Building and Construction Authority

An MND Statutory Board

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Dear Sir/Madam

FRAMEWORK ON RISK-BASED SLOPE DESIGNS

Objective

This circular is to inform the industry on the Framework on Risk-Based Slope Designs. The framework adopts a risk-based approach in stipulating the requirements of slope design depending on its impact category. The Framework also enables engineers to adopt an appropriate approach in designing slope to produce a safe and efficient design.

Background

2 In Singapore, rainfall induced slope failure is the most common form of slope failure that usually occurs during heavy or prolonged rainfall. Recent extreme weather events indicate that the impact of climate change is becoming a new normal. Design of slopes shall include measures to mitigate this impact to ensure the slopes remain safe and stable.

3 Over the past months, BCA has gathered feedback on the Framework from the Institution of Engineers Singapore, Association of Consulting Engineers Singapore, and Geotechnical Society of Singapore. This circular, which has incorporated inputs from the professional institutions, is for compliance by Qualified Persons (“QPs”), Accredited Checkers (“ACs”) and developers that are submitting plans for slopes/walls for the ERSS designs.

4 This framework is to be adopted for engineered hill slopes, both temporary and permanent. Engineering Approach is only applicable to GBW hill slopes. For all other excavated slopes, the QPs are to adopt onerous design ground water level which is normally taken to be close to full height of the slope especially at lower ground. Developers/builders are advised to engage QPs and ACs who are competent and have sufficient knowledge in advanced modelling of slope that considers onerous groundwater variation and rainfall loadings. Highly skilled and experienced QPs and ACs should be able to provide a safe and optimised slope design.

5 <u>Nothing contained in this circular is meant to replace or negate the need to comply with the provisions of the Building Control Act and building regulations in all aspects. QPs are to note that they have duties under the Building Control Act, amongst others, to take all reasonable steps and exercise due diligence to ensure that building works are designed in accordance with the provisions of the Building Control Act and building regulations.</u>

6 We would appreciate if you could disseminate the contents of this circular to your members. Please contact us at Tel 1800-3425222 or through the online feedback form (https://www.bca.gov.sg/feedbackform/) should you need any clarification. Thank you.

Yours faithfully

Er. Dr. POH TEOH YAW
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For COMMISSIONER OF BUILDING CONTROL

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Annex A

Framework on Risk-Based Slope Designs

DISCLAIMER

The authors and the working committee members of this guide are not to be held liable for any claim or dispute arising out of or relating to the information provided in this guide.

Professionals in charge of each project are strictly advised to do an independent assessment and verification to determine if the information provided in this guide is adequate and sufficient for the needs of their project.

Nothing contained in this guide is meant to replace or negate the need to comply with the provisions of the Building Control Act and building regulations in all aspects. QPs are to note that they have duties under the Building Control Act, amongst others, to take all reasonable steps and exercise due diligence to ensure that building works are designed in accordance with the provisions of the Building Control Act and building regulations.

Introduction

1.1 Engineered slopes can be either permanent or temporary, unreinforced or reinforced. When an engineered slope is proposed, it is important to assess that the slope will not impact adjacent properties even when it slips. Regulation 36 requires builder to provide earth retaining structures to protect the sides of all foundations or excavations for any building works to prevent any settlement or other movement which may impair the stability of or cause damage to the whole or part of any adjoining premises or building. For slopes where its potential failure zone is likely to affect adjoining premises or building, QP is expected to provide earth retaining structures to prevent such potential occurrence. Typical earth retaining structures adopted for permanent cutting slope are sheet pile wall, Contiguous-Bored-Pile (CBP) or Secant-Bored-Pile (SBP) walls or slope reinforced by soil nails or ground anchor with reinforced concrete grid beams.

1.2 This framework is to be adopted for engineered hill slopes, both temporary and permanent (where the final crest level of the slope is at SHD +5m or higher). Engineering Approach is only applicable to GBW hill slopes. The robustness requirement of subsoil drains for deemed to satisfy approach is only applicable to GBW hill slopes. For all other excavated slopes, the QPs are to adopt onerous design ground water level which is normally taken to be close to full height of the slope especially at lower ground. Requirements specified under Sections 2 to 4 are applicable to GBW slopes only. **Section 2** provides classification of slope impact categories. The engineered slope is to be classified into “High”, “Medium”, or “Low” depending on its proximity and the type of adjacent buildings/structures. The framework adopts a risk-based approach in stipulating the requirements of slope design depending on its impact category. **Section 3** provides guidelines for site investigation in accordance with the slope impact categories that are to be adopted when planning for slope design. **Section 4** provides special design considerations covering onerous ground water table incorporating impacts of climate change, surface and subsoil drain, long term monitoring of slope and robustness requirements for proposed building located at the crest of slope.

1.3 During construction, the Builder and the site supervision team shall ensure that the surcharge/ construction load is not exceeding design assumption and with no earth stockpile placed within the influence zone of the slope.

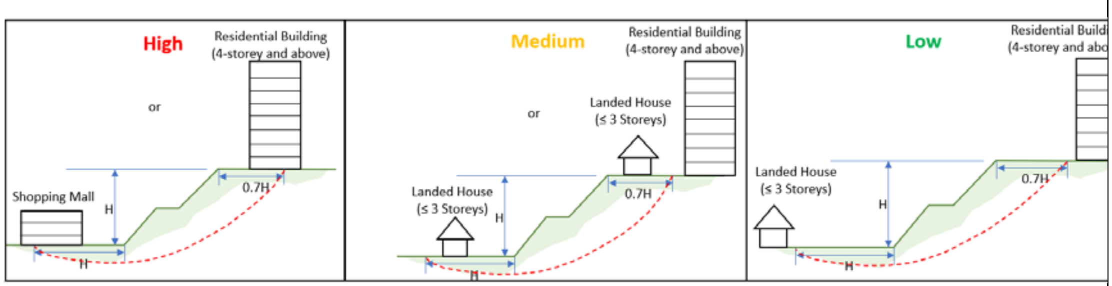
1.4 Requirements specified under **Sections 5 & 6** are applicable for both non-GBW and GBW slopes. **Section 5** provides design methodology for both unreinforced and reinforced slopes to also include soil nailed and ground anchored slope / wall. In **Section 6**, good practices in drainage of rainwater and protection of slope surface are provided.

Slope Impact Categories

2.1 In this framework, engineered slope may be categorised into "High", "Medium", or "Low" impact by considering the consequences of failure of the slope as given in **Table 1** below. A slope is categorised as "High" impact if there is densely populated building or major infrastructure located within the potential failure zone, defined as 0.7H at the crest or 1H at the toe. A slope is categorised as "Medium" impact if there is low density building located within 0.7H at the crest or 1H at the toe. For slope at green field, it is categorised as "Low" impact.

Table 1: Classification of Slope Impact Categories

Slope Impact Categories	Definition of Slope Impact Categories	Type of Adjacent Buildings / Structures	Close Proximity to Adjacent Buildings / Structures
High Impact	High consequence for loss of human life, or economic, social, or environmental consequences very great	• Densely populated residential area (4-storey and above) • Office building • Shopping mall • Major infrastructure (e.g. MRT)	Crest: Buildings located within 0.7H Toe: Buildings located within 1H
Medium Impact	Medium consequence for loss of human life, economic, social, or environmental consequences considerable	• Landed house, shophouse (up to 3-storey)	Crest: Buildings located within 0.7H Toe: Buildings located within 1H
Low Impact	Low consequence for loss of human life, and economic, social or environmental consequences small or negligible	• Non-habitable minor buildings or structures	Green Field



Note: The potential failure zone, defined as 0.7H at the crest or 1H at the toe is derived from local case studies of slope failure.

2.2 The slope impact categories may affect the requirements on 1) site investigation, 2) slope design ground water level, 3) provision and design on subsoil drain, and 4) long-term monitoring regime.

Table 2: Design Requirements and Slope Impact Categories

Design Requirements / Slope Impact Categories	Site Investigation	Design Approach		Long-Term Monitoring Regime to be Specified on Plans		Robustness Requirements of Foundation for Proposed Buildings Located at the Crest of Slope
		Option 1: Deemed to Satisfy Approach (Prescribed Onerous Design GWT)	**Option 2: Engineering Approach** (Design GWT Derived from Seepage Analysis Incorporating Climate Change)	Soil Nails / Ground Anchors System	Sub soil Drains System (Engineering Approach)	
High Impact	• Min 2 BHs per design section • Closer borehole interval	• Ultimate Limit State • Accidental Load Case with design GWT at 1.0H • Subsoil drains with closer spacing (Robustness requirements)	• Ultimate Limit State • Accidental Load Case with design GWT incorporating extreme daily rainfall • Subsoil drains designed for specified closer spacing with an overdesign factor of 3	Yes	Yes	Required
Medium Impact	• Min 1 BH per design section • Medium borehole interval	• Ultimate Limit State • Accidental Load Case with design GWT at 0.9H • Subsoil drains with medium spacing (Robustness requirements)	• Ultimate Limit State • Accidental Load Case with design GWT incorporating extreme daily rainfall • Subsoil drains designed for specified medium spacing with an overdesign factor of 3	QP to decide	Yes	QP to decide
Low Impact	• Min 1 BH per design section • Larger borehole interval	• Ultimate Limit State • Accidental Load Case – Not Applicable • QP to decide the need for subsoil drains. If provided may use larger spacing	• Ultimate Limit State • Accidental Load Case – Not Applicable • QP to decide the need for subsoil drains. If provided, subsoil drains may be designed for specified larger spacing with an overdesign factor of 3	QP to decide	Yes	Not applicable

Site Investigation and Soil Design Parameters

3.1 Proper site investigation (SI) shall be carried out for the design and construction of slope. The site investigation shall provide sufficient data, especially for the ground parameters and the ground water level. This will enable QP to derive the characteristic values of the ground parameters and ground water loading to be used in slope designs.

3.2 The minimum number of boreholes and tests per soil stratum are shown in **Appendix A**. Additional boreholes and tests should be carried out where necessary.

3.3 QP is advised to make use of some of the boreholes drilled during SI for the installation of piezometers or water standpipes to obtain reliable ground water level over a longer period. This will allow QP to optimise the slope design with more realistic design ground water loadings in according to this framework.

Special Design Considerations

4.1 Onerous Ground Water Table incorporating Impacts of Climate Change

4.1.1 The adoption of onerous ground water condition in slope design is crucial for slope stability. A slope will generally remain stable when the ground water table is low. As the ground water table rises during rainstorm, the stability of the slope decreases. It is therefore during periods of extended heavy rainfall that the phenomenon of slope failures may occur.

