion of the soil nail within the retaining wall and fill; H = Height of the R Feature; H_r = Height of the retained ground; T_w = Average retaining wall thickness.

(2) N, S_v, S_h and other dimensions for the soil nails are given in Table 5 based on the type of soil nail layout specified by the designer.

(3) See CED Drawing Nos. C2106/1F for details of soil nails and Figures 9 to 12 for details of soil nail heads on wall and wall facing.

(4) This Figure shows the arrangement of soil nails staggered at alternative rows. Alternatively, soil nails staggered at alternative columns may be adopted by the designer as appropriate to suit site conditions.

Figure 8 - Soil Nailing to R Feature

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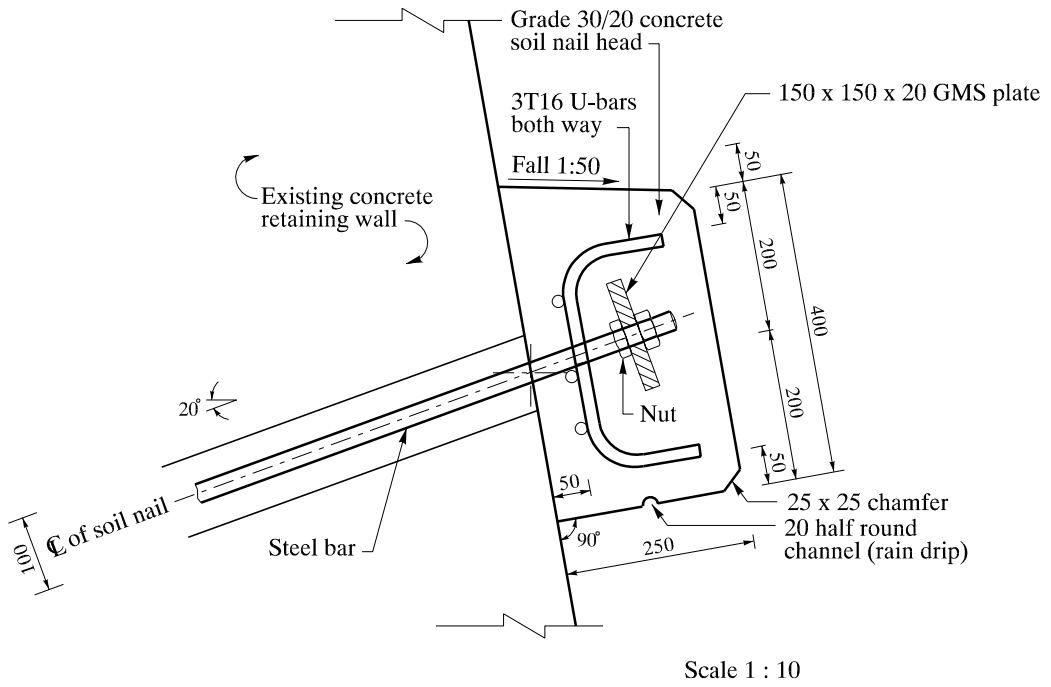
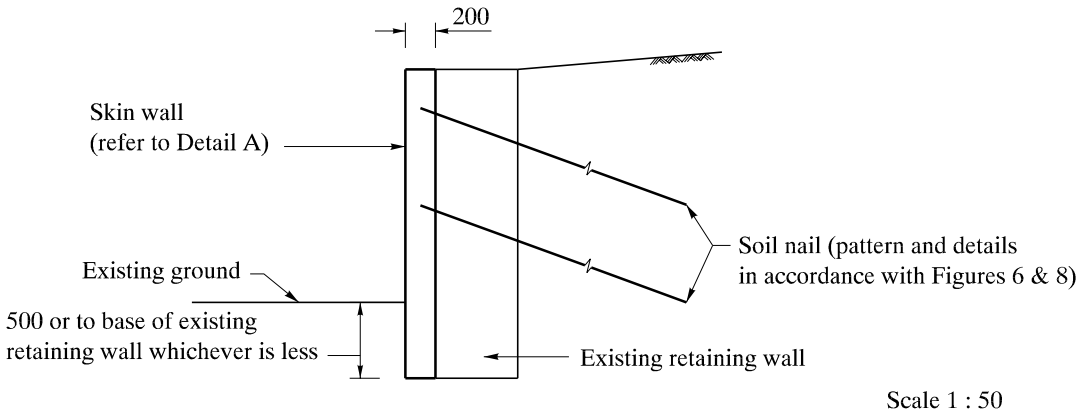
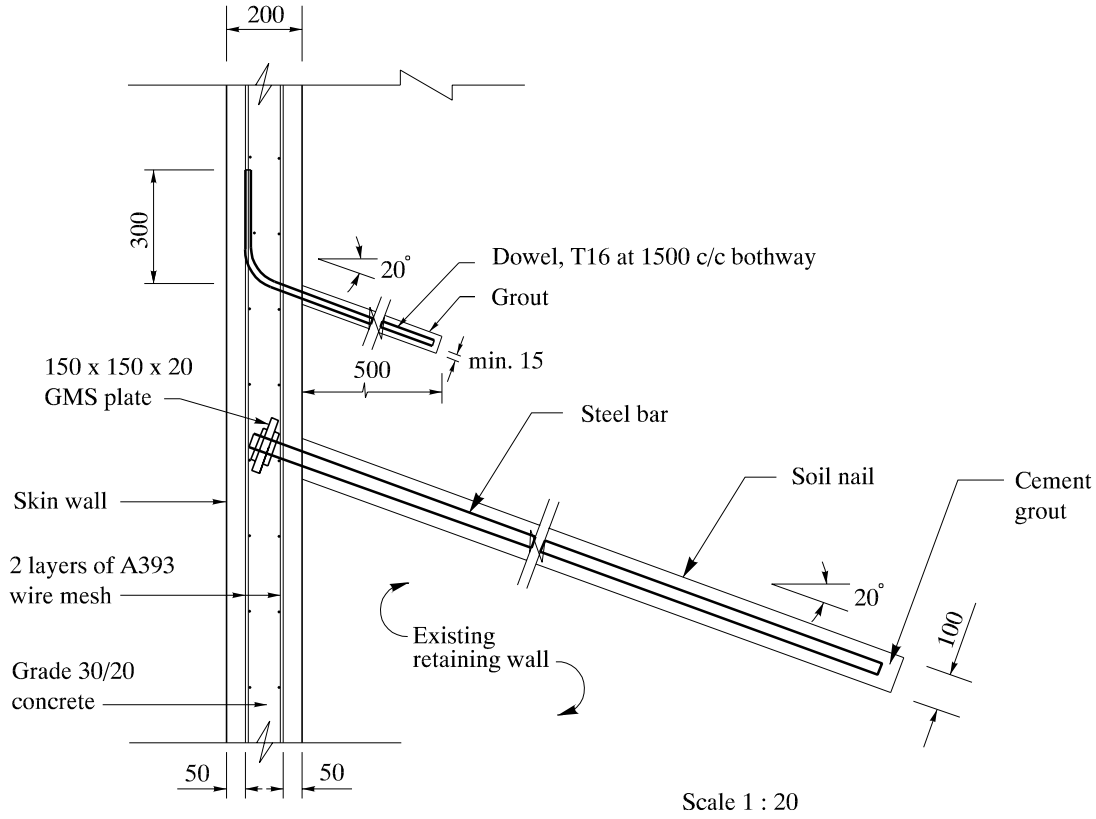


Note: All dimensions are in millimetres.

Figure 9 - Details of Exposed Soil Nail Head for Concrete Retaining Wall



Typical Layout of Skin Wall



Detail A

Notes:

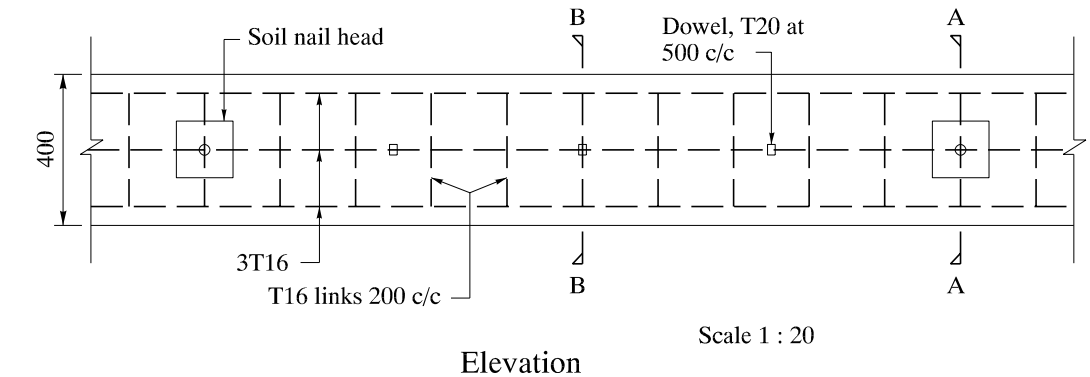
(1) All dimensions are in millimetres.

(2) Horizontal weepholes of size 50 mm diameters minimum (normally 50 PVC pipe) at approximately 1.5 m horizontal x 1.5 m vertical spacing should be provided through the skin wall and existing retaining wall. If there are existing weepholes at the wall, it is important to ensure that the existing weepholes are extended through the skin wall. If not, new weepholes should be constructed to beyond the back of the existing wall. Drainage channels should be provided along the crest of the existing wall. Prescriptive raking drains should also be provided where necessary to control transient rises in groundwater pressure.

(3) At any time, the maximum allowable length of excavation in front of the wall is 10 m or one third the wall length whichever is smaller.

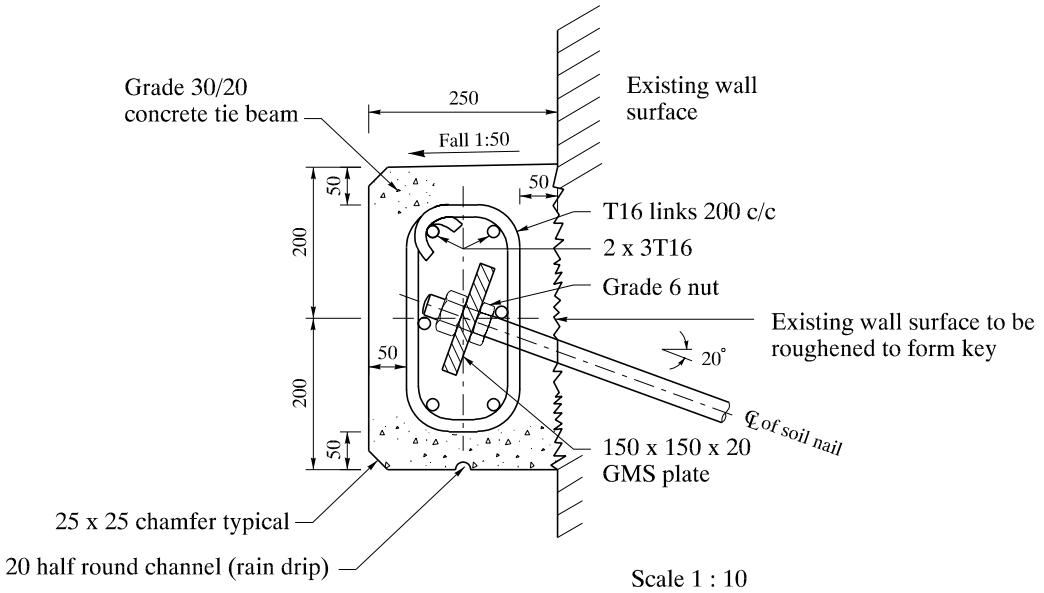
(4) The trench excavated for the construction of the skin wall should be properly backfilled with concrete.

Figure 10 - Details of Skin Wall



Scale 1 : 20

Elevation



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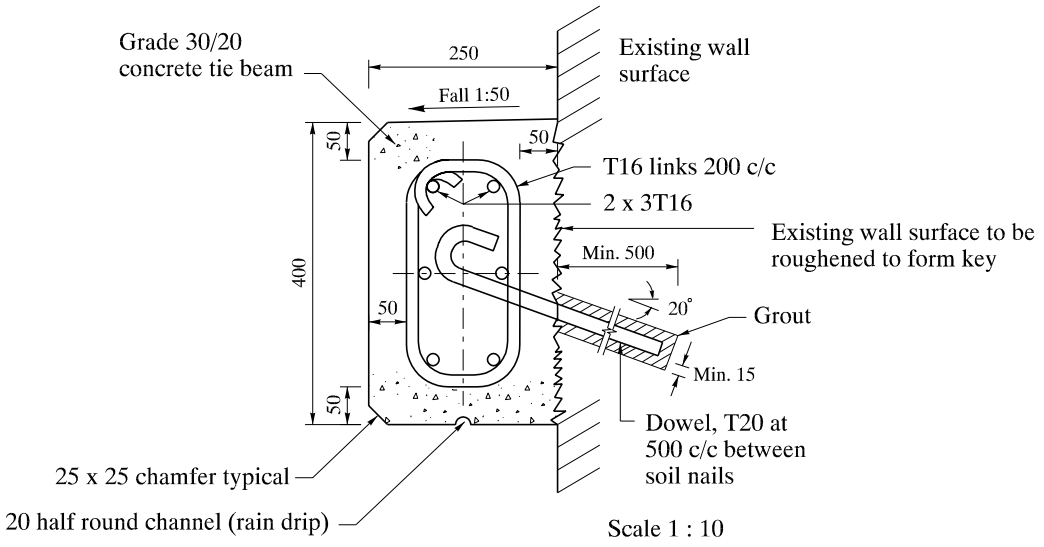
Section A-A

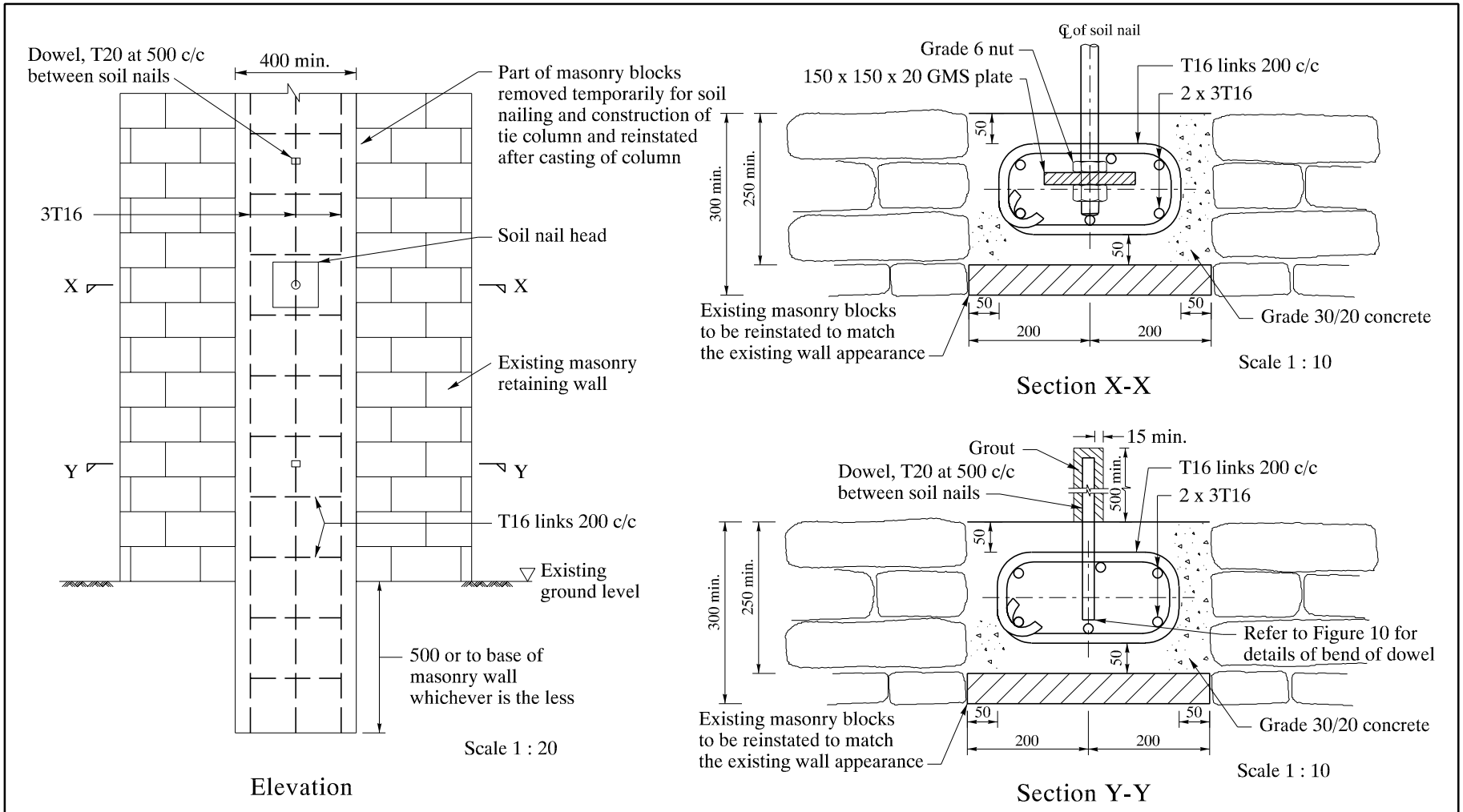


Scale 1 : 10

Section B-B

Note: All dimensions are in millimetres.

