USE OF STANDARDISED DEBRIS-RESISTING BARRIERS FOR MITIGATION OF NATURAL TERRAIN LANDSLIDE HAZARDS

GEO REPORT No. 182

H.W. Sun & T.T.M. Lam

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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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 2006

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FOREWORD

This Report presents the guidelines on the use of standardised modules of debris-resisting barriers to mitigate natural terrain landslide hazards. Some suitably conservative standardised modules of debris-resisting barriers have been developed to cater for the typical range of natural terrain profiles in Hong Kong and design events involving a debris volume of up to 600 m^3. The technical basis of the standardised modules of debris-resisting barriers is presented by Sun et al (2003).

This Report was prepared by the Landslip Preventive Measures Division 1 with the support of the landslide investigation consultant, Maunsell Geotechnical Services Ltd. (MGSL) together with their technical advisor, Professor Oldrich Hungr of the University of British Columbia. Their support is gratefully acknowledged.

K.K.S. Ho
Chief Geotechnical Engineer/LPM Division 1

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ABSTRACT

New developments on or close to steep natural hillsides in Hong Kong, together with the need to react to known natural terrain landslide hazards posed to existing developments, have created a growing demand for natural terrain hazard assessments as well as the design and construction of the necessary landslide mitigation works. The detailed design of a debris-resisting barrier can be a technically demanding and time-consuming process. Suitably conservative, standardised modules of debris-resisting barriers, together with a technical design framework, have been formulated by applying, and extending where appropriate, the methodology proposed by Lo (2000). These measures may be prescribed for a given site without the need for detailed investigation of the hillside, debris runout modelling and detailed structural design, and provide a simplified approach to deal with relatively small design events.

This Report presents the guidelines on the use of standardised debris-resisting barriers to mitigate potential natural terrain landslide hazards. Various types of standardised barriers are available to suit a range of natural hillside profiles and design events. The standardised modules of debris-resisting barriers are applicable for mitigation of channelised debris flows of up to 600 m^3 and open hillslope landslides of up to a 100 m^3.

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1. INTRODUCTION

There is a growing demand for the design and construction of natural terrain landslide mitigation measures in Hong Kong. The detailed design of a debris-resisting barrier can be a technically demanding and time-consuming process. There is scope for developing some relatively simple, standardised and robust modules of debris-resisting provisions for mitigation of natural terrain landslides without the requirements for complex debris mobility modelling, dynamic impact analyses and detailed structural design.

A suitably conservative design approach for standardised modules of debris-resisting barriers has been formulated by applying, and, where appropriate, extending the methodology proposed in Lo (2000). The technical approach and considerations in the development of the technical design framework for the standardised barriers are presented by Sun et al (2003).

This Report presents the guidelines for the use of the standardised debris-resisting barriers for mitigation of channelised debris flows with a design event of up to 600 m^3, and open hillslope landslides with a design event of up to 100 m^3.

2. GLOSSARY OF TERMS

The terms used in this Report to describe natural terrain features are consistent with those in Ng et al (2002). Terms relating to the calculation of debris impact forces and barrier design are defined by Lo (2000). Other key terms specific to this Report have the following meaning:

Barrier Location. This is defined in terms of the minimum required horizontal distance of the upstream face of a barrier from the commencement of the runout area using the design tables in Appendices A and B.

Design Volume. This refers to the total volume of landslide debris to be mitigated by the barrier, derived from the source area together with any additional debris that may be entrained less any debris deposited along the debris runout path.

Runout Area. The lower section of the potential debris runout path corresponding to the 'lower segment' of the Design Debris Runout Profile (see Appendices A and C for details).

Standardised Barrier. A pre-determined, standardised, landslide debris-resisting barrier in accordance with the standardised barrier framework formulated by Sun et al (2003).

3. ADVANTAGES AND LIMITATIONS OF THE STANDARDISED BARRIER FRAMEWORK

The advantages of using a standardised barrier framework over conventional design methods in the assessment of the required debris-resisting barrier include the following:

(a) Practical and technical benefits - geotechnical professional

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practitioners may implement the necessary natural terrain landslide mitigation measures for channelised debris flows and open hillslope landslides, based on suitably conservative design assumptions to cater for the uncertainty and complexity in the design process.