4.1.2 In Singapore, rainfall induced slope failure is the most common landslide that occurs during rainy seasons. In 2021, record high rainfall had caused serious flooding around the world and in part of Singapore. Climate change is becoming a new normal where the consequence of rainfall-induced slope failures occurring is getting realistic and the design of slopes shall include measures to mitigate this impact.

4.1.3 A study conducted by BCA shows that design of slope based on 2 load cases of i) maximum daily rainfall of 350mm and ii) maximum 5 days antecedent rainfall of 575mm will be able to account for the impact of climate change.

4.1.4 QP shall carry out the specified two load cases for Ultimate Limit State, ULS, with additional Accidental Load Case (AL) for slope stability analysis in “Engineering Approach”. Alternatively, designer may consider the “Deemed to Satisfy Approach” adopting onerous ground water loading for slope design in this section. During plan submission stage, QP should indicate the approach that will be adopted for the project. QP must substantiate that the proposed slope is stable regardless of the approach adopted.

<u>Deemed to Satisfy Approach (“DTS Approach”)</u>

4.1.5 In DTS Approach, the design of slope shall be carried out adopting the design ground water table for ULS and AL shown in **Appendix B**.

Engineering Approach ("Eng Approach")

4.1.6 The extent to which infiltration from rainfall reduces the stability of slopes is dependent on the existing position of the ground water table, and the intensity and duration of rainfall.

4.1.7 In Eng Approach, QP should determine the initial design ground water table before carrying out seepage analysis incorporating rainfall infiltration. The QP and the engineers assisting QP should have adequate knowledge of slope design and shall refer to relevant literature for full details. Refer to **Appendix C** for details on seepage analysis adopting Eng Approach.

4.2 Surface and Subsoil Drains

4.2.1 Regulation 10A(4)(d) requires the QP to provide internal and external drainage and protection measures including against surface weathering. QP may refer to PUB code of practice for surface drainage design.

4.2.2 During prolonged rainfall, part of the rainwater will seep into the slope. This water will fill up the void between soil particle, lead to increase in soil stresses and hence, affecting the stability of a slope. Provision of adequate subsoil drainage system near the toe of the slope will help to drain off the rainwater that seep into the slope. This will prevent accumulation of rainwater within the slope and help to maintain the slope stability during rainfall. Some of the good detailing for subsoil drains are included in **Appendix H**.

DTS Approach

4.2.3 When DTS approach is adopted, subsoil drain is to be installed as **Appendix D-1**. The design ground water level to be adopted in slope stability check shall comply with those specified in **Appendix B**.

Eng Approach

4.2.4 When Eng Approach is adopted, minimum 1 row of subsoil drain should be installed at the bottom of the slope which could be considered in the design analysis. QP may also design and specify additional rows of subsoil drain when necessary. Refer to **section 4.3** for requirements on maintenance of subsoil drains and **Appendix D-2** for requirements for subsoil drain in Eng Approach.

4.3 Long Term Monitoring of Slope

Monitoring of Soil Nail and Ground Anchor Slope

4.3.1 Monitoring is required to ensure safety and serviceability of the engineered slopes to their intended design lives. For reinforced slope with ground anchors and soil nails, the QP shall specify long term monitoring requirements in accordance with EN1537:2013 cl. 9.10 and EN14490:2010 cl. 9.5.3 respectively. For slopes categorised under high impact, QP to specify the monitoring regime on the approved plans. For slopes categorised as medium or low impact, QP to assess the need for long term monitoring regime and to specify on approved plans if required.

Monitoring and Maintenance of Slope designed with Eng Approach

4.3.2 It is crucial to ensure that the subsoil drains perform as per the design intent in the long term. For design adopting Eng Approach, QP to specify on the structural plans the long-term inspection and maintenance regime of the subsoil drain, surface drain and slope condition (vegetation / erosion, etc.). Developers are to undertake the monitoring and maintenance of these after TOP.

4.4 Robustness Requirement for Proposed Building Located at the Crest of Slope

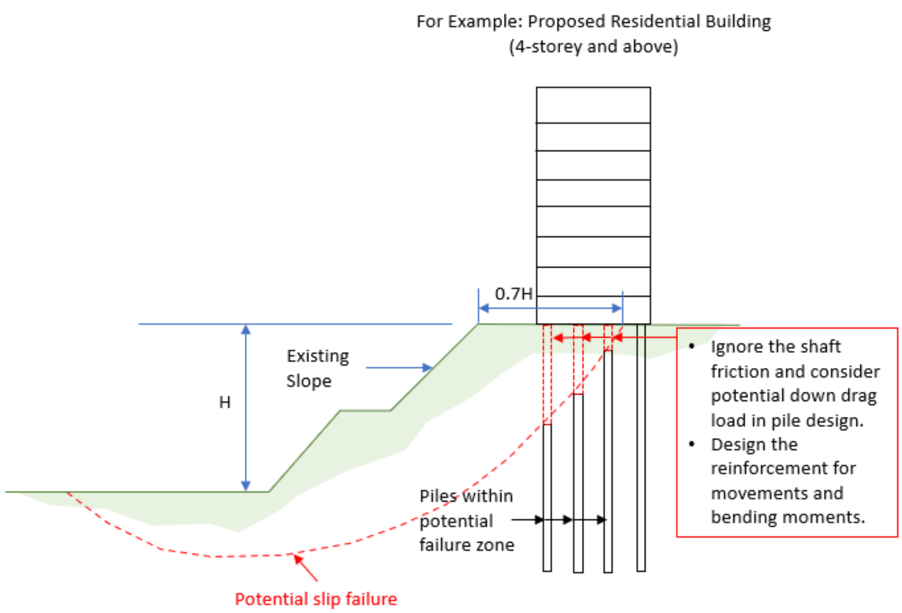
4.4.1 For buildings proposed at the crest of existing slope classified as "high impact" as per **Table 1**, the QP of the building should design the piles located within the potential failure zone of the slope for the following additional load case.

(a) Run a global stability slope analysis such as c/phi reduction or equivalent analysis for soil layer with SPT N value of less than 30 to simulate the potential slope failure without considering the piles and buildings.

(b) Design the pile foundation within the potential slope failure zone such that: -
   (i) Shaft friction within the potential failure zone is ignored. QP should also consider potential down drag load in the pile design.
   (ii) Full reinforcement designed for movement and bending moments due to potential slip failure is to be provided.

4.4.2 As a good practice, for robustness considerations, the QP of the building may consider providing tie-beams to connect piles located within the potential failure zone of the slope to those piles located outside the potential failure zone.

Figure 1: Additional Load Case for Proposed Building Located at the Crest of Slope



Design Methodology for Unreinforced and Reinforced Slopes/Walls

5.1 This section summarises design methodology for unreinforced and reinforced slopes/walls together with the applicable codes and execution standards. Design guideline for soil-nailed and ground-anchored slope/wall, which are typically adopted in Singapore, are also included. QP shall incorporate special design considerations including protection of foundations of existing structures, onerous design ground water level incorporating effect of climate change, and requirements on subsoil drains described in **Section 4.2** in the design. For proposed building located at the crest of slope, QP shall also complied with the robustness requirements stipulated in **Section 4.4**.

General

5.2 In designing engineered slopes whether unreinforced or reinforced slopes, QP is to ensure that the local stability, global (overall) stability and the resulting ground movement comply with the codes and regulatory requirements. **Appendix E** provides a summary of design codes and execution standards for each type of slope that the designer shall refer to in the analysis and design of unreinforced and reinforced slopes.

5.3 Slope stability analysis may be carried out using appropriate Limit Equilibrium methods (such as Morgenstern & Price 1965, Janbu 1972, among others), which can be done using limit equilibrium software (such as SLOPE/W). Slope stability analysis may also be carried out using finite element analysis, such as c-phi reduction analysis in Plaxis. Whichever method is adopted should be able to model the probable failure mode.

5.4 In addition to the slope stability analysis, QP is to carry out impact assessment of the slope excavation or embankment on the adjacent buildings / structures and to specify necessary measures to ensure that the adjacent buildings / structures are not likely to be damaged. For the impact assessment, QP is to carry out numerical analysis (e.g. finite element analysis) to estimate the ground movement.

5.5 Slope global stability analysis shall be carried out for both Design Approach 1 Combination 1 (DA1C1) and Combination 2 (DA1C2) in accordance with SS EN 1997-1, with the partial factors prescribed in Singapore National Annex, NA to SS EN 1997-1. The global stability analysis shall demonstrate that the engineered slope is adequate against overall instability, sliding failure, bearing failure and other relevant modes of failure.

5.6 For reinforced slope/wall, in addition to global stability, local stability analysis shall also be carried out to design the reinforcement such as soil nail or ground anchor. QP is to demonstrate that the reinforcement is adequate against rupture of reinforcement, pull-out of reinforcement, rupture of structural elements and their connections.

Single Source Principle / Finite Element Analysis for DA1C1 case

5.7 SS EN 1997-1 cl. 2.4.2(9) prescribes that if the unfavourable (or destabilising) and favourable (or stabilising) permanent actions are considered as coming from a single source, a single partial factor may be applied to the sum of these actions or to the sum of their effects", which is often referred to as "Single Source Principle".

5.8 Following the Single Source Principle, for ERSS analysis including slope analysis, the finite element analysis for DA1C1 case should be carried out in the DA1C1* approach. In DA1C1* approach, unit weight of the soil should not be multiplied by a partial factor. Surcharge and other unfavourable transient actions should be multiplied by a factor of γ_G / γ_Q = 1.5 / 1.35 = 1.11. For design of the structural elements, the effects of actions (bending moment, shear forces, other forces acting on a structural element) obtained from the DA1C1* analysis must be multiplied by γ_Q to obtain the design forces. Please refer to **Appendix C** for details.

Soil-Nailed Slope / Wall

5.9 SS EN 1997-1 did not cover soil nail design. For soil nail design, the designer is to refer to BS 8006-2 with its respective partial factors. In situations where a conflict arises between SS EN 1997-1 and BS 8006-2, partial factors specified in BS 8006-2 should govern. The soil nail design force shall be obtained from the envelope of load cases including global stability analysis of the slope/wall, e.g. from limit equilibrium analysis or finite element c-phi reduction analysis.

5.10 This guideline follows BS 8006-2 definition of temporary soil nail, where it is defined as soil nail with design life less than 2 years. The designer is to comply to durability requirements in BS 8006-2. The execution of soil nails shall follow BS EN 14490. Please refer to **Appendix F** for more details of soil nailed slope / wall.