Figure 11 - Details of Exposed Tie Beam



Notes:
(1) All dimensions are in millimetres.
(2) At any time, no more than one vertical trench for the construction of tie column should be opened over 1.5 m width of the wall.
(3) The pit excavated for the construction of tie column should be backfilled by concrete.

Figure 12 - Details of Concealed Tie Column for Mansonry Retaining Wall

Part A - Prescriptive Soil Nail Design for CR and R Features with Concrete/Masonry Retaining Wall	
Feature No. _____	Location (Address) _____
Feature Geometry and Consequence Category	Qualifying Criteria
Wall Type: Feature Height: (m) Upslope Angle: (degrees) Downslope Angle: (degrees) Group of Facilities Affected: 1 / 2 / 3 / 4 / 5 * Consequence-to-life Category: 1 / 2 / 3 * Records of Engineer Inspection available: Yes / No * If yes, date of inspection: HKGS Geology Map Sheet No.:	1. Within consequence and geometry limits. ☐ Yes 2. Slope-forming material confirmed on site as acceptable. ☐ Yes 3. No adverse geological conditions present. ☐ Yes 4. No adverse groundwater conditions. ☐ Yes
List of Reference Documents Reviewed _____ _____ _____ _____ _____ _____ _____	
Type of Improvement Works	
☐ Provide soil nails to improve overall slope stability	☐ For CR features with a FOS increase in ranges : A / B / C * (See Table 4 and Figure 6) ☐ For R features using : existing/wall * standard (See Table 5 and Figure 8)
Attachments: ☐ Site location plan ☐ Photographs ☐ Records of Engineer Inspections ☐ Plan, sketches/drawings showing locations/layout/key dimensions of the proposed prescriptive measures	

Designed by:	Signature:	Checked by:	Signature:
Post:	Date:	Post:	Date:

'*' Delete where appropriate

Figure 13 - Indicative Record Sheet for Prescriptive Soil Nail Design (Sheet 1 of 2)

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Part B - Design Amendments and Site Inspection Records

Design Amendments[(1)]	Reasons for Amendments	Designed by (name & post)	Initial (+ Date)	Checked by (name & post)	Initial (+ Date)

Post-construction Design Review Recommended: ☐ Yes ☐ No
If yes, give actions to be taken (e.g. site inspection after heavy rainstorms to check adequacy of surface or subsurface drainage measures installed for a period covering an intense rainstorm). _____
_____

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

Works commenced on	Works completed on	Works certified by (Name & Post)
_____	_____	_____

Figure 13 - Indicative Record Sheet for Prescriptive Soil Nail Design (Sheet 2 of 2)

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APPENDIX A

DERIVATION OF PRESCRIPTIVE DESIGN GUIDELINES

CONTENTS

A.1 DERIVATION OF THE PRESCRIPTIVE SOIL NAIL DESIGN GUIDELINES FOR CONCRETE/MASONRY RETAINING WALLS

A.1.1 General

Guidelines for prescriptive design of soil nails for soil cut slopes are given in MMBP & VLA (1999). These guidelines form the framework for the derivation of prescriptive soil nail designs for upgrading concrete/masonry retaining walls. As such, the basis of the prescriptive soil nails for soil cut slopes is outlined here for ease of reference. The current standard prescriptive soil nail layout for soil cut slopes was based on 469 data sets of soil nailed slopes. It is also based on the required range of increase in factor of safety (ΔFOS) for the slope to be upgraded and the maximum effective height of the slope (H_e). The three ranges of ΔFOS for the slope using prescriptive soil nail design are categorized as below:

- Range A for a large ΔFOS ($0.3 < \Delta FOS \leq 0.5$)
- Range B for a medium ΔFOS ($0.1 < \Delta FOS \leq 0.3$)
- Range C for a small ΔFOS ($0 < \Delta FOS \leq 0.1$)

According to MMBP & VLA (1999), for each required range of ΔFOS for the cut slopes, the approach of developing prescriptive soil nail design line involved adopting an upper bound design envelope for the total soil nail length per metre run. The prescriptive design for the nail density was then obtained by fixing the prescriptive design value for nail length. Figures A1 and A2 show the upper bound design envelopes in terms of total nail length and nail length plotted against effective height of the slopes respectively. These envelopes form the basis for the prescriptive design guidelines for concrete and masonry retaining walls.

A.1.2 Data Used for Deriving the Prescriptive Design Guidelines for Concrete/Masonry Retaining Walls

Designs of 80 CR and R features involving mass concrete, reinforced concrete or masonry retaining walls which were upgraded by soil nails have been reviewed in this study. As more than one cross-section have been analysed in a few features, a total number of 113 data sets have been studied.

In the review, 71 data sets coming from 51 features are found with exceptional situations which render these cases not suitable for use in deriving the prescriptive design line. The features and the reasons for rendering the features not suitable for use are listed in Table A1. These cases primarily involve the following situations:

(i) soil nails and skin walls were used together as upgrading measures for the features,

(ii) the maximum range of increase in factor of safety (ΔFOS) was exceeded, and

(iii) adverse geological features or groundwater conditions were present.

Forty-two data sets coming from 29 features reviewed have been found suitable for use in deriving the prescriptive design guidelines. The number of data sets under each category are shown in the table below. The details of the features are contained in Tables A2 and A3.

Types of Walls	R/CR Features	No. and Category of Data Sets	
		Government slopes with upgrading works designed by the GEO or consultants under the LPM Programme (up to August 2003)	Private slopes issued with Dangerous Hillside Orders with upgrading works designed by consultants (up to August 2003)
Mass Concrete Retaining Wall	R Features	5	1
	CR Features	6	8
Reinforced Concrete Retaining Wall	R Features	3	-
	CR Features	1	-
Masonry Retaining Wall	R Features	12	-
	CR Features	6	-
	Total:	33	9

For the purpose of derivation of the prescriptive soil nail design for CR/R features involving concrete/masonry retaining walls, the total length of a soil nail, L, of the data sets of the features studied is considered to be composed of the following components:

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

where L_{free} = Length of the portion of soil nail within retaining wall and fill layer (m)
L_s = Length of the portion of soil nail in material behind the fill and retaining wall (m)

A.1.3 CR Features

It is considered that soil nailed CR features behave like nailed cut slopes. In the cases reviewed which involved upgrading of CR features with soil nails, the nailed CR features were all designed in the same way as that for nailed cut slopes. Hence the three ranges of ΔFOS for prescriptive nailed soil cut slopes can also be applied to nailed CR features.

Using the data sets of CR features, the following plots were prepared for each of the three ΔFOS ranges:

(i) total soil nail length in material behind the fill and retaining wall per metre run, $L_{s(Total)}$, versus the effective feature height, and

(ii) average length of the portion of soil nail in material behind the fill and retaining wall, $L_{s(Average)}$, versus the effective feature height.

In these plots, the portion of length of soil nails in the retaining wall and fill of the CR features, L_{free}, are excluded. The plots form the basis for formulating the prescriptive design guidelines. The following sections discuss the results obtained for each ΔFOS range.

A.1.3.1 ΔFOS within Range A

Eight designs of the features are within this range. Details of the designs are contained in Table A2. Figures A3(a) and A4(a) show the plots of $L_{s(Total)}$ and $L_{s(Average)}$ against maximum effective feature heights respectively. The length of the portion of the soil nail in retaining wall and fill behind, i.e. L_{free}, of the data sets has been discarded. For comparison purpose, the data on nailed soil cut slopes and the prescriptive design lines for total nail length and nail length of soil cut slopes are also plotted in the figures. $L_{s(Average)}$ of the data point originating from Feature No. 11SW-A/CR18 exceeds the prescriptive design value for soil nail length, see Figure A4(a). Since the prescriptive design line of nail length for soil cut slopes is based on the 90^{th} percentile values and the $L_{s(Average)}$ of Feature CR18 exceeds the 90^{th} percentile value by only a small range, this data set is considered suitable for use.

A.1.3.2 ΔFOS within Range B

Thirteen designs of the features are within this range and their details are contained in Table A2. The data are plotted in Figures A3(b) and A4(b) respectively for $L_{s(Total)}$ and $L_{s(Average)}$, together with the data sets for nailed soil cut slopes and the prescriptive design lines. L_{free} of the data sets has been discarded. $L_{s(Average)}$ of the data point originating from Feature No. 7SE-B/CR2 slightly exceeds the prescriptive design value for soil nail length, see Figure A4(b). Since the prescriptive design line of nail length is based on 90^{th} percentile values and the $L_{s(Average)}$ value of Feature CR2 exceeds the 90^{th} percentile value by only a small amount, the data set is considered suitable for use.

A.1.3.3 ΔFOS within Range C

Six designs of features fall within this range and their details are contained in Table A2. The data for $L_{s(Total)}$ and $L_{s(Average)}$ are plotted in Figures A3(c) and A4(c) respectively, together with the data sets for nailed soil cut slopes and the prescriptive design lines. L_{free} of the data sets has been discarded. A data point originating from Feature No. 11SW-A/R159 exceeds the prescriptive design value for soil nail length. As discussed in previous sections, the prescriptive design line of nail length is based on the 90^{th} percentile values, the $L_{s(Average)}$ value of Feature R159 is considered suitable for use for deriving the prescriptive design line for CR features.

A.1.3.4 Discussion

The above sections demonstrate that $L_{s(Total)}$ of all data sets of the CR features are below the prescriptive design lines of total nail length derived for soil cut slopes for the three ranges of ΔFOS. They also indicate that, except individual outliers, $L_{s(Average)}$ of the data sets of the CR features also lie below the prescriptive design lines of nail length derived for soil cut slopes. As such, it is considered reasonable and practical to apply the prescriptive soil nail design for cut slopes to CR features with concrete/masonry retaining walls. That means L_s for CR features would be the same as soil nail lengths given in GEO Report No. 56.

A.1.4 R Features

In those cases reviewed that involved upgrading of R features by soil nails, designers normally carried out checks to ensure that the minimum FOS against overturning and sliding of the retaining wall were achieved. The whole nailed R feature can be regarded as a nailed cut slope with a steep facing. In this respect, the prescriptive soil nail design for soil cut slopes would also be applicable to R features with concrete/masonry retaining walls. For masonry wall with slenderness ratio greater than 5 or with dry packed masonry, the wall may not have adequate structural integrity to behave as a single body with the soil nails and the soil mass behind. Hence, a reinforced concrete skin wall should be constructed and it should be attached to the soil nails at the front face of the masonry wall.

To develop the prescriptive design guidelines for R features, $L_{s(Total)}$ and $L_{s(Average)}$ of the R features involving concrete/masonry retaining walls are plotted against effective feature height respectively for each of the two wall standards, i.e. new and existing wall standards. The following sections discuss the results obtained for each of the two standards.

A.1.4.1 New Wall Standard

Five designs of features are found to be upgraded using new wall standard in the study. Details of the designs are contained in Table A3. The data sets for these features are plotted in Figures A5(a) and A6(a) for $L_{s(Total)}$ and $L_{s(Average)}$ respectively. L_{free} of the data sets have been discarded. The prescriptive design lines for soil cut slopes in Range A are also plotted in the two figures for comparison purpose.

A.1.4.2 Existing Wall Standard

Ten designs of features are found to be upgraded using existing wall standard in the study. Details of the designs are contained in Table A3. The data sets for these features are plotted in Figures A5(b) and A6(b) for $L_{s(Total)}$ and $L_{s(Average)}$ respectively. L_{free} of the data sets have been discarded. The prescriptive design lines for soil cut slopes in Range B are also plotted in the two figures for comparison purpose.

A.1.4.3 Discussion

As shown in Figures A5(a) and A6(a), all the data sets based on new wall standard are below the prescriptive design lines derived for soil cut slopes in Range A. It is therefore considered adequately safe to adopt the prescriptive soil nail lengths for cut slopes in Range A as given in GEO Report 56 as L_s, (i.e. the length of portion of soil nail in material behind the retaining wall and fill) for upgrading R features with concrete/masonry retaining walls using new wall standard.

Similarly, as shown in Figures A5(b) and A6(b), the data sets based on existing wall standard are below the prescriptive design lines derived for soil cut slopes in Range B. It is considered reasonable to adopt the prescriptive soil nail lengths for cut slopes in Range B as given in GEO Report 56 as L_s for upgrading R features with concrete/masonry retaining walls using existing wall standard.

A.1.5 Free Length of Soil Nails

A.1.5.1 CR Features

Of the 21 data sets of CR features used for deriving the prescriptive design guidelines, five data sets are found to have fill behind the retaining wall at toe. Figure A7 shows a plot of free length (L_{free}) against retaining height of the wall (H_r) for the 5 data sets which have fill behind the wall of the features. It shows that 2 m is the upper bound of L_{free} for all the CR features with concrete/masonry retaining wall. L_{free} of 2 m is therefore assumed for the prescriptive design for CR features. Such assumption is considered reasonable since the extent of fill behind the toe retaining wall of a CR feature is expected to be limited or even absent once the qualifying criteria on the height and depth of fill above the wall are satisfied. Also in the data sets reviewed, majority of the heights of the toe wall of CR features are less than 4 m, the extent of fill behind the wall is also expected to be limited. The assumption is further supported by the small number of data sets of the CR features with fill present (5 out of the total 21 data sets of CR features).

A.1.5.2 R Features

Figure A8 shows a plot of L_{free} against H_r of R features which have fill behind the walls. The data was found to be below an upper bound envelope set at $L_{free} = H_r$. Therefore the assumption of $L_{free} = H_r$ is used for the prescriptive design for R features. The L_{free} derived for R features is larger than that for CR features. This is reasonable since the fill behind a R feature is expected to be in a larger extent than in CR features.