(b) Savings in time and human resources - the need for technically demanding debris runout modelling, dynamic impact analyses and detailed structural design on a case-by-case basis may be eliminated. The savings in time and human resources can be significant when there is a need to provide the mitigation works within a short period of time or as part of urgent protective works following landslides.

The standardised barrier framework provides an efficient approach for prescribing suitable mitigation measures for developments (including exempted small houses in the New Territories) subject to small to moderate scale design events ($\leq 600\ m^3$) and obviates the need for detailed design as in the conventional approach, which can be technically demanding and time-consuming. For developments affected by a large-scale design event ($> 600\ m^3$), the designer should consider carrying out site-specific detailed assessment and design to achieve cost-effectiveness. In this case, the standardised barrier framework may still be used as a reference for preliminary geotechnical assessment to facilitate site layout design and cost estimates.

Owing to the large number of parameters that can affect the mobility of natural hillside landslide debris and the corresponding dynamic impact characteristics, broad assumptions that err on the conservative side have been made with regard to the natural hillside profile, stream channel configuration and debris movement behaviour. The barriers may therefore be more substantial than structures based on a detailed site-specific design exercise.

It should be noted that the natural terrain landslide hazards must be assessed in a sufficiently comprehensive and rigorous manner, as required for the particular problem at hand. Guidance on standard good practice in respect of natural terrain hillside studies is given by Ng et al (2002).

4. APPLICATION OF THE STANDARDISED BARRIER FRAMEWORK

4.1 General

The standardised barrier framework has been developed largely based on the methodology proposed by Lo (2000), with due account taken of detailed observations on previous natural terrain landslides in Hong Kong and back analyses. The technical basis of the standardised modules of debris-resisting barriers is presented in detail by Sun et al (2003). Further refinement of the framework may be made in due course, including development of other types of barriers, based on experience gained from the implementation of the suggested standardised barriers as well as from detailed site-specific design and implementation of other forms of debris-resisting barriers (e.g. reinforced fill embankments).

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4.2 Scope of Application

Standardised barriers may be applied to the following scenarios:

(a) as urgent protective works following significant natural terrain landslides,

(b) as design provisions or contingency measures in new or existing developments (including minor developments such as exempted small-house developments in the New Territories), and

(c) preliminary geotechnical assessments to facilitate assessment of site layout design and cost estimation.

4.3 Types and Details of Standardised Barriers

To cater for a range of typical natural hillside profiles as well as different design events with debris volumes ranging from 50 m^3 to 600 m^3, different types of standardised barriers have been developed as follows:

(a) Type 1 - These comprise reinforced concrete barriers designed to resist significant impact loads from large-scale events and accommodate the corresponding run-up heights (Figure 1). Type 1 barriers may be constructed close to the mouths of drainage lines for design events of up to 600 m^3 in volume.

(b) Type 2 - These comprise gabion units in conjunction with an L-shaped reinforced concrete wall frame, which may be constructed close to the mouths of drainage lines for design events of up to 300 m^3 in volume (Figure 2).

(c) Type 3 - These comprise reinforced gabion units with two different arrangements: Type 3A comprises a reinforced gabion shell and gabion core (Figure 3), whilst Type 3B consists of a reinforced gabion shell and rockfill core (Figure 4). Type 3 barriers may be constructed close to the mouths of a drainage lines for design events of up to 150 m^3 in volume.

(d) Type 4 - These comprise tensioned wire mesh fences to mitigate open hillslope landslides of up to 100 m^3 in volume (Figure 6).

The typical details of construction of gabion units are shown in Figure 7. The locations of Types 1, 2 and 3 barriers in the debris runout area and the minimum length of the barriers should be established using the design tables in Appendix A. The locations of

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Type 4 barriers should be established using the design table in Appendix B.