Ground-Anchored Slope / Wall

5.11 For ground anchored slope, the ground anchor design force shall be obtained from global stability analysis of slope, e.g. from limit equilibrium analysis or c-phi reduction analysis. For ERSS supported by ground anchor, the ground anchor design force shall be obtained from the envelope of load cases including global stability analysis of the ERSS system, e.g. from limit equilibrium analysis or c-phi reduction analysis.

5.12 This guideline follows BS EN 1537 definition of temporary ground anchor, where it is defined as ground anchor with design life of 2 years or less.

5.13 This guideline outlines two approaches for design of ground anchor: Approach 1 – based on BS 8081 and Approach 2 – based on SS EN 1997-1. The requirements for structural plans submission are different for Approach 1 and Approach 2. The main difference is whether investigation test is carried out before the structural plans submission, and the partial factors to be adopted in the design. Refer to **Appendix G** for more details.

Good Practices for Slope Protection

6.1 One of the strategies in managing rainwater induced slope failure is by using an effective protective drainage system at slope front. This is to prevent the rainwater from infiltrating into the original slope that weakens the ground and thus causes shallow slippage failure.

6.2 NTU-HDB over the recent years has researched into this area to understand the failure mechanisms with appropriate preventive measures. As a good practice, QPs may incorporate Capillary Barrier System in the slope design in managing the drainage of rainwater and thus form protection to the slope surface. The details are included in **Appendix H**.

References

ASTM D6836-16 Standard Test for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge.

BS 8006-1:2010 + A1:2016 Code of practice for strengthened/ reinforced soils.

BS 8006-2:2011 + A1:2017 Code of practice for strengthened/ reinforced soils. Part 2: Soil nail design.

BS 8081:2015 + A2:2018 Code of practice for grouted anchors

BS EN 14490:2010 Execution of special geotechnical works – Soil nailing

BS EN 14475:2006 Execution of Special Geotechnical Works – Reinforced Fill

BS EN 1537:2013 Execution of Special Geotechnical Works – Ground Anchors

SS EN 1997-1:2010(2018) + A1:2018 Singapore Standard Eurocode 7: Geotechnical design. Part 1: General rules

Geotechnical Society of Singapore. 2015. Guide on Ground Investigation and Geotechnical Characteristic Values to Eurocode 7.

Rahardjo, H., A. Satyanaga Nio, E.C. Leong and Y.S. Ng (2010). “Effects of groundwater table position and soil properties on stability of slope during rainfall”. ASCE Journal of Geotechnical and Geoenvironmental Engineering. November, Vol. 136, No.11, pp. 1555–1564. DOI: 10.1061/(ASCE)GT.1943-5606.0000385

Rahardjo, H., E.C. Leong., A. Satyanaga, Y.S. Ng., H.T. Tan., C.J. Hua. (2014). “Rainfall-induced Slope Failures and Preventive Measures in Singapore.” Geotechnical Engineering Monograph. NTU-HDB Research Collaboration Project, Nanyang Technological University, Singapore, 84 pages (ISBN 978-981-07-9250-3)

Appendix A. Minimum Number of Boreholes and Tests per Soil Stratum

Table A-1: Minimum Site Investigation Requirements for Slope Designs

Slope Impact Categories	Site Investigation Requirements		
High Impact	1 BH every 10 to 30m	Min 2 BHs for every design section	BH should be at the crest of slope and toe of slope
Medium Impact	1 BH every 10 to 40m	Min 1 BH for every design section	BH should be at the crest of slope
Low Impact	1 BH every 10 to 60m	Min 1 BH for every design section	BH should be at the crest of slope

Note: -
Designers are recommended to specify 1 set of BH at crest and toe for each slope design section.

Table A-2: Minimum Field and Lab Test Requirements for Each Soil Stratum

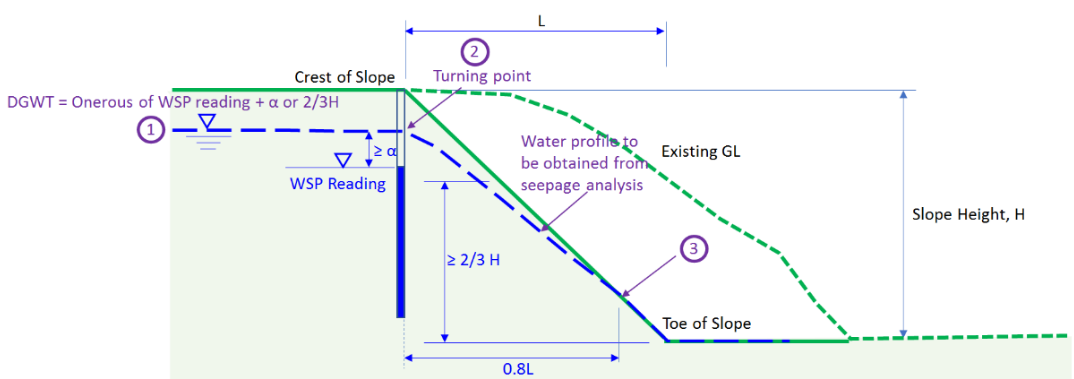
Parameters	Field Test	Laboratory Test	Remarks
Classification: ➢ Particle Size Distribution (PSD) ➢ Densities ➢ Water Content ➢ Atterberg Limits	-	Minimum 2 to 3 samples	Refer to Annex D GeoSS guidelines*.
Strength: ➢ Drained c' and ϕ ➢ Undrained Shear Strength, Cu ➢ Unconfined Compressive Strength (UCS), qu (for rock)	Undrained: Minimum 1 test either from field vane shear test, SPT or CPT correlation	➢ Drained: Minimum 3 set of each consists of 3 samples triaxial test ➢ Undrained: Minimum 4 test samples ➢ UCS: Minimum 4 test samples	Refer to Annex D GeoSS guidelines*.
Permeability: Saturated permeability, Ks (for steady and transient seepage analysis)	➢ Failing Head ➢ Raising Head Field Tests	➢ Triaxial (as per drained test) ➢ Other tests such as oedometer, consolidation tests, etc.	➢ Refer to Annex D GeoSS guidelines*. ➢ For anisotropy soil, horizontal permeability test should be considered.
Soil Water Characteristic Curve, SWCC (for transient seepage analysis)	➢ SWCC parameters can be obtained from tests according to ASTM D6836-16#. ➢ Most tests are time consuming. However, hygrometer test may give fast test results within minutes. ➢ For cases where tests to determine SWCC have not been carried out, the SWCC parameters can be estimated from PSD, soil types database from program and other models as appropriate with upper and lower bounds.		

**GeoSS (2015), Guide on Ground Investigation and Geotechnical Characteristic Values to Eurocode 7*
#ASTM D6836-16 Standard Test for Determination of the Soil Water Characteristic Curve for Desorption Using Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, or Centrifuge

Appendix B. Design Ground Water Table for Deemed-To-Satisfy Approach ("DTS Approach")

Table B-1: Minimum Design Ground Water Table for ULS in DTS Approach

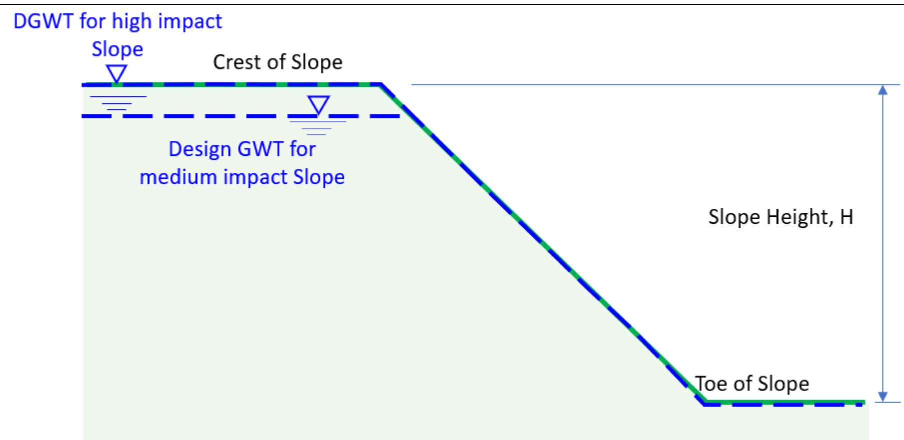
Design Ground Water Table (DGWT)		
Case 1: With Water Standpipe (WSP) readings taken min. weekly throughout November to March (Wet Season)	**Case 2:** With frequency of Water Standpipe (WSP) readings taken daily to weekly and with a minimum of 12 readings	**Case 3:** Other than Case 1 and Case 2
• DGWT = Onerous of WSP reading + α or 2/3H ≤ 0.9H • α = 0.2 slope height (H)	• DGWT = Onerous of WSP reading + α or 2/3H ≤ 0.9H • α = 0.3 slope height (H)	DGWT = 0.9H



Note:
1. Each design section to have at least 1 no. of WSP at the crest.
2. Water levels encountered during boring operations are known to be unreliable and should not be considered. Nevertheless, designer may utilise the site investigation borehole to install the WSP.
*3. For cases with the presence of retaining wall within the hill slope, QP shall also comply to the minimum Design Ground Water Table shown in **Table B-1**.*

Table B-2: Design Ground Water Table for AL in DTS Approach

	Slope Impact Categories		
	High	Medium	Low
Design Ground Water Table (DGWT)	At ground surface	At 0.9H	Not applicable
Overdesign Factor (ODF) to achieve 1.05 without partial factors			



Appendix C. Seepage Analysis for Engineering Approach ("Eng Approach")

C1. When QP adopts Eng Approach, QP is to carry out seepage analysis to determine the pore water pressure in the slope after rainfall and carry out slope stability analysis to assess the corresponding slope stability. QP and the engineers assisting QP in the slope design must have sufficient knowledge on seepage analysis and unsaturated soil mechanics.

C2. Key steps in slope design following the Eng Approach are summarized below. The designers shall refer to the relevant literature for full details.