A.2 DETAILS OF SOIL NAIL HEADS AND WALL FACING TO BE USED ON EXISTING WALL FACE

Table A4 summarizes details of the types of soil nail heads and wall facings for soil nails used in the cases reviewed. Based on this information, typical details of these anchorage types for use in the prescriptive design have been developed and are shown in Figures 9 to 12 of this report.

A.3 REFERENCES

GCO (1984). Geotechnical Manual for Slopes. (Second edition). Geotechnical Control Office, Hong Kong, 301 p.

MMBP & VLA (1999). Development of Improved Guidelines for Prescriptive Soil Nail Design. Final Report submitted to the Geotechnical Engineering Office under Consultancy Agreement no. GEO 13/97.

Wong, H.N., Pang, L.S., Wong, A.C.W., Pun, W.K. & Yu, Y.F. (1999). GEO Report No. 56, Second Edition - Application of Prescriptive Measures to Slopes and Retaining Walls. Geotechnical Engineering Office, Hong Kong, 73 p.

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Table A1 - List of Features with Concrete/Masonry Retaining Walls not Suitable for Use in Deriving Prescriptive Design Guidelines (Sheet 1 of 2)

Feature No.	No. of Sections Analyzed	Location	Reasons for not Being Suitable for Use
11SW-A/R650	2	68-70, Conduit Road	Drillhole diameter of soil nail between 120 and 150 mm > normal practice of 75 mm or 100 mm
11SW-A/CR241	1	48-52 South Lane, Sai Ying Pun	
11SW-B/CR181	2	7C Bowen Road	
15NE-C/R7	5	57-63, Chung Hom Kok Road	
11SE-A/R438	2	Hospital Road	Angle of slope in front of wall, α , > 10°
11SE-C/R200	3	Mount Butler Road	
11SW-A/R384	1	Robinson Road	
11SW-B/R459	1	78-80, Macdonnell Road	
11SW-D/R272	1	Borrett Road	
11SW-D/R89	2	Junction of Guildford Road and Peak Road	
11SW-D/CR30	1	Lingnan Secondary School, Stubbs Road	Adversely high design groundwater level used
14NW-D/CR38	1	Hillside Road, Cheung Chau	Adverse geology: residual soil being the major slope-forming material
15NW-B/CR72	2	Ocean Park, Wong Chuk Hang Road	Deep-seated slips analyzed in the study considered not practical
7SE-D/CR197	1	Ho Chung Road, Sai Kung	Presence of extensive amount of fill above retaining wall
8SW-C/CR92	1	Tsiu Hang Village, Sai Kung	
11NE-B/CR604	2	Clear Water Bay Road	
11SW-A/CR190	2	University Drive	
11SW-A/R452	1	Jockey Club Clinic, Queen's Road West	
11SW-A/R79	1	Bridges Street	
11SW-D/CR1218	1	Lloyd Path, the Peak	
11SW-D/CR311	2	Magazine Gap Road	
11SW-D/R90	1	Junction of Guildford Road and Peak Road	
12SW-A/CR169	1	Ha Yeung New Village, Clear Water Bay	
12SW-A/CR4	1	Ha Yeung New Village, Clear Water Bay	
9SE-C/CR43	1	Po Lin Monastery, Lantau Island	No information on design available
11SE-D/CR61	3	Tai Tam Road	Effective Height > 25 m

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Table A1 - List of Features with Concrete/Masonry Retaining Walls not Suitable for Use in Deriving Prescriptive Design Guidelines (Sheet 2 of 2)

Feature No.	No. of Sections Analyzed	Location	Reasons for not Being Suitable for Use
7SE-C/CR254	2	To Shek Village, Shatin	ΔFOS > 0.5
7SE-D/CR46	1	Luk Mei Tsuen, Sai Kung	
7SW-B/CR343	1	Pai Tau Village, Shatin	
8SW-C/CR161	1	Po Lo Che, Sai Kung	
8SW-C/CR35	1	Sai Kung	
11NE-B/CR518	1	Nam Wai, Sai Kung	
11NE-C/CR223	1	55, Kung Lok Rd, Kwun Tong	
12NW-B/CR1	1	Kau Sai Village, Sai Kung	
12NW-C/CR368	1	Mang Kung Uk, Sai Kung	
12SW-A/CR169	1	Ha Yeung New Village, Clear Water Bay	
12SW-A/CR3	1	Ha Yeung New Village, Clear Water Bay	
7NW-B/CR441	1	Pan Chung Village, Tai Po	Retaining wall upgraded by both soil nails and thickening
7SE-C/CR399	1	Kong Pui Tsuen, Kwun Yam Shan	
7SE-D/CR197	1	Kai Ham Village, Ho Chung Road, Sai Kung	
11NE-D/CR585	2	Mau Wu Tsai Village, Tseung Kwan O	
11SW-A/R109	1	Seymour Road	
11SW-A/R497	1	Hollywood Road	
11SW-B/R516	1	Borrett Road	
11SW-D/R367	1	Lingnan Secondary School, Stubbs Road	
11SW-D/R1043	1	98A-100 Kennedy Road	
14NE-B/C185	1	Yung Shue Long New Village, Lamma Island	
14NE-B/R8	3	Po Wah Yuen, Lamma Island	
14NE-B/R119	1	Po Wah Yuen, Lamma Island	
14NW-D/CR212	1	Lung Tsai Tsuen Road, Cheung Chau	
15NE-B/R2	1	Shek O Road	

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Table A2 - List of Features with Concrete/Masonry Retaining Walls Selected for Deriving the Prescriptive Design Guidelines for CR Features (Sheet 1 of 2)

Range A

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
6SW-D/CR432	Tai Lam Correctional Institution	1	Section A-A	Mass Concrete Wall	Government	17.33	45	12.86
11NE-B/CR719	Tseng Lan Shue, Sai Kung	1	Section 1-1	Mass Concrete Wall	Government	9.11	24.33	7.3
11SW-A/CR18	62A-F, Conduit Road	1	Section B-B	Mass Concrete Wall	Private	8.03	20	10
11SW-B/CR155	42 Kennedy Road	3	Section 1-1	Mass Concrete Wall	Government	7.37	18	5.4
			Section 2-2	Mass Concrete Wall	Government	6.96	19.33	5.8
			Section 3-3	Mass Concrete Wall	Government	7.16	22.67	5.67
11SW-D/CR152	Shouson Hill Road	1	Section 3-3	Mass Concrete Wall	Private	7.48	5	7.5
11SW-D/CR439	2 Stubbs Road	1	Section B-B	Masonry Wall	Government	12.42	22	6.6

Range B

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
7SE-B/CR2	Wong Chuk Shan San Chuen, Sai Kung	3	Section 2-2	Masonry Wall	Government	8.25	5.25	5.25
			Section 5-5	Masonry Wall	Government	14.38	22	11
			Section 6-6	Masonry Wall	Government	15.09	33.33	10
11SE-A/R39	Sir Ellis Kadoorie School, So Kon Po	1	Section A-A	Masonry Wall	Government	9.64	10.5	3.78
11SW-A/R159	Buxey Lodge, Conduit Road	1	Section C-C	Masonry Wall	Government	15.99	16.2	10.8
11SW-A/R227	Chater Hall, 1 Conduit Road	1	Section 1-1	Masonry Wall	Government	15.66	18.16	7.57
11SW-A/R446	Leung Kau Kui College, Hospital Road	1	Section 1-1	Mass Concrete Wall	Government	12.17	15	10

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Table A2 - List of Features with Concrete/Masonry Retaining Walls Selected for Deriving the Prescriptive Design Guidelines for CR Features (Sheet 2 of 2)

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
11SW-B/R311	Between Magazine Gap Road and May Road	1	Section 1-1	Masonry Wall	Government	4.19	6.67	5
11SW-C/CR56	Wah Sang House, Wah Fu Estate	1	Section 1-1	RC Wall	Government	17.83	37.35	10.67
11SW-C/CR203	56-62, Mount Davis Road	3	Section 1-1	Mass Concrete Wall	Private	11.66	12	8
			Section 3-3	Mass Concrete Wall	Private	15.82	36	10.8
			Section 4-4	Mass Concrete Wall	Private	13.96	21	10.5
11SW-D/CR152	Shouson Hill Rd	1	Section 4-4	Mass Concrete Wall	Private	7.18	5.2	7.8

Range C

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
8SW-C/CR 145	Sun King Terrace, Sai Kung	1	Section 1-1	Mass Concrete Wall	Government	3.16	3.5	3.5
11SW-C/CR203	56-62, Mount Davis Road	1	Section 5-5	Mass Concrete Wall	Private	20.56	21	10.5
7SE-B/CR2	Wong Chuk Shan San Chuen, Sai Kung	1	Section 3-3	Masonry Wall	Government	9.65	5.25	5.25
11SW-A/R159	Buxey Lodge, Conduit Road	3	Section A-A	Masonry Wall	Government	11.01	10.4	10.4
			Section B-B	Masonry Wall	Government	13.04	14.6	9.73
			Section D-D	Masonry Wall	Government	15.75	21.2	10.6

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Table A3 - List of Features with Concrete/Masonry Retaining Walls Selected for Deriving the Prescriptive Design Guidelines for R Features

New Wall Standard

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
11SW-C/CR201	56-62, Mount Davis Road	1	1-1	Mass Concrete Wall	Private	6.03	5.2	5.2
11SW-C/R171	56-62, Mount Davis Road	1	2-2	Mass Concrete Wall	Private	7.73	4.5	4.5
11SW-C/R15	Queen Mary Hospital	3	Section E-E	Mass Concrete Wall	Government	7.53	8.75	3.5
			Section F-F	Mass Concrete Wall	Government	6.53	2.625	3.5
			Section G-G	Mass Concrete Wall	Government	5.23	4.25	4.25

Existing Wall Standard

Feature No.	Location	No. of Sections Analyzed	Section No.	Wall Type	Government/ Private?	Effective Height, H_e (m)	Total Nail Length/m Run, $L_{s(Total)}$ (m)	Nail Length, $L_{s(Average)}$ (m)
11SW-D/R89	Junction of Guildford Road and Peak Road	2	Section 2-2	RC Wall	Government	11.37	8.1	4.97
			Section 4-4	RC Wall	Government	7.11	8.7	8
11SW-D/R194	17 Kennedy Street, Wan Chai	1	Section 1-1	Mass Concrete Wall	Government	8.06	4.33	6.5
11SW-A/R80	Bridges Street	1	Section 1-1	Masonry Wall	Government	13.26	15.1	4.3
11SW-A/R385	Robinson Road	1	Section 3-3	Masonry Wall	Government	15.21	2.8	1.8
11SW-A/R602	Between Lyttelton Road and Babington Path	3	Section A-A	Random Rubble Wall	Government	4.59	2	1.2
			Section B-B	Random Rubble Wall	Government	6.39	4.83	1.45
			Section C-C	Masonry Wall	Government	7.69	6	3
11SW-C/CR231	Gough Hill Road, the Peak	1	Section D-D	Masonry Wall	Government	9.36	9.6	7.2

Table A4 - Details of Prescriptive Skin Wall, Tie Beams and Soil Nail Heads (Sheet 1 of 2)

Items		Skin Wall	Tie Beams	Soil Nail Heads
Geometrical Details		Thickness: • 8SW-C/CR145 - 125 mm • 11SW-D/CR152 (2 sections) - 150 mm • 11SW-D/R89 (2 sections) - 400 mm	Cross Sectional Dimension: • 11SW-A/R162 - 340 mm x 200 mm • 11SW-D/R194, 11SW-C/R171 & CR201 - 400 mm x 250 mm	Dimension on wall face x depth: • 11SW-C/R15 - 300 mm dia. x 250 mm inside the existing concrete retaining wall
Dowel Bars	Bar Type and Diameter	• 11SW-D/CR152 (2 sections) - T20 • No dowel bars for other features	• 11SW-A/R162 - HILTI bolts of 12 mm diameter • 11SW-D/R194 - T20 • 11SW-C/R171 & CR201 - Y10	• 11SW-C/R15 - No dowel bars
	Hole Diameter	• 11SW-D/CR152 (2 sections) - No details	• 11SW-A/R162 - No details • 11SW-D/R194 - 50 mm • 11SW-C/R171 & CR201 - No details	
	Bar Spacing	• 11SW-D/CR152 (2 sections) - 200 mm to 500 mm	• 11SW-A/R162 - 200 mm vertical spacing and 2 m horizontal spacing • 11SW-D/R194 - 500 mm horizontal spacing • 11SW-C/R171 & CR201 - 250 mm vertical spacing; 1 m horizontal spacing	
	Bar Inclination	• 11SW-D/CR152 (2 sections) - horizontal	• 11SW-A/R162 - Perpendicular to wall • 11SW-D/R194 - 35° downward to horizontal • 11SW-C/R171 & CR201 - horizontal	
	Anchorage Length	• 11SW-D/CR152 (2 sections) - 150 mm	• 11SW-A/R162 - 110 mm • 11SW-D/R194 - minimum 500 mm • 11SW-C/R171 & CR201 - 75 mm	
	Bend	• 11SW-D/CR152 (2 sections) - 450 mm	• 11SW-A/R162 - Nil • 11SW-D/R194 - J-bend without dimensions • 11SW-C/R171 & CR201 - Nil	

Table A4 - Details of Prescriptive Skin Wall, Tie Beams and Soil Nail Heads (Sheet 2 of 2)

Items		Skin Wall	Tie Beams	Soil Nail Heads
Reinforced Concrete	Reinforcement	• 8SW-C/CR145 - 1 layer of A252 wire mesh • 11SW-D/CR152 (2 sections) - Front & rear face: T12 at 110 spacing - Longitudinal: T16 at 125 spacing • 11SW-D/R89 (2 sections) - Front & rear face: T25 at 125 spacing - Longitudinal: T20 at 200 spacing	• 11SW-A/R162 - Longitudinal: 4 nos. of T10 - Shear Links: T10 at 250 spacing • 11SW-D/R194 - Longitudinal: 6 nos. of T16 - Shear Links: T16 at 200 spacing • 11SW-C/R171 & CR201 - No details	• 11SW-C/R15 - No reinforcement
	Concrete Grade	• Grade 30	• Grade 30	• Grade 30
Soil Nail End Details in Skin Wall, Tie Beams and Soil Nail Heads		• 8SW-C/CR145 - No details • 11SW-D/CR152 (2 sections) - No details • 11SW-D/R89 (2 sections) - Bend with 500 mm	• 11SW-A/R162 & 11SW-D/R194 - end with 150 mm x 150 mm x 20 mm steel plate and nuts • 11SW-C/R171 & CR201 - end with 175 mm x 175 mm x 20 mm steel plate and nuts, with 3 nos. of U-bars T16 in both ways around nail end.	• 11SW-C/R15 - end with 150 mm x 150 mm x 20 mm steel plate and nuts, with 3 nos. of U-bars T16 in both ways around nail end.