4.4 Criteria and Recommended Procedures for Application

The criteria for application of standardised barriers are given in Table 1. The recommended procedures for the assessment of standardised barriers are as follows:

(a) Determine the type of potential natural terrain landslide hazard (i.e. channelised debris flow or open hillslope landslide).

(b) Determine the design event that may affect the site in accordance with the guidance given by Ng et al (2002). For channelised debris flows, different standardised barriers may be prescribed for design events of 150 m^3, 300 m^3, 450 m^3 or 600 m^3. For open hillslope landslides, different standardised barriers may be prescribed for design events of 50 m^3 or 100 m^3.

(c) Assess the potential debris runout profile by reference to the topography of the site using 1:1000 or larger scale topographic map and check if the profile of the debris runout path satisfies the criteria in Table 1.

(d) Produce a longitudinal section of the likely debris runout path and follow the 'segment fitting' procedures as described in Appendix A for channelised debris flows and Appendix B for open hillslope landslides to determine the permissible regions within the lower segment runout area where a standardised barrier should be located.

(e) Select a standardised barrier based on the design tables in Appendices A and B for channelised debris flows and open hillslope landslides respectively and determine the minimum acceptable distance of the barrier from the start of the runout area and the minimum barrier length for a given barrier type and height.

(f) Assess the retention capacity of the standardised barrier with respect to the proposed location and dimensions of the barrier. The retention capacity of the barrier shall cater for at least twice the design volume to enhance the robustness of the design and the top surface of the landslide debris retained behind the barrier is taken to be horizontal.

(g) Confirm that the ground conditions at the possible barrier location satisfy the criteria in respect of the founding stratum as shown in Table 1, make any suitable amendments

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to the barrier location if needed and design the necessary site formation and drainage works.

(h) Where no suitable barriers amongst the standardised barriers can be selected due to site constraints, a detailed study should be carried out. In this case, the standardised barrier framework may serve as a reference for the detailed design.

A number of worked examples for the prescription of standardised barriers to mitigate channelised debris flows and open hillslope landslides are given in Appendices C and D respectively to illustrate the application of the recommended procedure.

4.5 Guidance on Application

4.5.1 General

In selecting the locations and types of barrier structures, the designer should take due account of the site conditions, maintenance requirements as well as appearance. Detailed guidelines are given by Ng et al (2002).

4.5.2 Clearance from Downhill Facilities

Types 1, 2 and 3 barriers should be located such that no building structures or sheltered facilities are within a buffer zone of 1.5 m in front of the barrier in order to allow for possible forward movement of the barrier under a more severe landslide impact event (i.e. impact by landslide debris with a volume twice that of the design event).

Type 4 barriers rely on a relatively large deformation to dissipate the impact energy and should therefore be located at least 4 m upslope of any facility above ground level to provide a buffer zone for the deformation of the barrier under debris impact.

4.5.3 Surface Drainage

Surface drainage provisions have to be site-specific to avoid undue interruption of the surface water flow. In addition to the recommendations on the design of surface drainage provisions as given in the Geotechnical Manual for Slopes (GCO, 1984) and the Highway Slope Manual (GEO, 2000a), the main considerations to be taken into account when designing the arrangement of the surface drainage system are as follows:

(a) Any surface water flow from the drainage line should be collected and directed around the barrier, or alternatively through the barrier using suitable decanting or straining measures (e.g. see Figure 22 of Lo (2000)), in such a way as to prevent any ponding upslope of the barrier. This is to reduce the possibility of build-up of high groundwater levels and reduce the potential for erosion of the material below the base of the barrier.

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(b) Drainage pipes, culverts or channels built underneath the barriers should be avoided as far as possible in order to avoid potential blockage. The surface drainage provisions should preferably be directed around the barrier so that the drainage provisions will not be affected following a debris flow.

Relevant Government departments, including the Drainage Services Department, should be consulted regarding the proposed drainage provisions since they may have an impact on the downstream drainage facilities.

4.5.4 Aesthetic and Environmental Considerations

Aesthetic and environmental considerations are important aspects that need to be addressed by the designer.