<table>
<tr><th>Key step #</th><th>Description</th></tr>
<tr><td>1</td><td>
Determine the initial design ground water table in the slope.
The designer should determine the initial design ground water table complying to requirements shown in Table C-1.
Table C-1: Initial Design Ground Water Table in Eng Approach
<table>
<tr><th colspan="2">Initial Design Ground Water Table (DGWT)</th></tr>
<tr><td>Case 1
With Water Standpipe (WSP) readings taken min. weekly throughout November to March (Wet Season)</td><td>Case 2
With frequency of Water Standpipe (WSP) readings taken daily to weekly and with a minimum of 12 readings</td></tr>
<tr><td>Initial DGWT = WSP reading + α ≤ 0.9H

• α = 0.15 slope height (H)
• DGWT shall not be lower than the wettest GWT in Chart C-1</td><td>Initial DGWT = WSP reading + α ≤ 0.9H

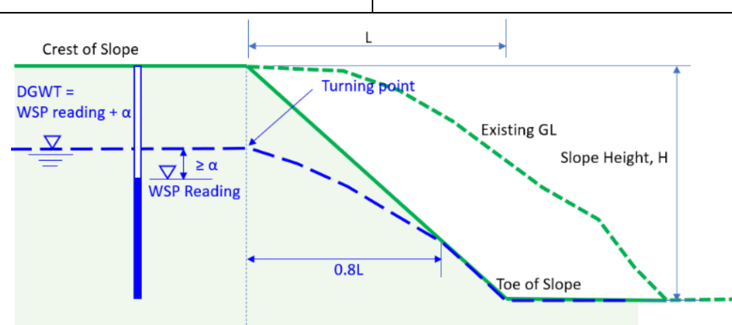
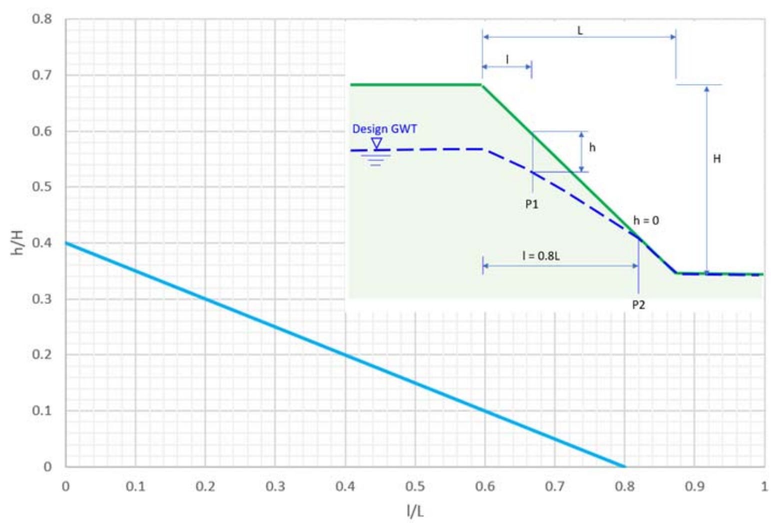
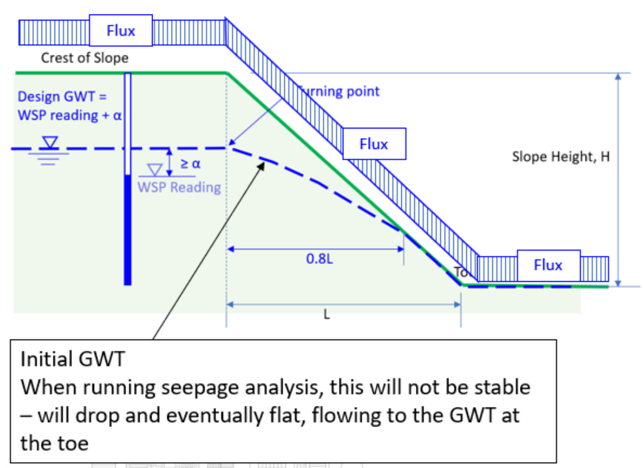
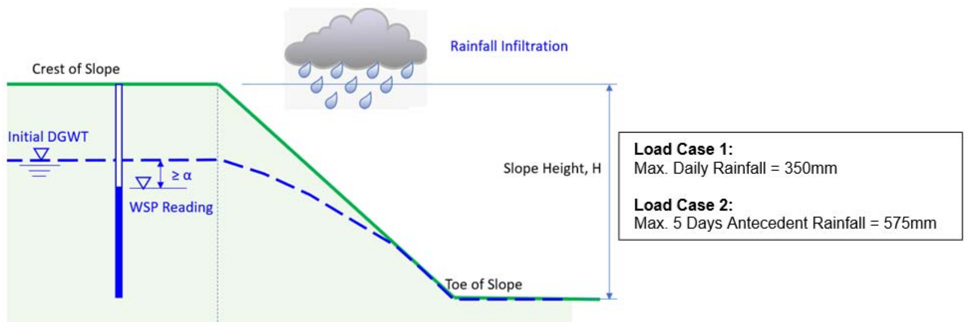
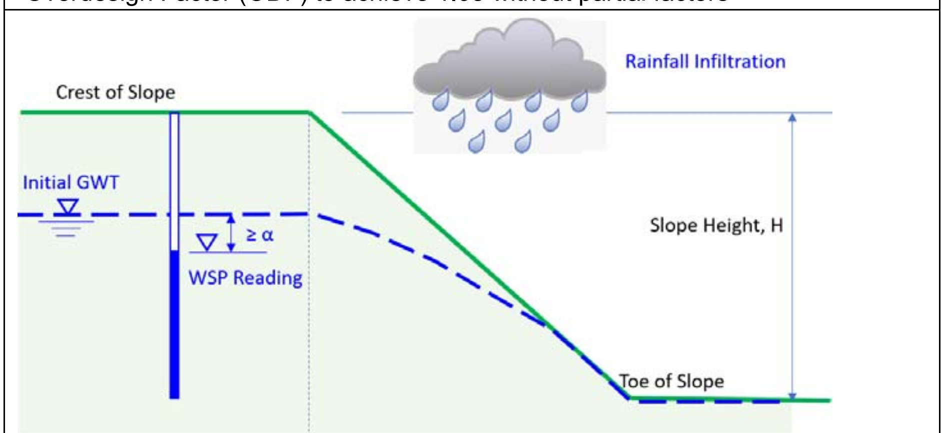
• α = 0.3 slope height (H)
• DGWT shall not be lower than the wettest GWT in Chart C-1</td></tr>
<tr><td colspan="2">
</td></tr>
</table>
Note:
1. Each design section to have at least 1 no. of WSP at the crest.
2. Water levels encountered during boring operations are known to be unreliable and should not be considered. Nevertheless, designer may utilise the site investigation borehole to install the WSP.
</td></tr>
</table>

	Chart C-1: Wettest Ground Water Table 
2	Carry out initialisation for rainfall infiltration modelling to achieve initial design ground water table in step 1. To achieve the initial design ground water table in the model, the designer is required to run a transient seepage analysis with appropriate precipitation (rainfall per area) [flux] value for a period of time until the initial design ground water table in step 1 is established. **Figure C.1: Initialisation to Model the Initial Design Ground Water Table** 
3	Carry out seepage analysis for ultimate limit state (ULS) check. After establishing the initial design ground water table, designer should carry out transient seepage analysis. QP may include subsoil drains in the analysis model and may consider the beneficial effects in the seepage analysis. The seepage analysis shall include rainfall infiltration as specified below to assess the slope stability.

	For ultimate limit state, designer should include 2 load cases (see **Figure C-2**): • Load Case 1: seepage analysis with input flux of 350mm for 24 hours • Load Case 2: seepage analysis to simulate 5 days antecedent rainfall of 575mm. The 5 days antecedent rainfall may be simulated as flux of 115mm/day for 5 days, or distribution that QP deems appropriate. BCA's study concluded that by adopting 2 load cases covering maximum daily rainfall of 350mm and maximum 5 days antecedent rainfall of 575mm, impact of climate change deemed to be included. **Figure C-2: Slope Design with Rainfall Infiltration for Ultimate Limit State (ULS) in Eng Approach** 
4	Carry out slope stability analysis for ULS check. With the pore-water pressure distribution obtained from the seepage analysis, carry out slope stability analysis according to SS EN 1997-1 requirements. When adopting unsaturated soil principles in assessing slope stability, it is common to incorporate a parameter ϕ^b, increase of soil shear strength with suction, in the analysis (refer to e.g. Rahardjo et al. 2012). When this parameter is incorporated in slope stability analysis, the designers should apply a partial factor to ϕ^b. The partial factor is to be the same partial factor for f' according to SS EN 1997-1. SS EN 1997-1 cl. 2.4.2(9) prescribes that "unfavourable (or destabilising) and favourable (or stabilising) permanent actions may in some situations be considered as coming from a single source. If they are considered so, a single partial factor may be applied to the sum of these actions or to the sum of their effects", which is often referred to as "Single Source Principle". Based on the Single Source Principle, NA to SS EN 1997-1 (Table A.NA.13) specifies that the permanent actions from the passive earth pressure and active earth pressure can be treated as permanent, unfavourable actions and a single partial factor may be applied to these actions. Following the Single Source Principle, for ERSS analysis including slope analysis, the finite element analysis for DA1C1 case should be carried out in the DA1C1* approach, namely:

	• Unit weight of the soil should not be multiplied by a partial factor. In DA1C1* analysis, fully saturated weight of the soil should be used everywhere in the slope regardless of the adopted design ground water table. • Surcharge and other unfavourable transient actions should be multiplied by a factor of γ_G / γ_Q = 1.5 / 1.35 = 1.11. • For design of the structural elements, the effects of actions (bending moment, shear forces, other forces acting on a structural element) obtained from the DA1C1* analysis must be multiplied by γ_Q to obtain the design forces.
5	Carry out seepage analysis for Accidental load case. When a proposed slope falls in High or Medium impact category as defined in **Table 1**, the slope shall also be designed for Accidental case of heavy rainfall. **Table C-2** summarized the Accidental load case. In the transient seepage analysis, the maximum daily rainfall of 530mm/day may be modelled as a flux of 22mm/h for 24 hours. **Table C-2: Design Ground Water Table for Accidental Load Case (AL) in Eng Approach**

	Slope Impact Categories		
	High	Medium	Low
Design Ground Water Table (DGWT)	Max Daily Rainfall = 530mm	Max Daily Rainfall = 530mm	Not applicable
Overdesign Factor (ODF) to achieve 1.05 without partial factors			



6	Carry out slope stability analysis for Accidental case To demonstrate that the slope ODF ≥ 1.05.

Appendix D. Requirements for Subsoil Drain

D-1: Requirements for Subsoil Drain in DTS Approach

a) The robustness requirement of subsoil drains for deemed to satisfy approach specified under this section is only applicable to GBW hill slopes. For cases where QP adopt design ground water table at ground surface, the requirements in this **section D-1** will not be applicable.
b) Minimum 1 row of subsoil drain is to be provided at the bottom of the slope (see **Figure D-1**).
c) Another row of subsoil drain at the interface between permeable and less permeable soil layer is to be provided (see **Figure D-1**) where the surface soil layer is much more permeable than the underlying soil and perched water table is likely to occur during heavy rain.
d) The diameter of the subsoil drain should be minimum 75mm perforated pipe and wrapped with geotextile filters. Geosynthetic drains or PVC pipe with UV protection should be used.
e) The longitudinal gradient of subsoil drain should be 1:10 or steeper.
f) The minimum length of the subsoil drain should be H / 1.5 up to 12m long. H = Slope Height.
g) Refer to **Table D-1** for maximum horizontal spacing for subsoil drain.
h) Cap should be provided at the end of the subsoil drain at soil side.