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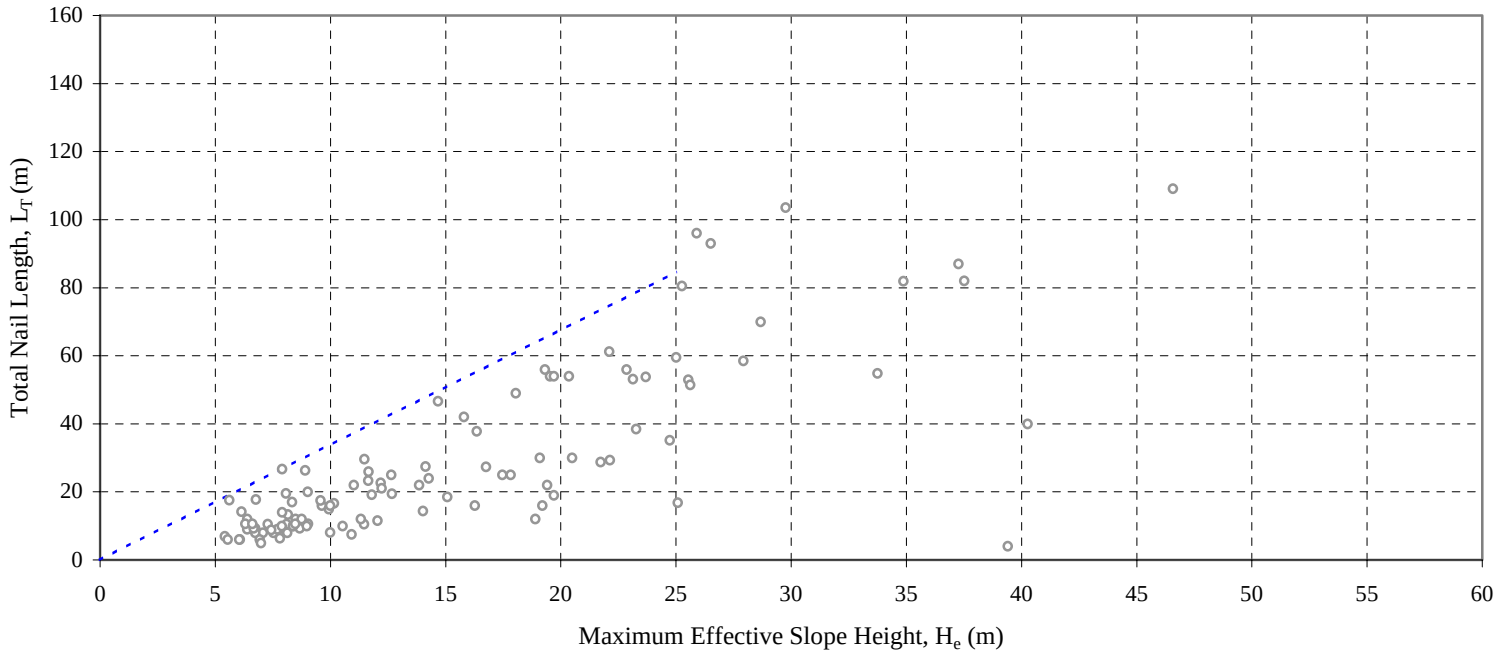


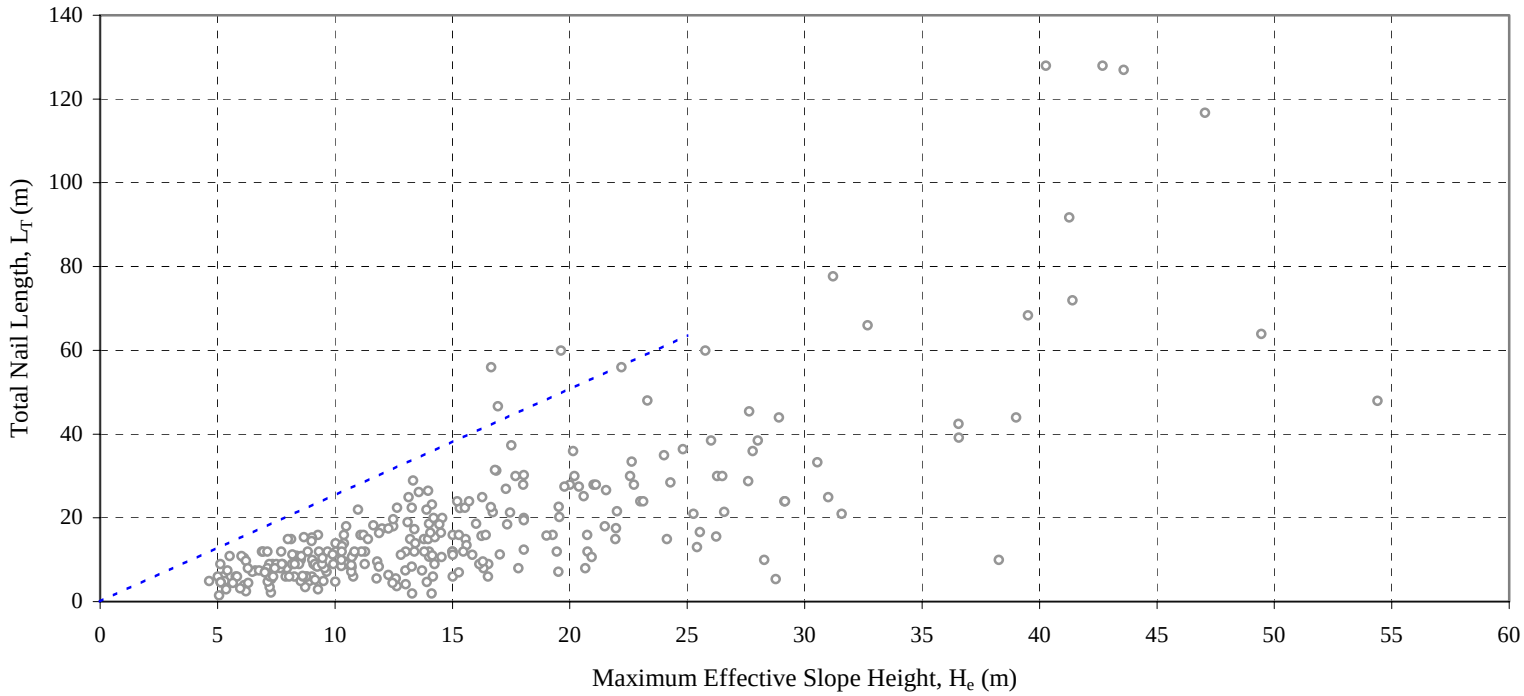
Legend:

○ Cut slope data

------ Upper bound design envelope

Notes:
(1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A1(a) - Total Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range A, i.e. $0.3 \leq \Delta FOS < 0.5$



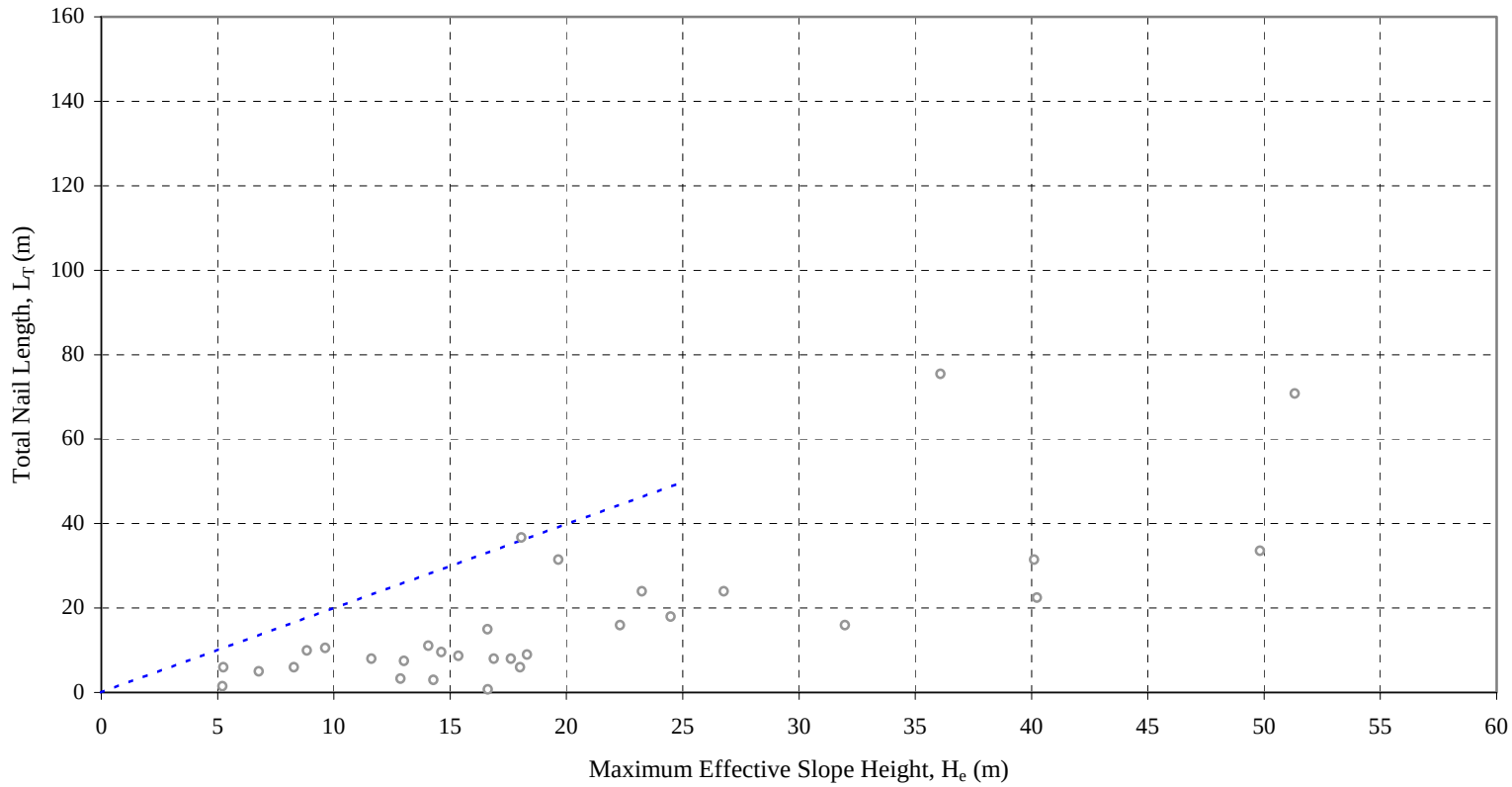
Legend:

○ Cut slope data

------ Upper bound design envelope

Notes: (1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A1(b) - Total Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range B, i.e. $0.1 \leq \Delta FOS < 0.3$



Legend:

○ Cut slope data

------ Upper bound design envelope

Notes:
(1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A1(c) - Total Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range C, i.e. ΔFOS < 0.1

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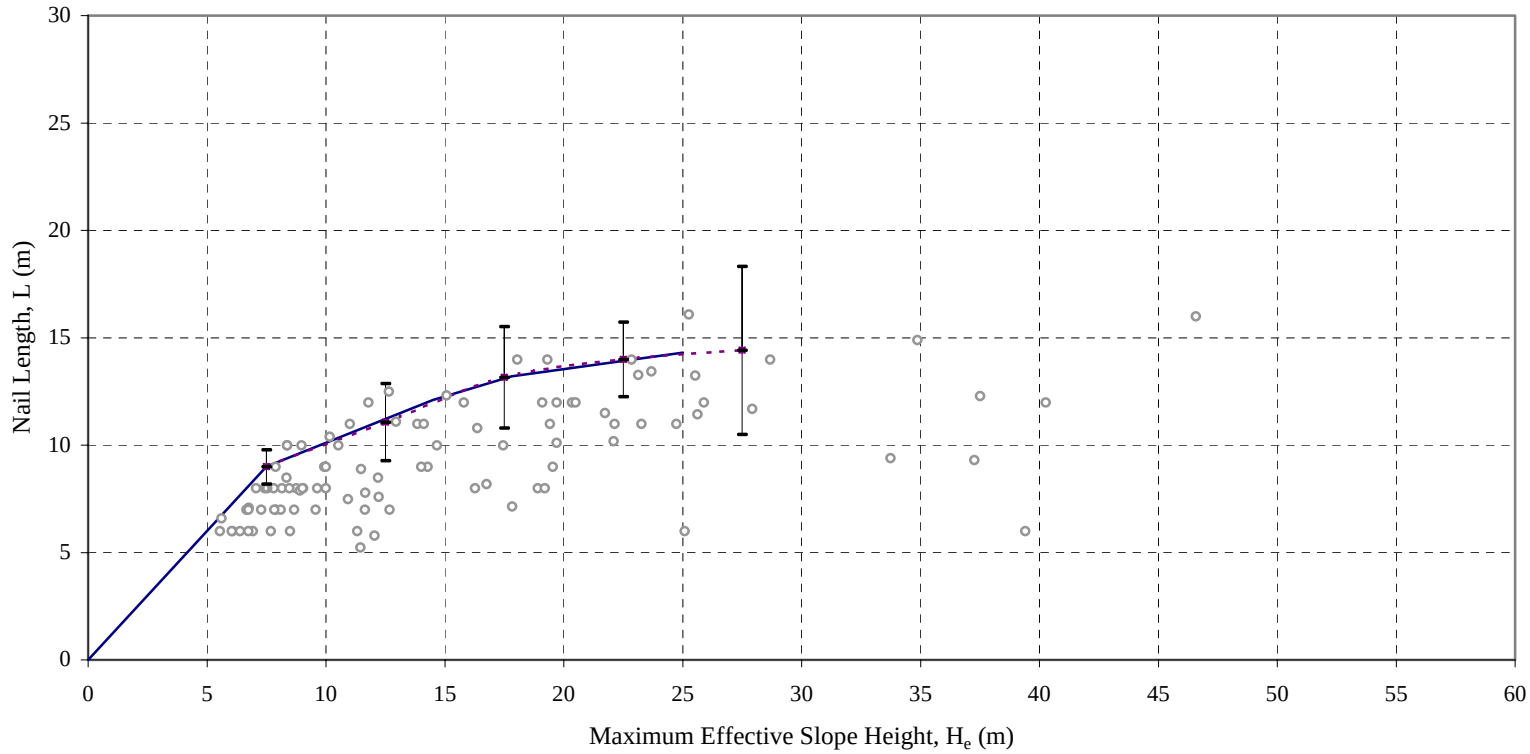

Legend:

Cut slope data — Prescriptive design line for cut slopes — 90% percentile of cut slope data

Notes: (1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A2(a) - Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range A, i.e. $0.3 \leq \Delta FOS < 0.5$

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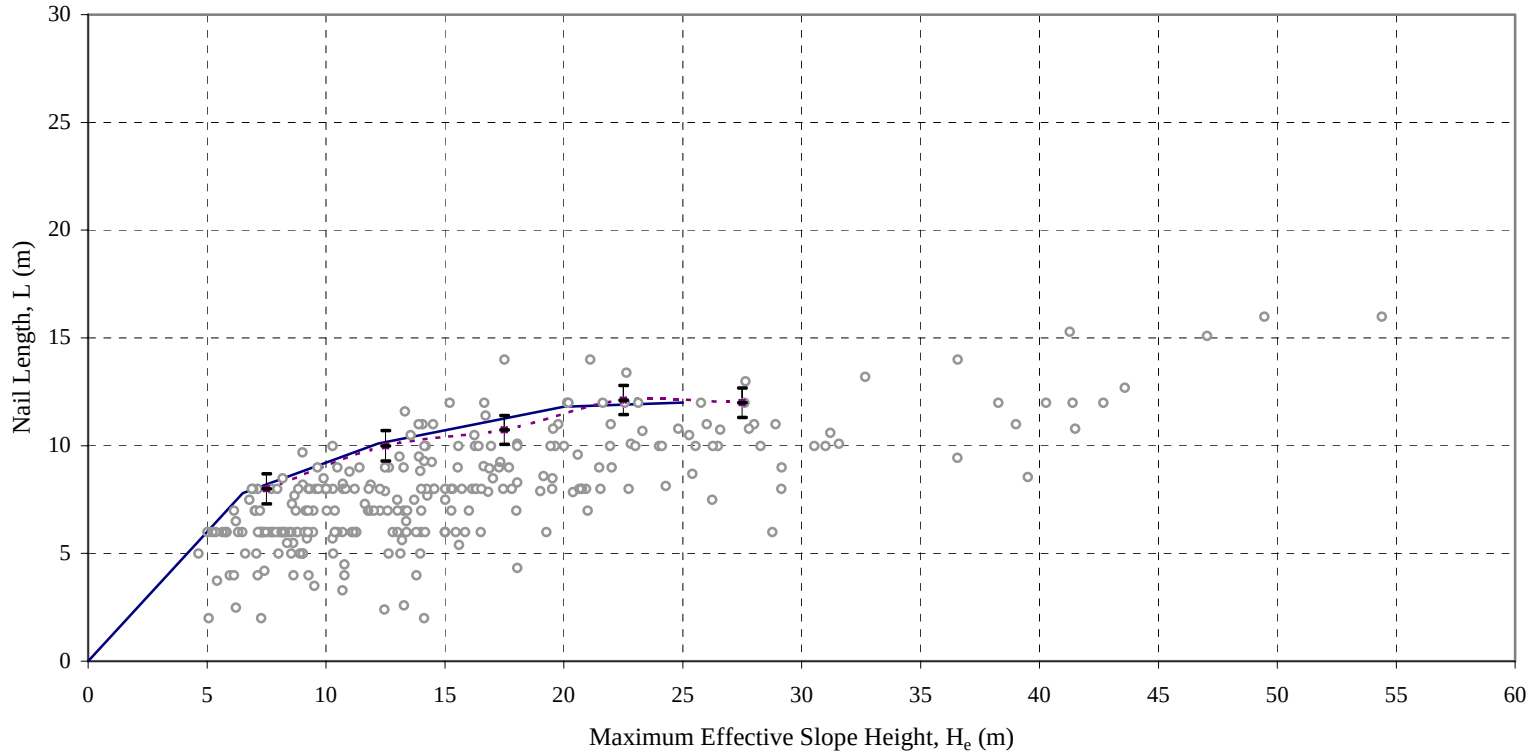
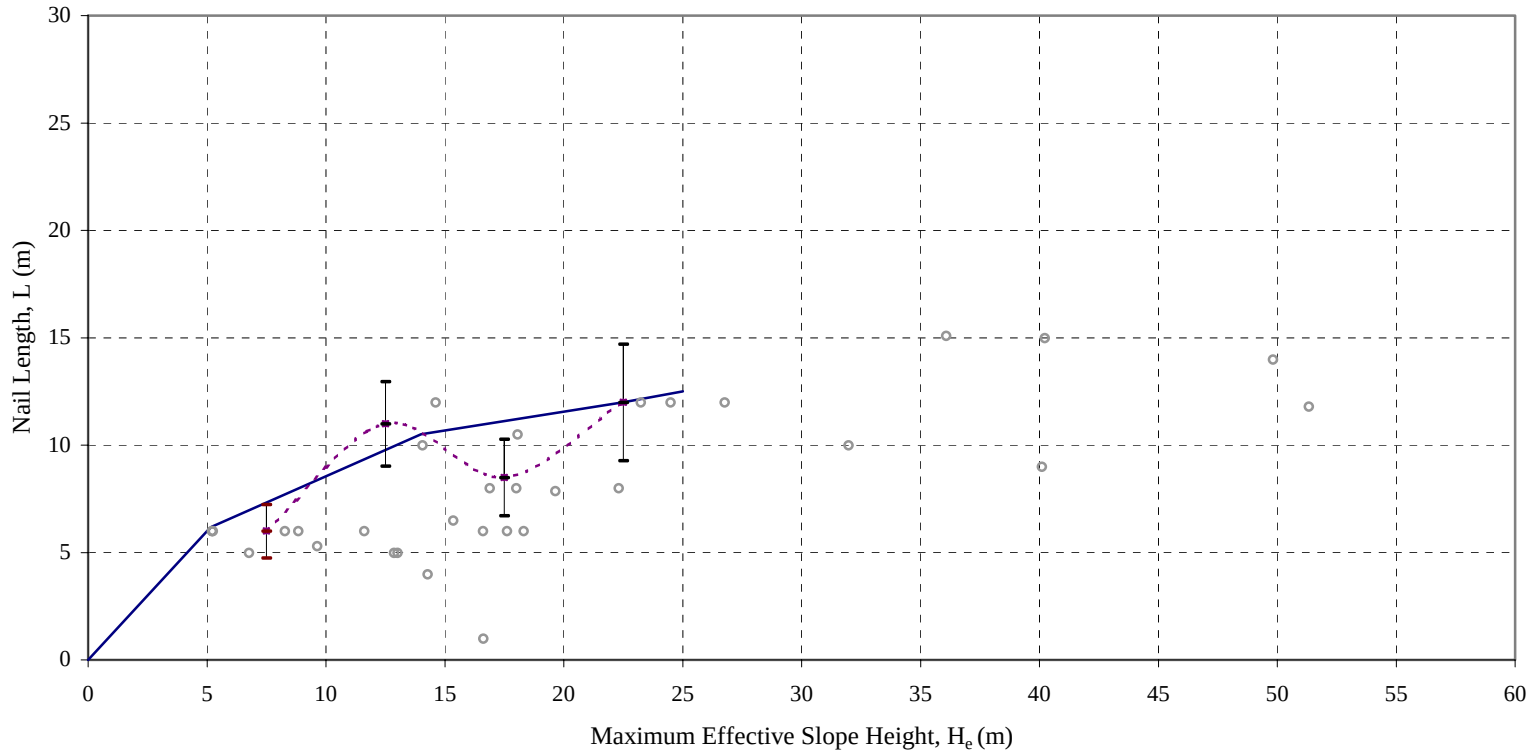


Legend:

Cut slope data — Prescriptive design line for cut slopes — 90% percentile of cut slope data

Notes: (1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A2(b) - Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range B, i.e. $0.1 \leq \Delta FOS < 0.3$

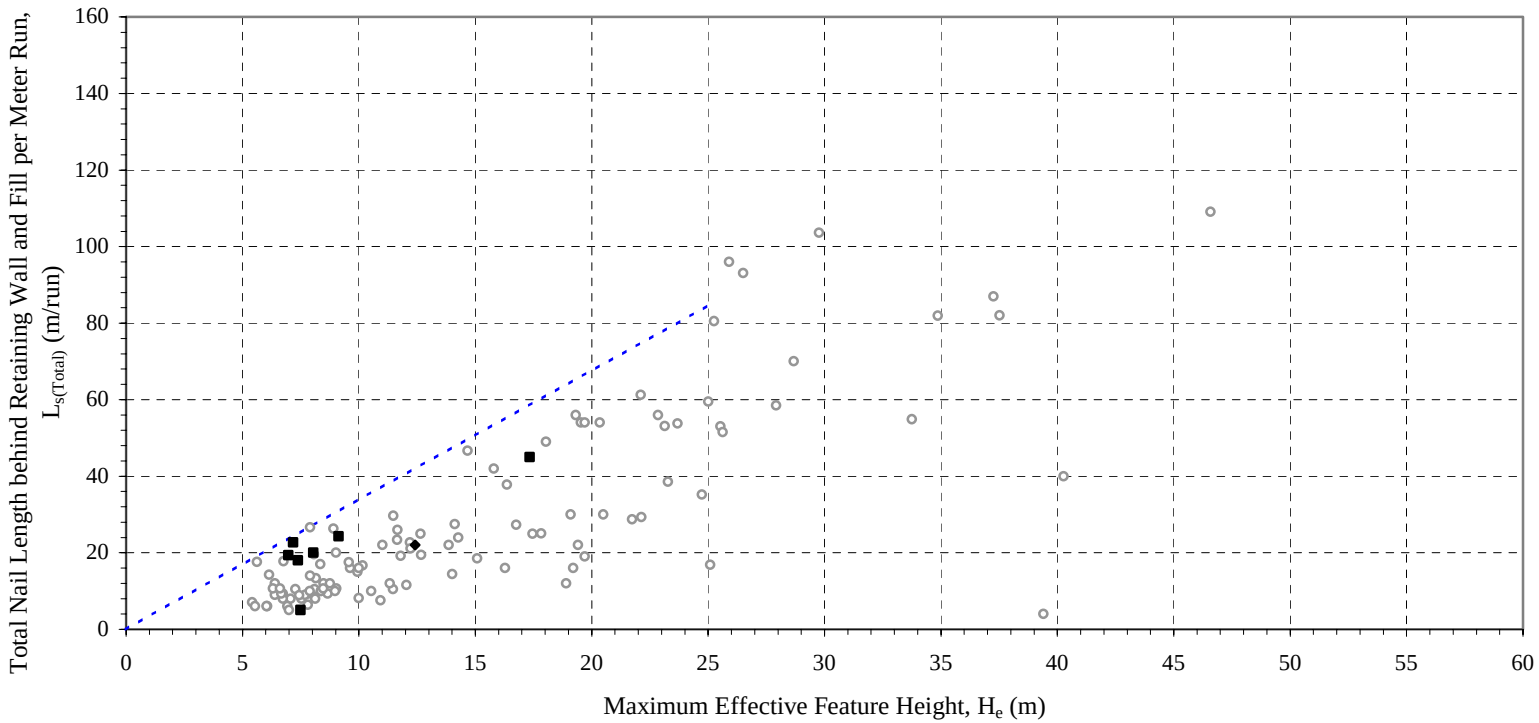


Legend:

Cut slope data — Prescriptive design line for cut slopes — 90% percentile of cut slope data

Notes: (1) The Figure covers all data sets reported in MMBP & VLA (1999) for $1.5 < S_h < 3$ and $75 < D < 100$ and $L/H_e \leq 1.2$.
(2) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A2(c) - Nail Length versus Maximum Effective Slope Height for Cut Slopes in Range C, i.e. $\Delta FOS < 0.1$



Legend:

- Cut slope data reported in MMBNP & VLA (1999)
- Upper bound design envelope for cut slopes (MMBP & VLA, 1999)
- CR Feature data - concrete wall (this study)
- CR Features data - masonry wall (this study)

Notes:
(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A3(a) - Total Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range A, i.e. $0.3 \leq \Delta FOS < 0.5$

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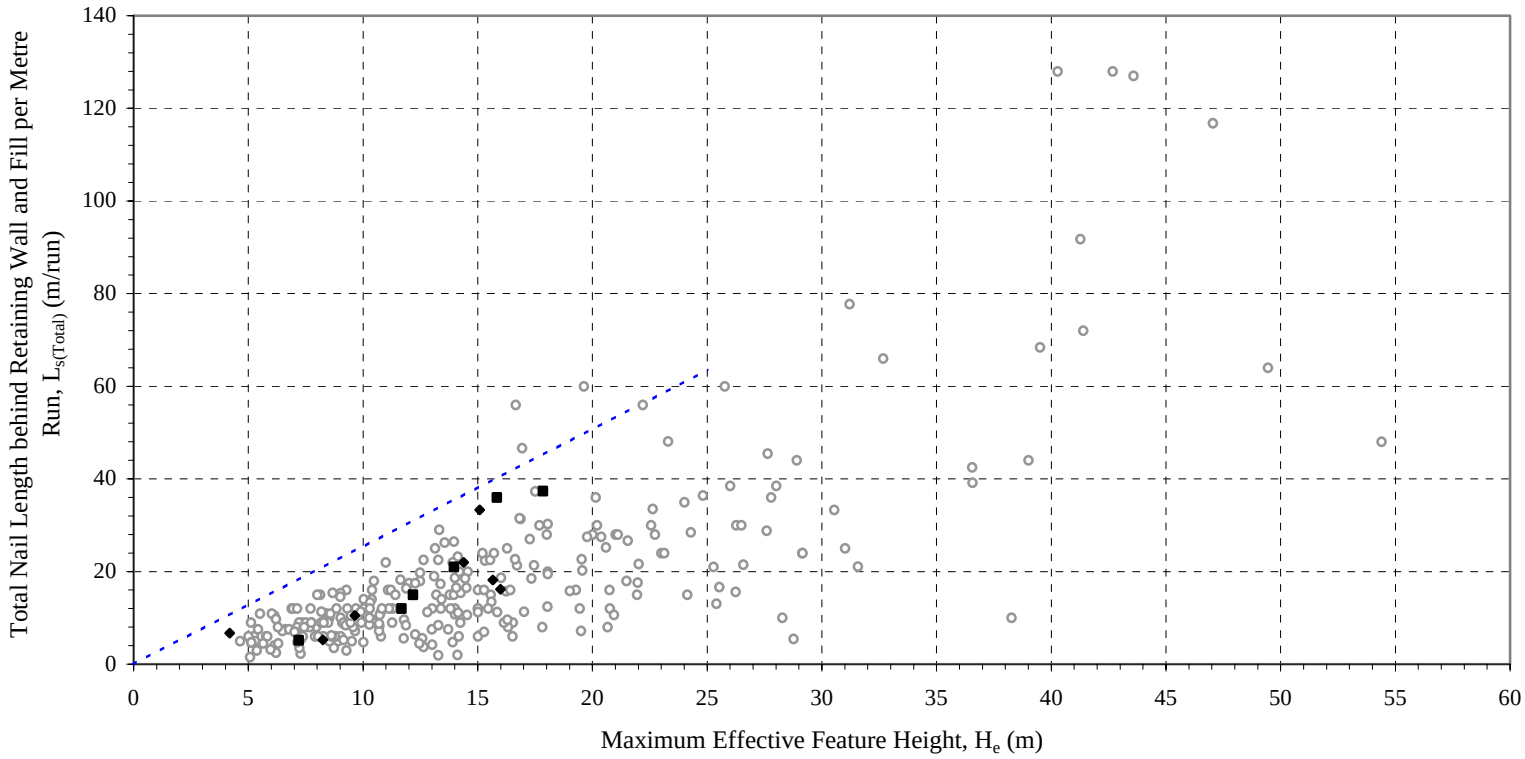

Legend:

- Cut slope data reported in MMBNP & VLA (1999)
- Upper bound design envelope for cut slopes (MMBP & VLA, 1999)
- CR Feature data - concrete wall (this study)
- CR Features data - masonry wall (this study)

Notes:
(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A3(b) - Total Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range B, i.e. $0.1 \leq \Delta FOS < 0.3$