Figure D-1: Requirements for Subsoil Drain in DTS Approach

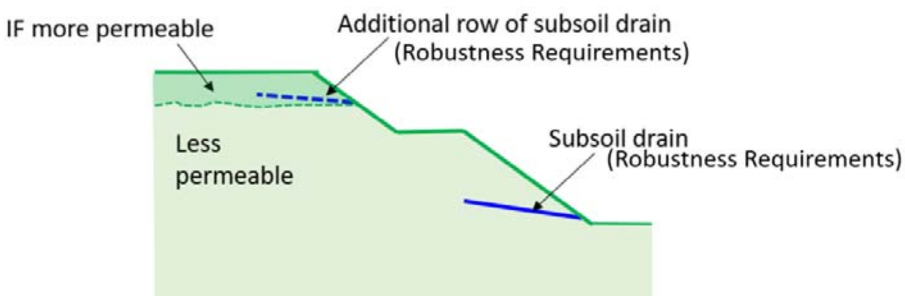


Table D-1: Maximum Horizontal Spacing for Subsoil Drain in DTS Approach

	Slope Impact Categories		
	High	Medium	Low*
Max. Subsoil Drain Horizontal Spacing	2m	2.5m	3m

**QP to decide the need for subsoil drain*

D-2: Requirements for Subsoil Drain in Eng Approach

D-2.1. When subsoil drain is included in numerical seepage analysis, the assumptions/details of the subsoil drain, e.g. drain is modelled as "drain element", or as soil element with input permeability value are to be stated in the design report and specified on structural plans. The length, diameter, gradient, and rows of subsoil drain are to be designed in according with specified spacing as shown in **Table D-2** to achieve minimum overdesign factor of 3.

Figure D-2: Requirements for Subsoil Drain in Eng Approach

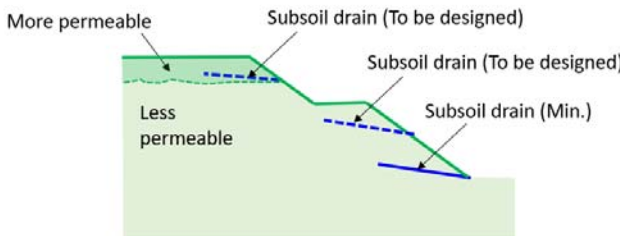


Table D-2: Maximum Horizontal Spacing for Subsoil Drain in Eng Approach

	Slope Impact Categories		
	High	**Medium**	**Low***
Max. Subsoil Drain Horizontal Spacing	2m	2 to 3m	3 to 4m

**QP to decide the need for subsoil drain*

Note:
1. The minimum length of the subsoil drain should be slope height, H / 1.5 up to 12m long. H = Slope Height.

Appendix E. Design Codes for Each Type of Slope

Table E-1: Design Code for Each Type of Slope

	Earth Slope	**Soil Nailed Slope**	**Ground Anchored Slope**	**Gabion Wall**	**Reinforced Soil Slope (i.e. Geotextile, Geogrid, etc.)**
Code of Practice	SS EN 1997-1 (2018)[1]	BS 8006-2 (2011)[3]	• BS 8081 (2015)[4] • SS EN 1997-1 (2018)[1]	SS EN 1997-1 (2018)[1]	BS 8006-1 (2010)[2]
Execution Standard	-	BS EN 14490: 2010[5]	BS EN 1537: 2013[6]	-	BS EN 14475: 2006[7]

[1] *SS EN 1997-1:2010(2018) + A1:2018 Singapore Standard Eurocode 7: Geotechnical design. Part 1: General rules*
[2] *BS 8006-1:2010 + A1:2016 Code of practice for strengthened/ reinforced soils.*
[3] *BS 8006-2:2011 + A1:2017 Code of practice for strengthened/ reinforced soils. Part 2: Soil nail design.*
[4] *BS 8081:2015 + A2:2018 Code of practice for grouted anchors*
[5] *BS EN 14490:2010 Execution of special geotechnical works – Soil nailing*
[6] *BS EN 1537:2013 Execution of Special Geotechnical Works – Ground Anchors*
[7] *BS EN 14475:2006 Execution of Special Geotechnical Works – Reinforced Fill*

Note: Designer shall refer to the latest edition of design codes.

Appendix F. Design of Soil-Nailed Slope

Specific Requirements on Soil Nails

F1. Soil Nails are generally used to enhance the stability of slopes and faces either for temporary slope excavation or for permanent slopes. Soil nail slope is applicable for ground with undrained shear strength of 50kN/m^2 or greater (BS 8006-2 cl. 3.4.2). The design of soil nail slope shall consider one nail failure as accidental load case for robustness consideration.

F2. The soil nails temporary or permanent that are inserted into the ground (behind the slope facing) beyond the land boundary will encroach and obstruct the future development of the adjacent land. A consent letter from the adjacent landowner shall be obtained before the design proposal are being developed and submitted to Authorities. For temporary soil nail, Fibre Reinforced Plastic (FRP type instead of steel type) should be considered to avoid encumbrances for adjacent development.

F3. For permanent soil nail slope, long term monitoring and maintenance are required and shall be carried out following BS EN 14490 cl. 9.5. Regular inspection and maintenance are needed and should be implemented for such a design life to be achieved and to make sure that safety is not degraded.

Workflow to Determine Suitable Soil Nailing System and Design Considerations

<table>
<tr><th>Key Consideration</th><th>Description</th></tr>
<tr><td>(a)
Site investigation to determine corrosive environment within soil (refer BS EN 14490 Table B.1 and B.2)</td><td>
1. Carry out site investigation to determine strength and stiffness for each of the soil layers for design. The SI shall also include corrosive environment within the soil according to Table B.2 of BS EN 14490 which is the aggregated ΣA from 4 criterion: (a) type of soil, (b) resistivity, (c) moisture content and (d) pH.

2. Without test data, conservative weight A shall be adopted for each criterion in the ΣA computation.

Table B.2 — General method for corrosiveness assessment
<table>
<tr><th>Criterion</th><th>Features</th><th>Weight A of Criterion</th></tr>
<tr><td>Type of soil 2)</td><td>Texture</td><td></td></tr>
<tr><td></td><td>— heavy, plastic, sticky impermeable;</td><td>2</td></tr>
<tr><td></td><td>— clayey sand;</td><td>1</td></tr>
<tr><td></td><td>— light, permeable, sandy, cohesionless soils</td><td>0</td></tr>
<tr><td></td><td>Peat and bog/marshlands</td><td>8</td></tr>
<tr><td></td><td>Industrial waste</td><td></td></tr>
<tr><td></td><td>clinker, cinders, coal</td><td>8</td></tr>
<tr><td></td><td>builders waste (plaster, bricks)</td><td>4</td></tr>
<tr><td></td><td>Polluted liquids</td><td></td></tr>
<tr><td></td><td>waste water, industrial</td><td>6</td></tr>
<tr><td></td><td>water containing de-icing salts</td><td>8</td></tr>
<tr><td>Resistivity (Ω·cm)</td><td>p < 1 000</td><td>5</td></tr>
<tr><td></td><td>1 000 < p < 2 000</td><td>3</td></tr>
<tr><td></td><td>2 000 < p < 5 000</td><td>2</td></tr>
<tr><td></td><td>5 000 < p</td><td>0</td></tr>
<tr><td>Moisture content</td><td>Water table – brackish water (variable or permanent)</td><td>8</td></tr>
<tr><td></td><td>Water table – pure water (variable or permanent)</td><td>4</td></tr>
<tr><td></td><td>Above water table – moist soil (water content > 20 %)</td><td>2</td></tr>
<tr><td></td><td>Above water table – dry soil (water content < 20 %)</td><td>0</td></tr>
<tr><td>pH</td><td>< 4</td><td>4</td></tr>
<tr><td></td><td>4 to 5</td><td>3</td></tr>
<tr><td></td><td>5 to 6</td><td>2</td></tr>
<tr><td></td><td>> 6</td><td>0</td></tr>
<tr><td></td><td>Global Index</td><td>Sum of above ΣA</td></tr>
</table>
NOTE Table B.2 is an excerpt from Clouterre (Soil Nailing Recommendation – 1991). Further information regarding the soil features can be found in Clouterre.