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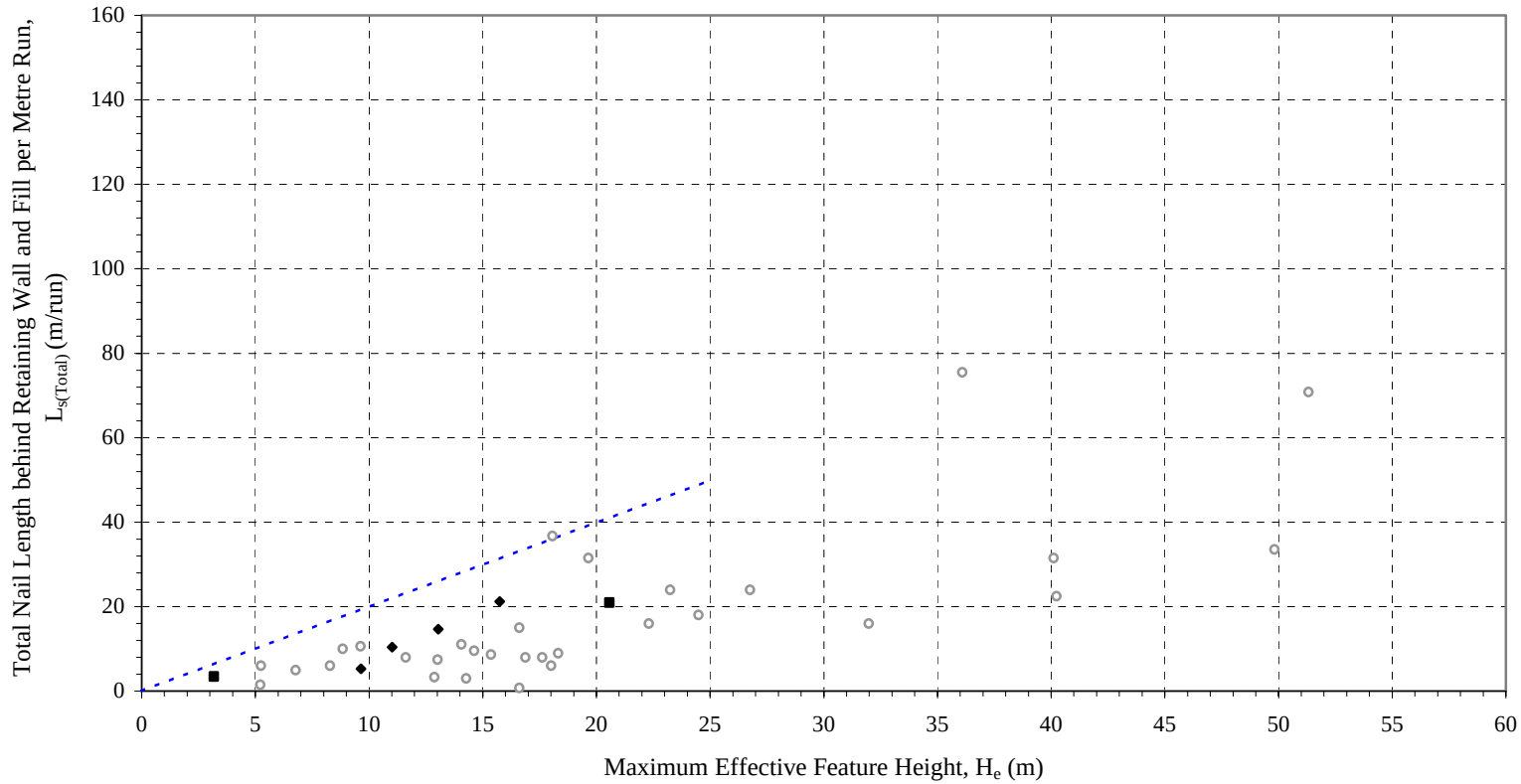

Legend:

- Cut slope data reported in MMBNP & VLA (1999)
- Upper bound design envelope for cut slopes (MMBP & VLA, 1999)
- CR Feature data - concrete wall (this study)
- CR Features data - masonry wall (this study)

Notes:
(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A3(c) - Total Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range C, i.e. ΔFOS < 0.1

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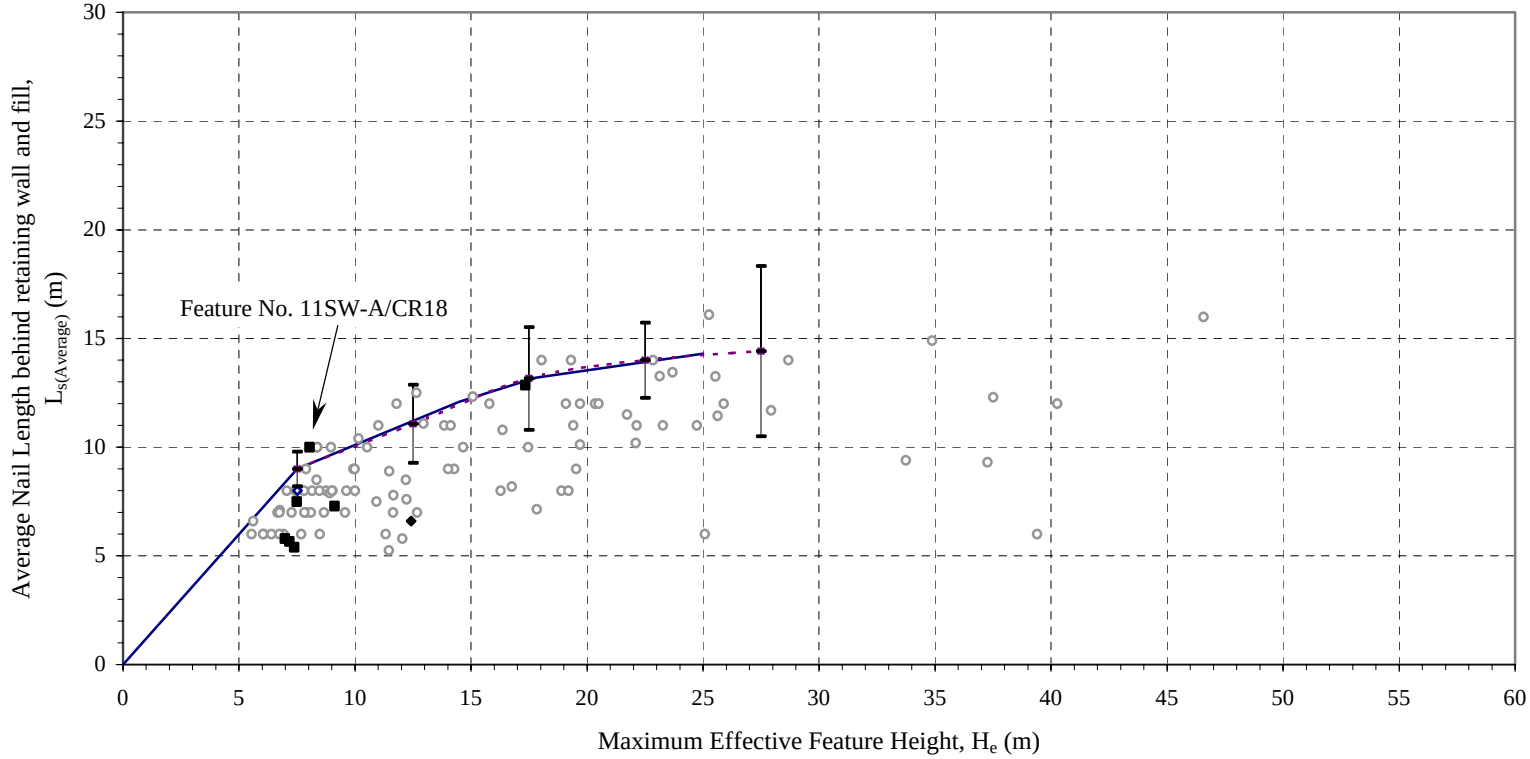

Legend:

- Cut slope data reported in MMBP & VLA (1999)
- CR Feature data - concrete wall (this study)
- 90% percentile for cut slopes (MMBP & VLA, 1999)
- Prescriptive design line for cut slopes (MMBP & VLA, 1999)
- CR Feature data - masonry wall (this study)

Notes:

(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A4(a) - Average Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range A, i.e. $0.3 \leq \Delta F < 0.5$

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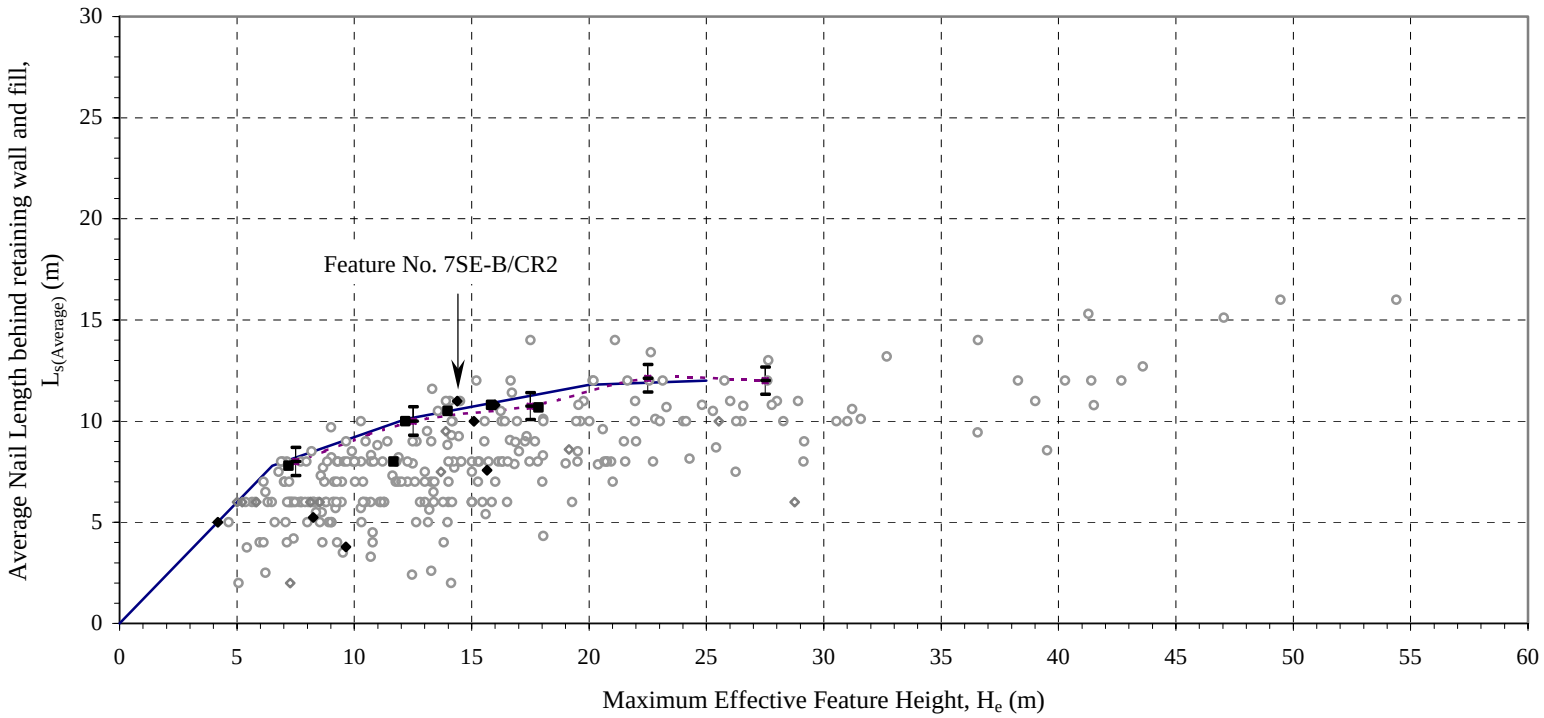

Legend:

- Cut slope data reported in MMBP & VLA (1999)
- CR Feature data - concrete wall (this study)
- 90% percentile for cut slopes (MMBP & VLA, 1999)
- Prescriptive design line for cut slopes (MMBP & VLA, 1999)
- CR Feature data - masonry wall (this study)

Notes:

(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A4(b) - Average Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range B, i.e. $0.1 \leq \Delta FOS < 0.3$

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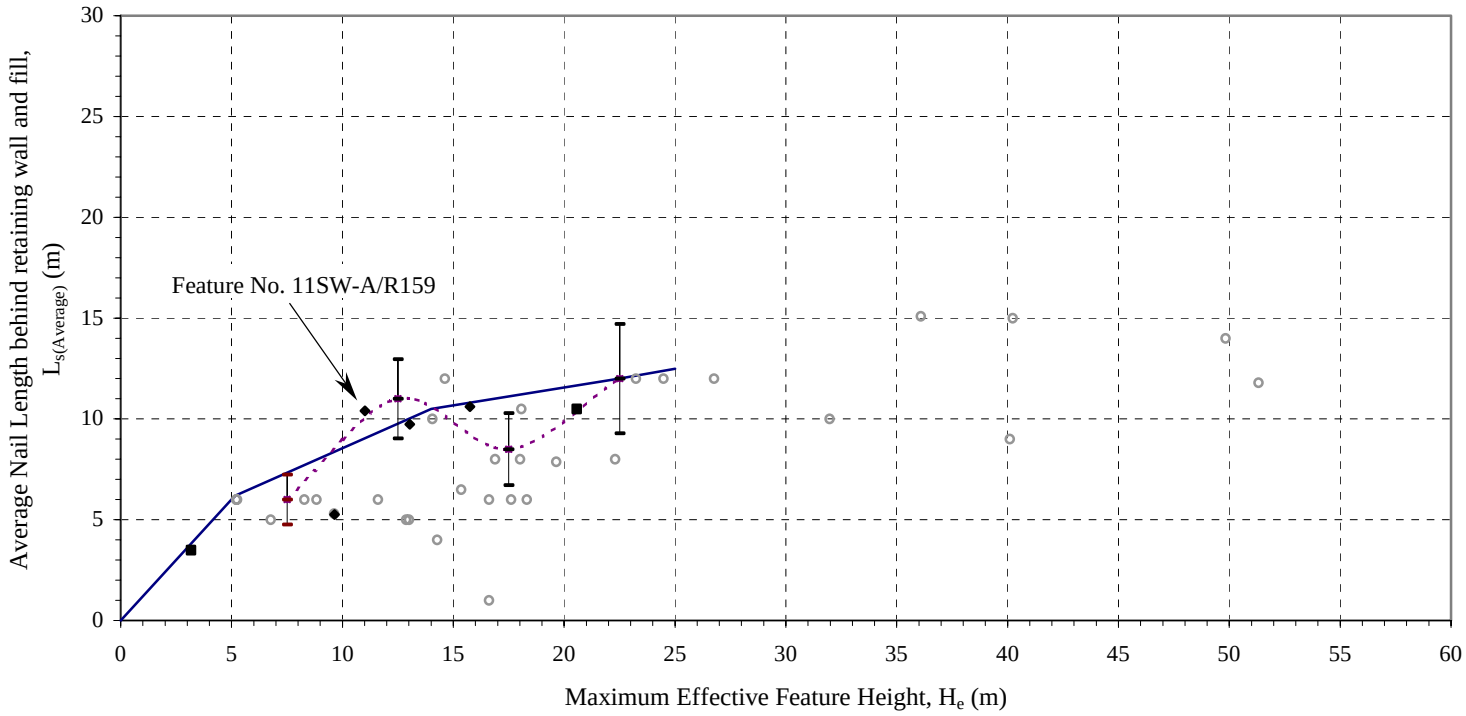

Legend:

- Cut slope data reported in MMBP & VLA (1999)
- CR Feature data - concrete wall (this study)
- 90% percentile for cut slopes (MMBP & VLA, 1999)
- Prescriptive design line for cut slopes (MMBP & VLA, 1999)
- CR Feature data - masonry wall (this study)

Notes:

(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A4(c) - Average Nail Length versus Maximum Effective Feature Height for CR Features and Cut Slopes in Range C, i.e. ΔFOS < 0.1

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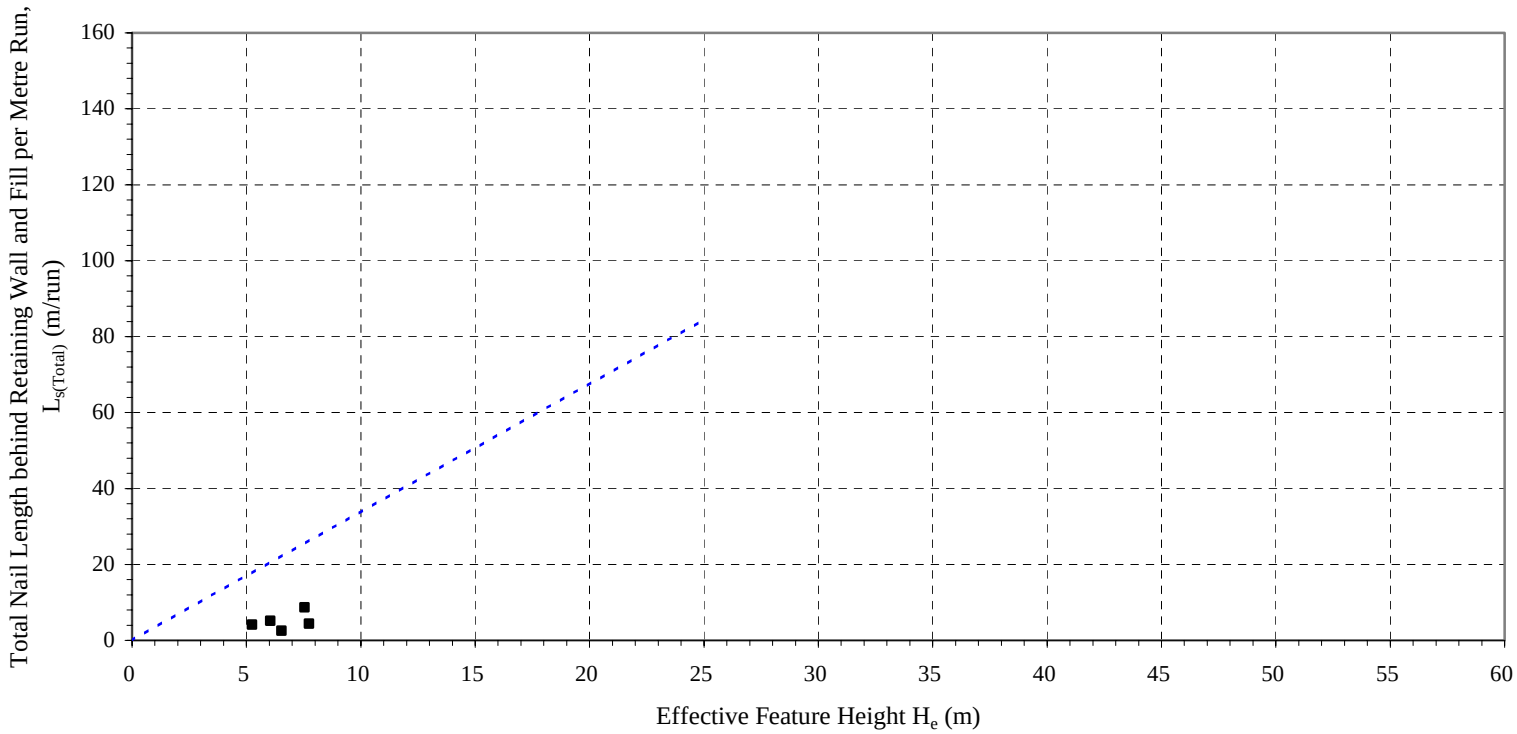

Legend:

■ R Feature data - concrete wall (this study)

Upper bound design envelope for soil cut slopes in GEO Report No. 56

Notes:

(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.

(2) Data standardized to D = 100 mm.

(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A5(a) - Total Nail Length versus Maximum Effective Feature Height for R Features with New Wall Standard

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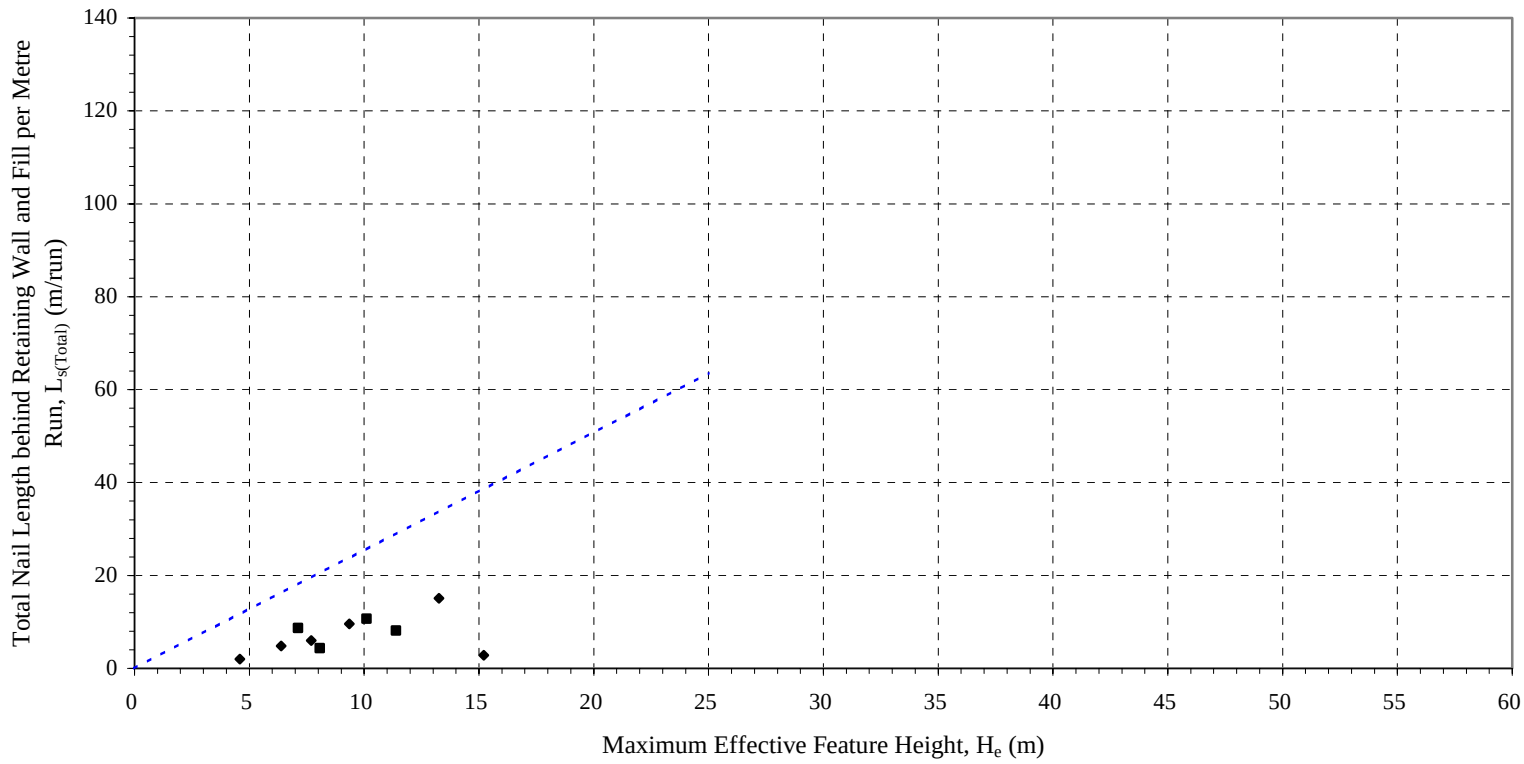

Legend:

- ■ R Feature data - concrete wall (this study)
- ◆ R Feature data - masonry wall (this study)
- ····· Upper bound design envelope for soil cut slopes in range B (MMBP & VLA, 1999)

Notes:

(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A5(b) - Total Nail Length versus Maximum Effective Feature Height for R Features with Existing Wall Standard

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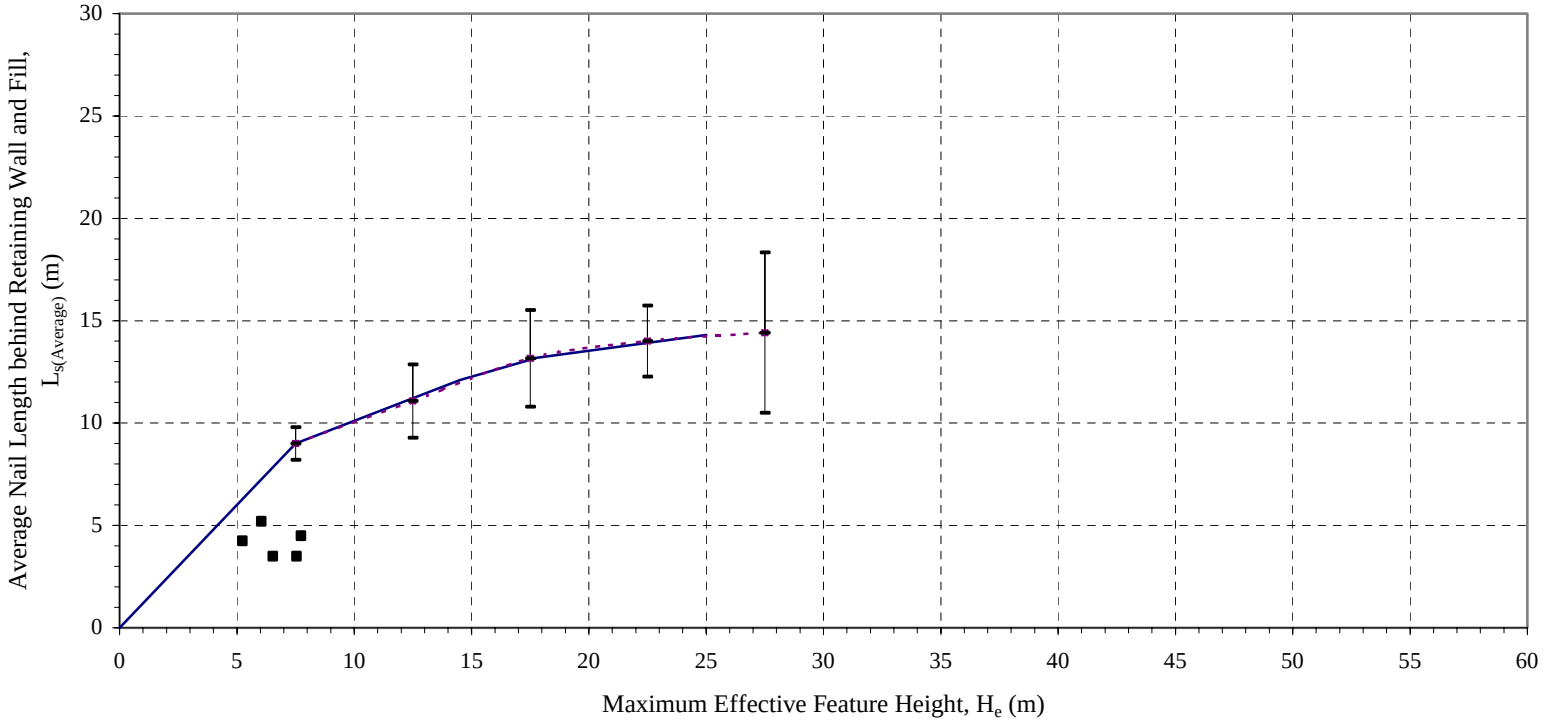


Legend:

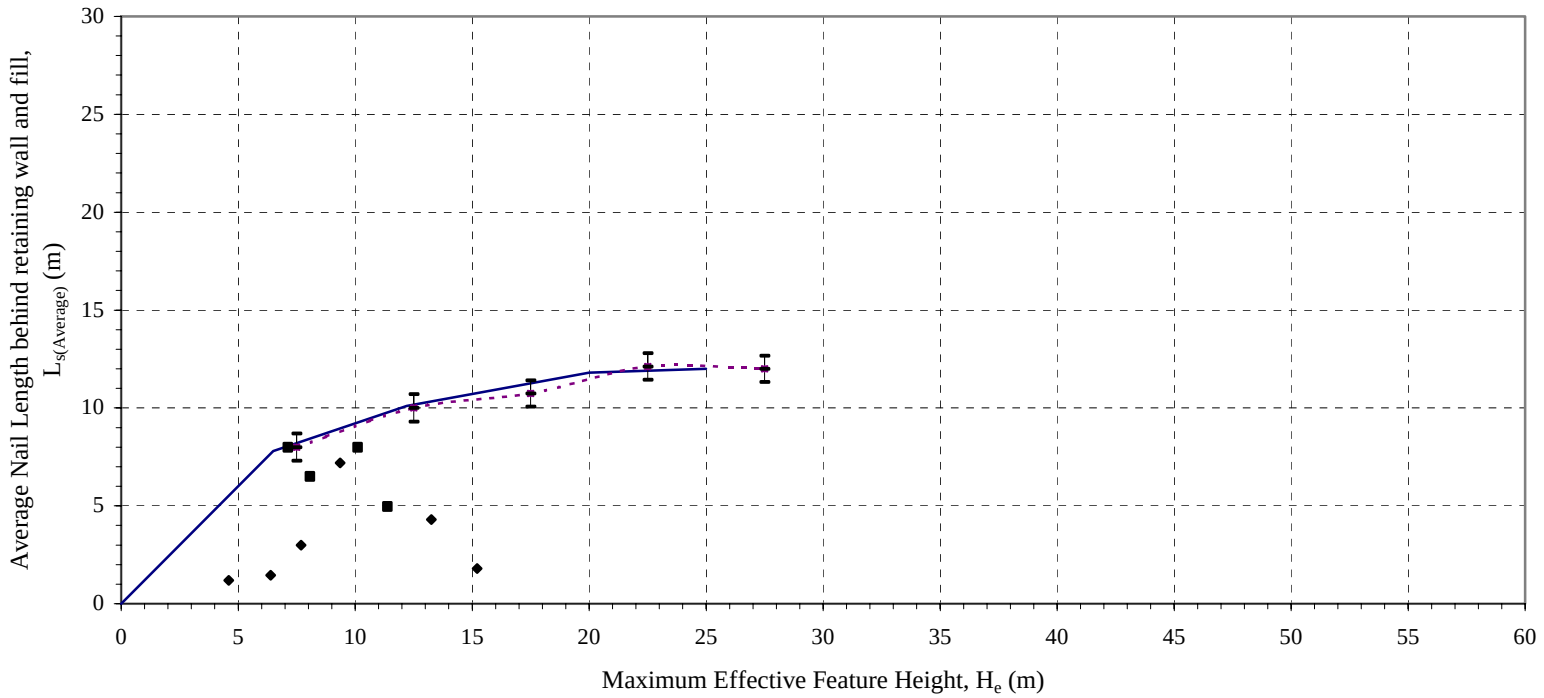
- - ∗ - - 90% percentile of cut slopes (MMBP & VLA, 1999)

——— Prescriptive design line for cut slopes in range A (MMBP & VLA, 1999)

■ R Feature data - concrete wall (this study)

Notes:
(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A6(a) - Average Nail Length versus Maximum Effective Feature Height for R Features with New Wall Standard