3. Corrosive environment from Highly corrosive to Slightly corrosive within the soil is determined according to Table B.1 of BS EN 14490 which is the aggregated ΣA from Table B.2 of BS EN 14490. The corrosive environment will affect the selection of suitable soil nail system in Table 9 of BS EN 14490.
</td></tr>
</table>

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<table>
<tr><th>Key Consideration</th><th>Description</th></tr>
<tr><td></td><td>
Table B.1 — Classification of soil condition
<table>
<tr><th>Soil features</th><th>Classification</th><th>Index ΣA</th></tr>
<tr><td>Highly corrosive</td><td>I</td><td>13 or greater</td></tr>
<tr><td>Corrosive</td><td>II</td><td>9 to 12</td></tr>
<tr><td>Average corrosive</td><td>III</td><td>5 to 8</td></tr>
<tr><td>Slightly corrosive</td><td>IV</td><td>4 or less</td></tr>
</table>
Example: Bukit Timah Granite residual soil G(VI) with SPT N < 20
Soil type (clayey type): value 2
Resistivity: No test (use conservative weight value of 5)
pH: No test (use conservative weight value of 4)
Moisture content: below water table, use weight value of 4
The aggregated wight value would be 15 and would be classified as high corrosive environment.
</td></tr>
<tr><td><u>(b):</u> Determine Geotechnical Risk Category</td><td>
1. The risk category refers to Geotechnical Category 1 (low risk) to 3 (high risk) according to SS EN 1997-1.
2. Designer shall refer to GeoSS Guide (2015) for Geotechnical Category in local Singapore’s context. The risk category of low to high will affect the selection of suitable soil nail system in Table 9 of BS EN 14490.
</td></tr>
</table>

<table>
<tr><th>Key Consideration</th><th>Description</th></tr>
<tr><td></td><td>
<table>
<tr><th>Geotechnical Category</th><th>Description of Category</th><th>Example of projects (in Singapore's context)</th></tr>
<tr><td>1</td><td>- small and relatively simple structures:
- for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations;
- with negligible risk.</td><td>- Landed housing on shallow foundations in firm residual soil
- Single storey sheds
- Link-ways
- Minor roadside drain</td></tr>
<tr><td>2</td><td>- conventional types of structure and foundation
- with no exceptional risk or difficult ground or loading conditions</td><td>- canal
- conventional buildings on
- shallow or raft foundations;
- pile foundations;
- walls and other structures retaining or supporting soil or water < 6m height;
- excavations < 6m depth
- bridge piers and abutments;
- embankments and earthworks;
- ground anchors and other tied-back systems;
- tunnels in hard, non-fractured rock/ competent soils, and not subjected to special water tightness or other requirements.</td></tr>
<tr><td>3

EC7. Clause 2.1 Expectations of GI, refer table 2.2</td><td>fall outside the limits of Geotechnical Categories 1 and 2</td><td>- very large structure such as infrastructure projects for rail and road tunnels
- utilities tunnels of more than 3 m in diameter
- airport terminal buildings
- foundation for building of 30 storey or more;
- unusual structures such as port structures in poor ground conditions;
- structures involving abnormal risks such as dam, dikes
- GBW(ERSS) in close proximity to existing buildings except for single unit landed housing development,
- unusual or exceptionally difficult ground such as foundation in limestone areas for more than 6 storey or unusually loading conditions
-foundation for high-rise of more than 10 storey on reclaimed land, or soft soils with combined thickness of soft soils of more than 8 m
-GBW (ERSS) in soft soil ground conditions
- special buildings subjected to seismic risks (according BC3);</td></tr>
</table>

Example: for a project with 8m high soil nailed slope, the submission would be GBW and the risk category will be high risk (Geotechnical Category 3).</td></tr>
<tr><td><u>(c):</u>
Determine temporary or permanent soil nail</td><td>1. Temporary nail defined as (<2 years) while permanent nail as (>2 years) according to Table 9 of BS 8006-2.</td></tr>
</table>

Key Consideration	Description
(d): Select suitable type of soil nail system	1. Refer Table 9 of BS 8006-2 for suitable type of soil nail according to (1) corrosive environment within soil, (2) geotechnical risk category and (3) temporary or permanent soil nail.

Table 9 — *Summary of recommendations for different soil nailing systems in relation to different categories of risk*

After Barley and Mothersille [33].

Type of soil nail	Category of risk								
	Low risk			Medium risk			High risk		
	T or P in SCE	T in HCE	P in HCE	T or P in SCE	T in HCE	P in HCE	T or P in SCE	T in HCE	P in HCE
Steel directly in soil	R	R	NR	R	NR	NR	NR	NR	NR
Coated steel directly in soil	R	R	R	R	R	NR	NR	NR	NR
Steel surrounded by cement grout	R	R	R	R	R	NR	R	NR	NR
Self drilled steel surrounded by cement grout	R	R	R	R	R	NR	R	NR	NR
Coated steel surrounded by cement grout	R	R	R	R	R	NR	R	NR	NR
Self drilled coated steel surrounded by cement grout	R	R	R	R	R	NR	R	R	NR
Polyester composite surrounded by cement grout	R	R	R	R	NR	NR	R	NR	NR
Vinylester composite surrounded by cement grout	R	R	R	R	R	R	R	R	NR
Stainless steel surrounded by cement grout	R	R	R	R	R	R	R	R	NR
Self drilled stainless steel surrounded by cement grout	R	R	R	R	R	R	R	R	NR
Steel surrounded by grouted impermeable ducting	R	R	R	R	R	R	R	R	R
Coated steel surrounded by grouted impermeable ducting [A)]	R	R	R	R	R	R	R	R	R
Stainless steel surrounded by grouted impermeable ducting [A)]	R	R	R	R	R	R	R	R	R
Steel surrounded by pregrouted double impermeable ducting [A)]	R	R	R	R	R	R	R	R	R

Key

T = Temporary (< 2 years) SCE = Slightly corrosive environment [B)] R = Recommended

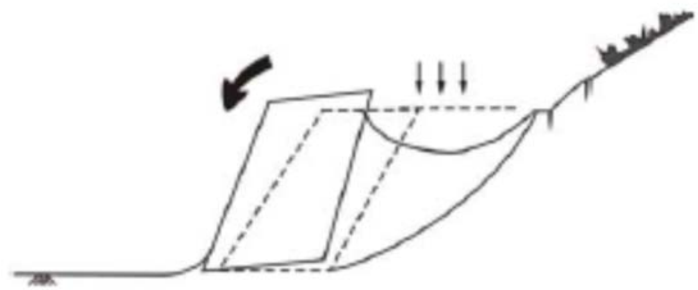
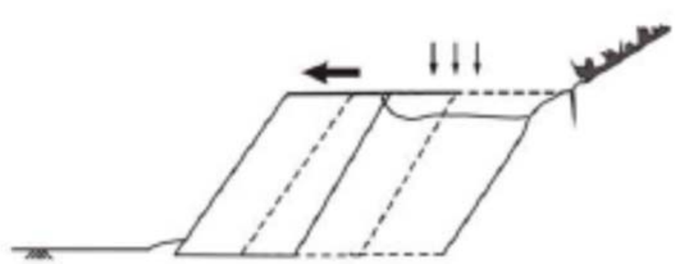
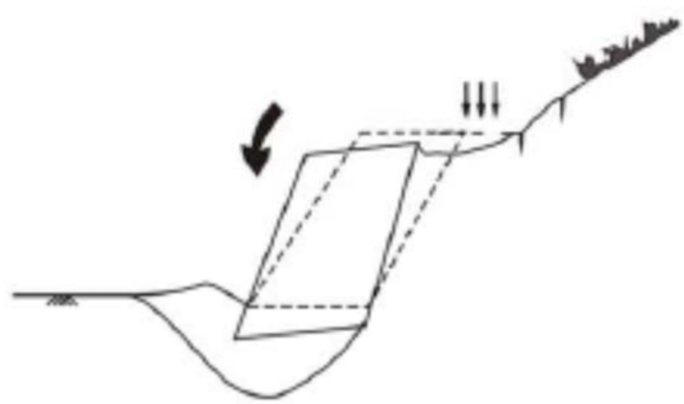
P = Permanent (> 2 years) HCE = Highly corrosive environment [B)] NR = Not recommended

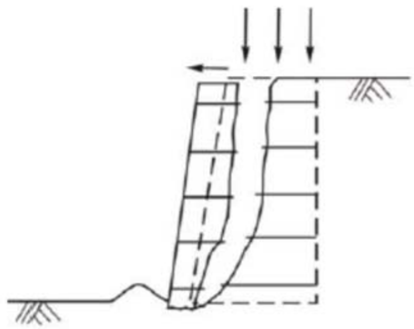
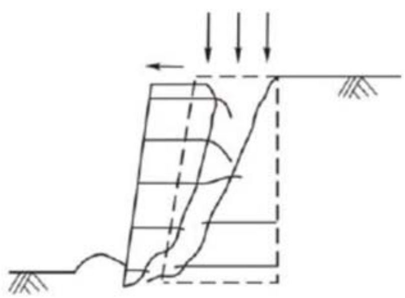
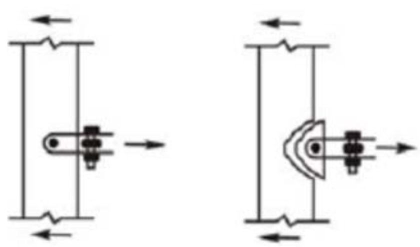
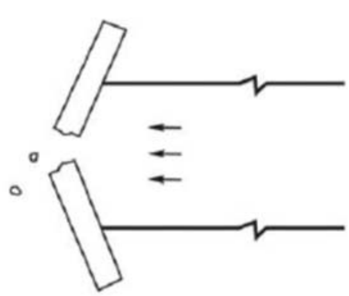
[A)] System particularly suitable for heavy or long nails for permanent works where one of the two protective layers may become damaged during handling or installation. This approximately equates to double corrosion protection required for permanent anchors.

[B)] As defined in BS EN 14490:2010.

Example: In high corrosive environment and high geotechnical risk, for permanent soil nails, the suitable nail system shall be:

a. Steel surrounded by grouted impermeable ducting, or
b. Coated steel surrounded by grouted impermeable ducting, or
c. Stainless steel surrounded by grouted impermeable ducting, or
d. Steel surrounded by pre-grouted double impermeable ducting

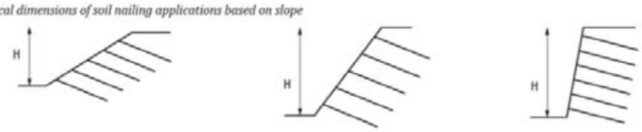
Key Consideration	Description
(e): Slope Design - Global Stability	Slope stability analysis using either limit equilibrium method or finite element methods to substantiate the reinforced slope has adequate factor of safety against global instability (i.e. over-turning, sliding and bearing failure, etc). In the slope analysis, the reinforced soil body can be treated as a rigid stable mass (similar to a gravity retaining wall) to resist the lateral soil pressure and onerous ground water pressure. (a) Overturning  (b) Sliding  (c) Bearing 

Key Consideration	Description
(f): Slope Design - Local Stability	From the global stability analysis, the forces for the reinforcement can be obtained to design the slope against local instability (i.e. rupture of reinforcement, pull-out of reinforcement, rupture of connections, etc) (a) Rupture of reinforcement  (b) Pull-out of reinforcement  (c) Rupture of connection/ Rupture of facing  

Key Consideration	Description
	As an initial design assessment, BS 8006-2 has requirements on

a) spacing and length of the soil nails,

Figure 13 — *Typical dimensions of soil nailing applications based on slope*



Slope angle (to horizontal)	up to 45°	45° to 60°	60° to 90°
Nail length (L/H)	0.5 to 2.0	0.5 to 1.5	0.5 to 1.2
	Minimum L/H ratio shall be not less than the average value of the range, unless otherwise demonstrated.		
Nail spacing			
– vertical	1.5 m to 3.0 m	1.0 m to 2.0 m	0.75 m to 1.5 m
– horizontal	1.5 m to 3.0 m	1.0 m to 2.0 m	0.5 m to 2.0 m
	Maximum nail spacing shall be not more than the average value of the range, unless otherwise demonstrated.		
Facing	Generally *soft* non-structural, for erosion control but with enlarged plates at nail head	Typically *flexible* facings used that perform a structural role in maintaining stability	Typically *hard* facings used that perform a structural role in maintaining stability and permit high forces to be mobilized at the facing connection.