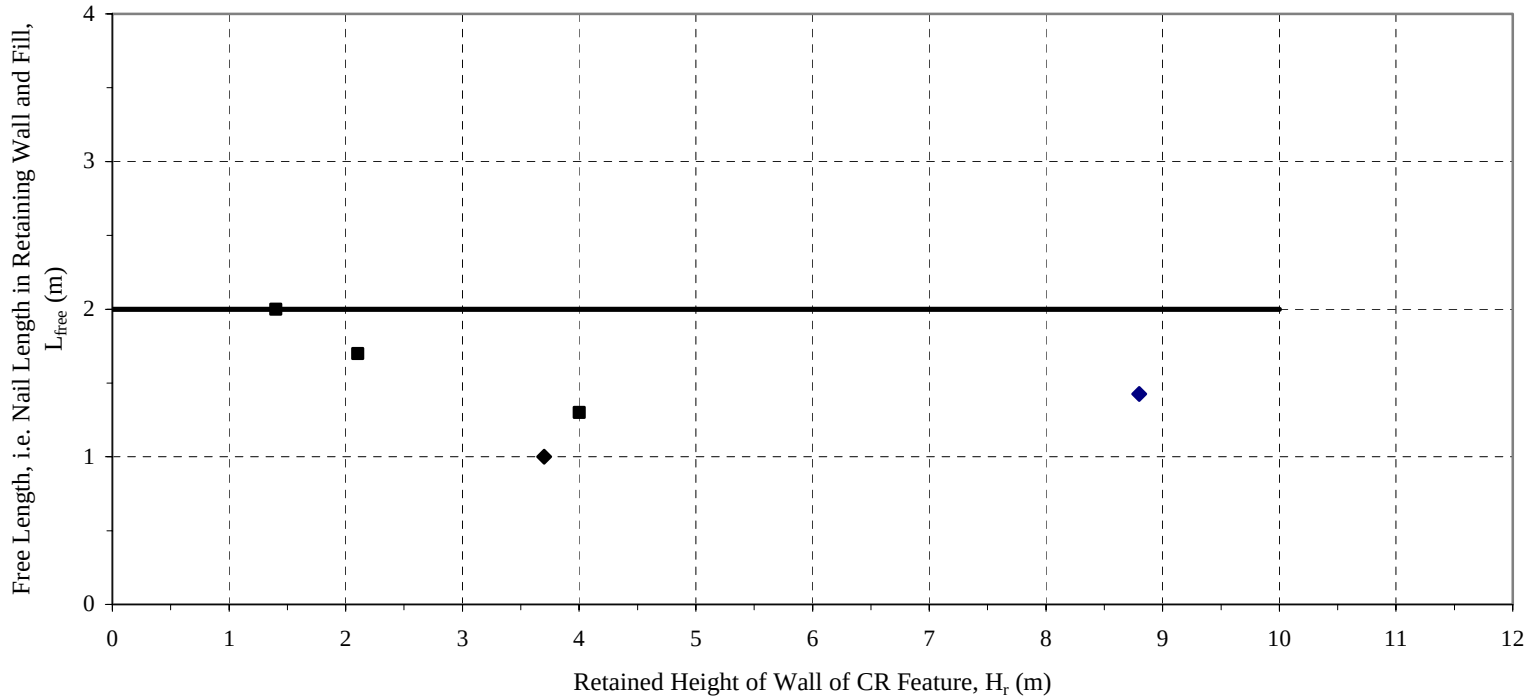


Legend:

- - ∗ - - 90% percentile of cut slopes (MMBP & VLA, 1999)
Prescriptive design line for cut slopes in range B (MMBP & VLA, 1999)
■ R Feature data - concrete wall (this study)
◆ R feature data - masonry wall

Notes:
(1) The Figure covers all data sets for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A6(b) - Average Nail Length versus Maximum Effective Feature Height for R Features with Existing Wall Standard



Legend:

■ CR Feature data - concrete wall

◆ CR Feature data - masonry wall

Upper bound design envelope for free length for CR Features

Notes:

(1) The Figure covers data sets with fill behind wall of CR Features for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.

(2) Data standardized to D = 100 mm.

(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A7 - Free Length versus Retained Height for CR Features

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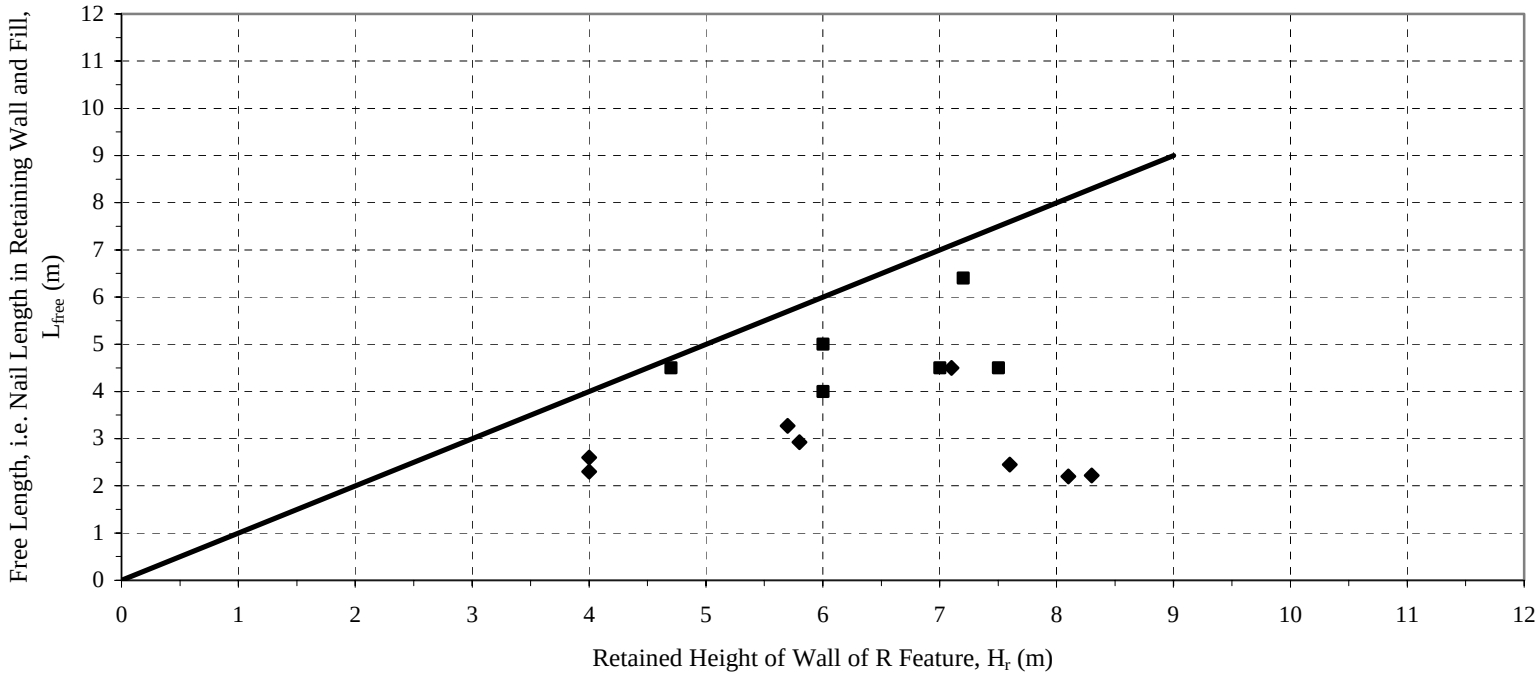

Legend:

■ R Feature data - concrete wall

◆ R Feature data - masonry wall

Upper bound design envelope for free length for R Features

Notes:
(1) The Figure covers data sets with fill behind wall of R Features for $1.5 \leq S_h \leq 3$ and $75 \leq D \leq 100$.
(2) Data standardized to D = 100 mm.
(3) S_h denote horizontal nail spacing (m), D denote hole diameter (mm).

Figure A8 - Free Length versus Retained Height for R Features

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APPENDIX B

DERIVATION OF MINIMUM REQUIRED WALL THICKNESS FOR R FEATURES

CONTENTS

B.1 GENERAL

The minimum thickness for retaining wall required to satisfy the current geotechnical standards has been derived using analytical approach based on the requirements of GCO (1982 and 1984). The derivations are for "R" features comprising a mass concrete or masonry retaining wall, with surcharge on the retained ground above the wall of not greater than 10kPa.

B.2 DERIVATION OF MINIMUM REQUIRED WALL THICKNESS FOR R FEATURES

Figure B1 shows the simplified geometry of the ground and the retaining wall for the analyses. Concrete and masonry retaining walls are considered. For reinforced concrete walls, only the wall stems are considered and the base slabs or keys of the walls, if present, are not included in the analyses because their dimensions are difficult to determine without an extensive ground investigation. Table B1 gives the assumptions adopted in the stability analyses with reference to guidelines outlined in Geoguide 1 (GEO, 1993).

The following two geotechnical standards as recommended in the Geotechnical Manual for Slopes (GCO, 1984) are adopted in the analysis for both the concrete and masonry retaining walls:

- for "new" walls, i.e. minimum required factors of safety against sliding and overturning of 1.5 and 2.0 respectively; and

- for "existing" walls, i.e. minimum required factors of safety against sliding and overturning of 1.25 and 1.5 respectively

For masonry wall, the middle-third rule is imposed to limit the wall deformation and ensure the wall integrity (GEO, 1993). From the analysis, masonry wall thicknesses required to fulfil the middle-third rule always exceed the ones required to satisfy the "new" and "existing" wall standards. As such, there is only one set of minimum wall thicknesses for masonry wall for no works.

The minimum wall thicknesses developed for the "new" wall and "existing" wall standards for the concrete retaining walls and the one developed for the middle-third rule of masonry retaining walls are shown in Figure 7.

B.3 REFERENCES

GCO (1982). Geoguide 1 - Guide to Retaining Wall Design. (First edition). Geotechnical Control Office, Hong Kong, 153 p.

GCO (1984). Geotechnical Manual for Slopes. (Second edition). Geotechnical Control Office, Hong Kong, 301 p.

GEO (1993). Geoguide 1 - Guide to Retaining Wall Design. (Second Edition). Geotechnical Engineering Office, Hong Kong, 267 p.

LIST OF TABLES

Table B1 - Design Assumptions Adopted in Deriving the Minimum Required Thickness for R Features with Mass Concrete/Masonry Retaining Wall

Material at retained ground	Fill
Material at founding material	Completely Decomposed Granites or Completely Decomposed Volcanics
Values of soil parameters of retained ground	c' = 0 kPa , ϕ' = 30°, γ = 18 kN/m^3
Surcharge above retained ground	10 kPa
Groundwater level behind retaining wall, H_w (m)	1/3 H_r where H_r = height of retained ground
Angle of wall friction, δ	2/3 ϕ' = 20°
Angle of base friction, δ_b	ϕ' = 30°
Unit Weight of Retaining Wall	Concrete = 24 kN/m^3 Masonry = 22 kN/m^3
Notes: (1) The mass concrete/masonry retaining wall is assumed to be rectangular in shape. (2) Reference should be made to Figure B1 for simplified geometry of the ground and retaining wall.	

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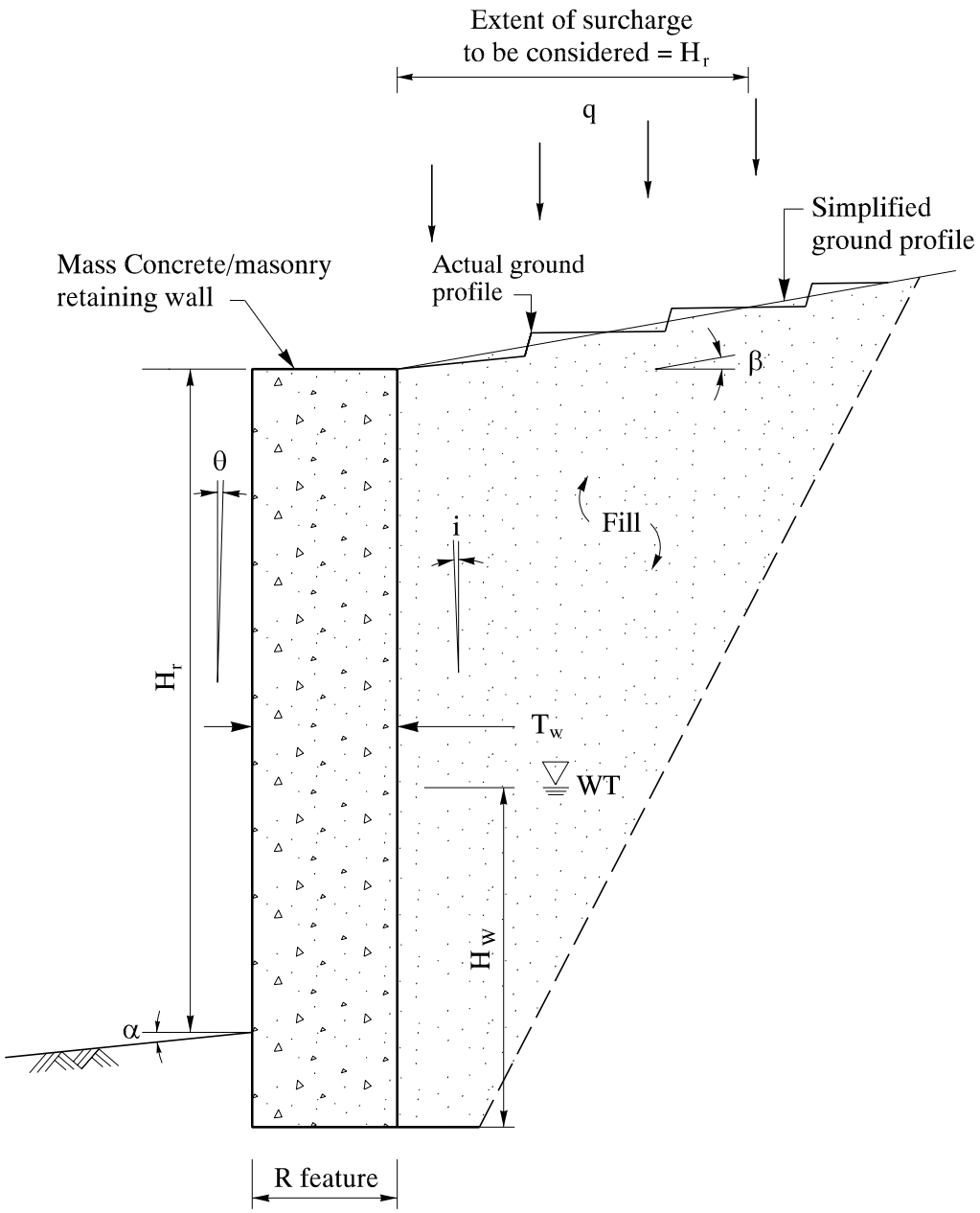

Legend:

α	Gradient of ground in front of wall	β	Gradient of retained ground
q	Design surcharge	θ	Wall face angle
H_r	Height of retained ground	i	Wall face angle
H_w	Height of groundwater level behind the wall from wall base	T_W	Average thickness of concrete retaining wall
∇_{WT}	Design water table		

Figure B1 - Simplified Geometry of the Ground and the R Feature with Mass Concrete/Masonry Retaining Wall

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

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

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

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GEOSPECS

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

GEO PUBLICATIONS

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

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GEOLOGICAL PUBLICATIONS

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

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

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