NOTE May be used as a first design assessment tool. Actual nail spacings, lengths and facing requirements have to be determined by analysis.

BS 8006-2, cl 4.2.1.4:

In uniform ground vertical spacings between nail rows are traditionally kept constant with depth, or decreasing with depth in stages as appropriate; variations to this general trend may be appropriate in layered ground of varying strength. The vertical spacing between nail rows should be limited in any case to 2 m in intermediate slopes and 1.5 m in steep slopes.

b) partial factors for design bond stress

Table 6 — *Ultimate limit state approach to deriving design values*

Method of determining ultimate bond stress, τ_{bu}	**Factors for determining characteristic bond stress from ultimate values** $\tau_{bk} = \tau_{bu} / \gamma_k$	**Factors for determining design bond stress from characteristic values for set 1,** $\tau_{bd} = \tau_{bk} / \gamma_{\tau b}$	**Factors for determining design bond stress from characteristic values for set 2,** $\tau_{bd} = \tau_{bk} / \gamma_{\tau b}$
Empirical pullout test data	γ_k = 1.35 to 2.0 Selected value to be based on degree of confidence relative to proposed structure, soils, construction method, etc.	$\gamma_{\tau b} = 1.11$	$\gamma_{\tau b} = 1.50$
Effective stress *NOTE* τ_{bu} derived from characteristic φ'	γ_k = 1.0 to 1.35 Selected value to account for potential for dilation and degree slope deformation in active zone	$\gamma_{\tau b} = 1.11$	$\gamma_{\tau b} = 1.50$
Total stress *NOTE* τ_{bu} derived from characteristic c_u.	γ_k = 1.35 to 2.0 selected value to account for potential for strain softening, plasticity and shrink swell effects	$\gamma_{\tau b} = 1.11$	$\gamma_{\tau b} = 1.50$
Pullout tests	See BS EN 14490:2010 *Characteristic selected as a cautious estimate of the test data, taking into account the number of test results, location and consistency.*	$\gamma_{\tau b}$ = 1.1 to 1.3 for coarse grained soils $\gamma_{\tau b}$ = 1.5 to 1.7 for medium and high plasticity soils	$\gamma_{\tau b}$ = 1.5 to 1.7 for coarse grained soils $\gamma_{\tau b}$ = 2.0 to 2.25 for medium and high plasticity soils

<table>
<tr><th>Key Consideration</th><th>Description</th></tr>
<tr><td></td><td>

BS 8006-2, cl 4.3.6:

NOTE 2 The values in Table 6 have been selected to result in equivalent experience with lumped factors of between 1.5 and 3.0 on ultimate bond resistances (and micropile/ground anchor designs). The range given for γ_k is to reflect whether nails are used in a temporary or permanent application and the degree to which full dissipation of pore pressure is relevant.

Though the value of γ_k is chosen to reflect whether the nails are used in temporary or permanent application, however in order to align with BCA Advisory Note1/09 for the safety factor for temporary slope to be not less than that of permanent slope, γ_k (= 2.0) shall be adopted which will gives a lump factor of 3.0 in DAC2.

</td></tr>
<tr><td>

(g):
Verification Test

</td><td>

For performance verification of the reinforced soil nailed slope, BS EN 14490 has the following requirements:

Table 12 — *Recommended test frequency (from BS EN 14490:2010)*

<table>
<tr><th rowspan="2">Test type</th><th colspan="2">Suggested minimum frequency of load tests</th></tr>
<tr><th>Sacrificial nail test</th><th>Production nail test</th></tr>
<tr><td>Geotechnical Category 1:
negligible risk to property or life.</td><td>Optional</td><td>Optional</td></tr>
<tr><td>Geotechnical Category 2:
no abnormal risk to property or life.</td><td>If no comparable experience of soil type: a minimum of three sacrificial nails with at least one sacrificial nail per soil type.
Where direct experience exists then sacrificial nail tests are optional.</td><td>2%, minimum of three tests.
These criteria are subject to a minimum of one test per soil type and per excavation stage.</td></tr>
<tr><td>Geotechnical Category 3:
all other structures not in Category 1 or 2.</td><td>A minimum of five sacrificial nails with at least two sacrificial nails per soil type.</td><td>For number of nails:
3%, min. five tests.
These criteria are subject to a minimum of one test per soil type and per excavation stage.</td></tr>
<tr><td colspan="3">NOTE 1 Geotechnical Category of structure as defined in BS EN 1997.
NOTE 2 Test nails should be evenly distributed throughout the structure.
NOTE 3 The frequency of testing is a suggested minimum.
NOTE 4 Where sacrificial nail tests are carried out the number of production nail tests can be reduced on a pro-rata basis.
NOTE 5 For spacing less than 0.8 m, a group test of four nails is recommended.</td></tr>
</table>

</td></tr>
</table>

Appendix G. Design of Ground-Anchored Slope / Wall

Specific Requirements on Ground Anchors

G1. Ground anchors are typically used to restrain and support earth retaining structures or in engineered slopes either temporarily or permanently. As per cl. 3.1.21 of BS EN 1537, temporary ground anchor is defined as ground anchor with design life of 2 years or less. The design of ground anchor slope shall consider one anchor failure as accidental load case for robustness consideration.

G2. The ground anchors that are inserted into the ground (behind the retaining wall or slope facing) beyond the land boundary will form land encroachment and obstruction to future adjacent land development. A consent letter from the adjacent landowner shall be obtained before the design proposal are being developed and submitted to Authorities. For temporary ground anchors, removable type ground anchors shall be adopted, and all the temporary ground anchor shall be removed. These are to be clearly specified on approved plans.

G3. A minimum of 5 % of the anchors should be monitored on a regular basis during their design life, whether temporary or permanent, in accordance with BS EN 1537 cl. 9.10. Adequate working space for re-stressing and replacement of ground anchor as remedial measures shall be provided. For permanent GA where long-term monitoring is not provided, the GA are to be designed for a case of whole row of anchor failure.

Durability Requirements on Ground Anchors

G4. The corrosion protection of GA shall comply with BS EN 1537 cl. 6.3. In general, the anchor should be protected overall, as partial protection of the tendon might only induce more severe corrosion on the unprotected part. Thus, the least protected zone of a grouted anchor defines the class of protection provided, e.g. single or double.

G5. **Table G-1** provides acceptable corrosion protection systems for temporary and permanent anchors, in accordance with BS EN 1537.

Table G-1: Acceptable Corrosion Protection System for Temporary and Permanent Anchors in Accordance with BS EN 1537

Item	Temporary Ground Anchor	Permanent Ground Anchor
Corrosion Protection System	• As per cl. 3.1.21, temporary ground anchor is defined as ground anchor with design life of 2 years or less. • The corrosion protection system is specified in cl. 6.7 and Annex C Table C.1	• As per cl. 3.1.18, permanent ground anchor is defined as ground anchor with design life in excess of 2 years. • The corrosion protection system is specified cl. 6.7 and Annex C Table C.2
Specific requirements	• Need to establish the presence of aggressive ground conditions. • Specific conditions for aggressive ground condition to be fulfilled.	• Cl. 6.3.3.2 & Annex C Table C.2: Double protective barriers is required to protect against possibility of damage during tendon handling and installation. • Cl. 6.3.3.2: Single protective barrier to corrosion shall be proven by falling head water test for each anchor in-situ as per Annex C Table C.2. • BS8081 cl. 13.2.3.2: Grout injected in-situ to bond the tendon to the ground does not constitute a part of a protection system as the grout quality and integrity cannot be assured.
Testing of Corrosion Protection System	NA	• Cl. 6.7.1 and Annex C Table C2: Investigation test to be carried out in laboratory after loading. • Refer to Annex A of BS EN 1537 for testing method).

Design Approaches

G6. The design codes applicable for ground anchor are described in BS8081 and SS EN 1997-1 Section 8. **Table G-2** provides two design approaches as described in BS8081 (Approach 1) and SS EN 1997-1 (Approach 2) which the designer may adopt accordingly in the design submission. The main difference between the two approaches is whether investigation test is carried out before the design submission and therefore the relevant partial factors to be adopted.

Table G-2: Design Approaches for Ground Anchors

	APPROACH 1	APPROACH 2
Carrying out investigation test before ST submission	• Not compulsory • Tests may be carried out after ST submission.	• Compulsory • Investigation tests for each geological formation to be carried out before ST submission.
For ST submission	• Submit design calculation of anchor based on BS 8081. • Resistance factors are applied to calculated resistance.	• Submit result of investigation tests for each geological formation. • Partial factors are applied to measured resistance (i.e. test result).
Resistance / partial factors	• 2.5 to 4 for ground/grout resistance (see Table 2 of BS 8081)	• 1.1, 1.35 (see SS EN 1997-1 Section 8) • Overall = 1.1 x 1.35 = 1.485
Anchor testing requirements	• To comply to SS EN 1997, BS EN 1537, BS EN ISO 22477-5. • For temporary removable anchor using Approach 1, QP may consider following the criteria in Annex G of BS 8081. • For Approach 2, even for temporary removable anchor → must comply to the load loss and creep criteria in Table A.NA.21 of NA to SS EN 1997.	
Illustration	• Calculate characteristic ground/grout resistance ($R_{GG,k}$) based on appropriate skin friction parameters, e.g. fs=2N • In ST submission, to show that ultimate and serviceability conditions in BS 8081 Section 11 are satisfied: $F_{ULS,d} \le R_{GG,k}$ and $F_{Serv,k} \le R_{GG,k} / g_{GG}$ • Use resistance factors of BS 8081 (e.g. g_{GG} = 2.5 to 4)	• From investigation tests, obtain measured ultimate resistance ($R_{ULS,m}$) and serviceability resistance ($R_{SLS,m}$). • In ST submission, to substantiate that ultimate and serviceability conditions in SS EN 1997-1 Section 8 are satisfied: $E_{ULS,d} \le R_{ULS,d}$ and $F_{Serv,k} \le R_{SLS,d}$ $R_{ULS,d} = (R_{ULS,m})min / (x_{ULS}\ g_{a,ULS})$ $R_{SLS,d} = (R_{SLS,m})min / g_{a,SLS}$
Demarcation of QP responsibility	Demarcation of responsibility between the supported structure QP and the ground anchor QP is to follow recommendation in BS 8081 cl. 4.2.	

Testing Requirements

G7. The testing requirements (investigation test, suitability test and acceptance test) of Ground Anchors shall comply to SS EN 1997, BS EN 1537 and BS EN ISO 22477-5. For Temporary removable anchors using Approach 1, the criteria in Annex G of BS 8081 may be adopted. For Approach 2, even for temporary removable anchors, the testing requirements must comply to the load loss and creep criteria in Table A.NA.21 of NA to SS EN 1997.

G8. **Table G-3** provides the testing requirements for temporary or permanent ground anchors in relation to the design consideration using either Approach 1 or Approach 2.

Table G-3: Testing Requirements for Ground Anchors

	Only for temporary removable anchors using Approach 1	**Temporary removable anchors using Approach 2, and all other anchors using either Approach**
Investigation Test Minimum 1 test	• Max Test Load Pp - see SS EN 1997, cl. 8.6.1 • Load cycle, holding time – see BS 8081 Table G.1/G.2, Figure G.1/G.2 • Creep, load loss at $F_{serv,k}$ (see BS 8081 Table G.4, G.5), value of a2 and kl follows NA to SS EN 1997 Table A.NA.21 for SLS • Calculation of apparent tendon free length Lapp – see BS 8081 G2.11 • Rate of prestress loss should not be greater than kl in Table A.NA.21 (see BS 8081 G2.15)	• Max Test Load Pp – see SS EN 1997, cl. 8.6.1 • Load cycle, holding time – see ISO 22477-5, cl. 9.2.2 • Creep, load loss criteria at Pp (see NA to SS EN 1997 Table A.NA.21) • Calculation of apparent tendon free length Lapp – see ISO 22477-5 Annex D.1 • Anchor pull-out resistance $R_{ULS,m}$
Suitability Test Min 3 tests	• Max Test Load Pp - see SS EN 1997, cl. 8.6.1 • Load cycle, holding time – see BS 8081 G3.3/ Figure G.6 • Creep, load loss at Pp (BS 8081 G3.4, G3.5), value of a2 and kl follows NA to SS EN 1997 Table A.NA.21 for ULS • Creep, load loss at $F_{serv,k}$ (BS 8081 G3.6, G3.7), value of a2 and kl follows NA to SS EN 1997 Table A.NA.21 for SLS • Apparent tendon free length Lapp (BS 8081 G3.8)	• Max Test Load Pp - see SS EN 1997, cl. 8.6.1 • Load cycle, holding time (ISO 22477 cl.5 9.3.2) • Creep, load loss at Pp (see NA to SS EN 1997 Table A.NA.21) • apparent tendon free length Lapp (see ISO 22477-5 Annex D.1)

Acceptance Test To be carried out for each working anchor	• Max Test Load Pp see SS EN 1997, cl. 8.6.2 • Load cycle, holding time (G4.3/Figure G.6/Table G.7) • Creep, load loss at Pp (BS 8081 G3.4, G3.5), value of a2 and kl follows NA to SS EN 1997 Table A.NA.21 for ULS • Creep, load loss at F serv,k (see BS 8081 Table G.4, G.5), value of a2 and kl follows NA to SS EN 1997 Table A.NA.21 for SLS • Apparent tendon free length Lapp (G2.11)	• Max Test Load Pp see SS EN 1997, cl. 8.6.2 • Load cycle, holding time (ISO 22477-5, cl. 9.4.2) • Creep, load loss at Pp (see NA to SS EN 1997 Table A.NA.21) • apparent tendon free length Lapp (see ISO 22477-5 Annex D.1)

Notes on Temporary Removable Anchors

G9. Temporary removable anchors (e.g. U-turn anchor, Korean system) are commonly used in Singapore. For projects that adopt temporary removable anchors, the following good practice shall be considered, where applicable.

1. For multi-stage construction e.g. ERSS wall supported by ground anchors, anchor lock-off load is 110% of design preload instead of 110% of anchor working load. A lower percentage (e.g. BS 8081 mentioned 102%) might be considered if verified by prestress loss measurement on site using load cell.
2. For compression type grouted anchors (e.g. U-turn or Korean system), the design shall ensure that the U-turn holding piece is adequate to sustain the design load (note: grout/tendon resistance is not specifically covered in BS 8081).
3. For removable anchors, the strands are usually in loops. The bending of the strand at the end of such loop will result in reduction of strength of the strands (TR 26-2010). Designer should apply a reduction factor in structural capacity calculation of U-turn anchor due to the bend. The reduction factor is to be derived via test.
4. Ground anchor test load shall not exceed the structural resistance (which is 1.5 working load).

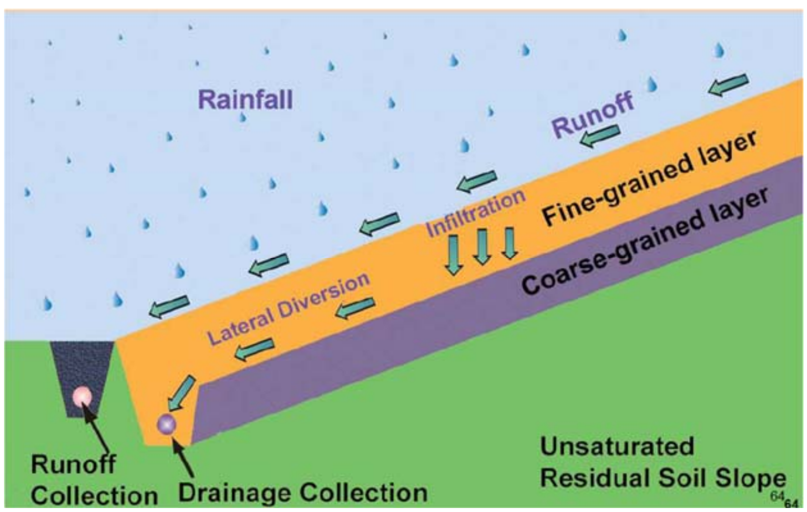
Appendix H. Good Practices for Slope Protection

Capillary Barrier System (CBS)

H1. Capillary barrier may be adopted for slope protection to minimize rainwater infiltration into existing unsaturated residual soil slopes. A capillary barrier system is a man-made two-layer system with distinctly different hydraulic properties between a fine-grained (drainage) layer and a coarse-grained (capillary break) layer of soils.

H2. Under unsaturated conditions, the difference in permeability between the fine-grained layer and the coarse-grained layer limits the downward movement of water through capillary barrier effect. The infiltrated water is stored temporarily in the fine-grained layer (Rahardjo et al., 2007b) and then removed by lateral drainage through the slope, minimizing percolation into the underlying layer. **Figure H-1** shows the example of capillary barrier system (Rahardjo et al., 2014).

Figure H-1: Capillary Barrier System for minimizing rainwater infiltration into existing unsaturated residual soil slopes



Detailing for Subsoil Drains

H3. Good detailing for subsoil drains will reduce potential clogging and thus ensure its long-term functionality with minimum maintenance frequency. Some of the good detailing for subsoil drains include double pipes (**Figure H-2**), double filtration layers (**Figure H-3**) and external longitudinal ribs at the outer surface of pipe as part of channels to perforated holes (**Figure H-4**).

Figure H-2: Typical Details of Double Pipes for Subsoil Drain (HK Geo Publication CEDD Standard Drawing No. C2403)

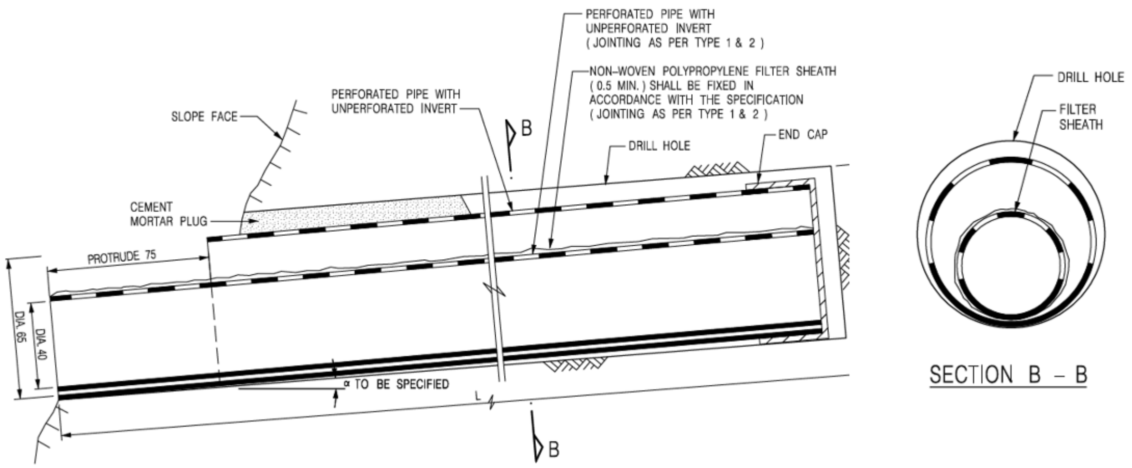
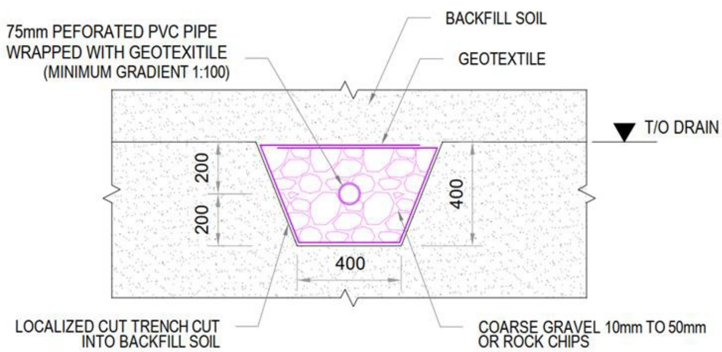


Figure H-3: Example of Double Filtration Layers for Subsoil Drain



- 1st filtration layer: 400x400m of cut trench filled with 10-50mm coarse gravel or rock chips wrapped around with geotextile.
- 2nd filtration layer / drainage layer: 75mm perforated PVC pipe wrapped around with geotextile with minimum gradient 1:100.

Figure H-4: Example of External Longitudinal Ribs along Perforated Subsoil Drain Pipe