Environmental impact arising from the construction of debris-resisting barriers should be carefully considered since these may be located within natural terrain and across drainage lines. The designer should observe all relevant regulations and requirements. Depending on the details of specific sites, an environmental impact assessment may be required.

The designer should give due consideration to the necessary measures to minimise visual impact. Trees and planters could be provided to hide the barriers from direct view and reduce visual impact. Suitable surface finishes or facing could be considered to make the barrier structure less visually intrusive. Detailed guidelines on this are given by GEO (2000b).

4.5.5 Maintenance

Access for maintenance inspections and debris clearance should be provided to the upstream side of the barrier. For sites with a limited space, this could be provided via the route taken by the surface drainage channel constructed around the edge of the barrier. The maintenance access route should preferably have a minimum width of 2 m to allow access by small plant for debris clearance, as necessary.

The general principles and guidance on the maintenance requirements for natural terrain mitigation measures including debris-resisting barriers, together with the requirements for maintenance manuals, are given in Geoguide 5 (GEO, 2003) and GEO Technical Guidance Note No. 8 (GEO, 2002).

5. PERSONNEL

Given the nature of the work involved, a multi-skilled team is normally required to assess the natural terrain landslide hazards and design the necessary mitigation works (Ng et al, 2002). The location and sizing of a standardised barrier in accordance with the recommendations given in this Report, together with the associated local site formation works

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where necessary, should be specified by a professionally qualified geotechnical engineer with experience in Hong Kong. A suitable qualification is Registered Professional Engineer (Geotechnical), information on which can be obtained from the Engineers Registration Board. Engineering geological expertise is needed for certain elements of the assessment of natural terrain landslide hazards (Ng et al, 2002). Assistance from an experienced engineering geologist should therefore be sought by the responsible geotechnical professional, as necessary.

For continuity, it would be preferable if the personnel responsible for the assessment of natural terrain landslide hazards could also be made responsible for applying the standardised barrier framework.

Regular reviews should be carried out during construction. These should include an inspection of the site and an assessment of the geology, groundwater conditions and the environmental effect of works during the various stages of construction. The suitability of the layout of the barriers and drainage provisions should also be reviewed, taking due account of the actual site conditions. The professional engineer undertaking the reviews should be conversant with the design assumptions.

6. CHECKING BY GEO

Where standardised debris-resisting barriers as per this Report are to be used as permanent landslide mitigation works, GEO checking will be required as per the prevailing Environment, Transport and Works Bureau Technical Circulars (Works).

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Table 1 - Summary of Criteria for Application of the Standardised Barriers (Sheet 1 of 2)

Consideration	Criteria for Application
Design Event	- For channelised debris flows, design events volumes of 150 m^3, 300 m^3, 450 m^3 and 600 m^3 are applicable. - For open hillslope landslides, design event volumes of 50 m^3 and 100 m^3 are applicable. - The design event, including the source volume and entrainment/depositional effect along the debris runout path, should be assessed by a geotechnical professional with engineering geological expertise using the Design Event Approach in accordance with Ng et al (2002).
Design Debris Runout Profiles	- The design channel configurations are defined in Appendices A and B for channelised debris flows (three-segment profile) and open hillslope landslides (two-segment profile) respectively. - For channelised debris flows, the following criteria are relevant: • the height of the upper segment is limited to 150 m (see Figures A1 and A2); • the average depth of the landslide source is less than 2 m; • a natural drainage channel with a channelisation ratio (i.e. width to depth ratio of the cross-sectional area in a channel/depression) of less than 10 (as estimated from a 1:1 000 topographic map with 2 m interval contours, detailed survey plans or site observations) must exist for at least 30% of its length and at least 50 m in horizontal distance above the commencement of the lower segment; • at least one 10 m-long segment of the channel within the 50 m zone above the lower segment must have a channelisation ratio of less than or equal to 5 when estimated from a 1:1000 topographic map with 2 m interval contour or, detailed survey plans or site observations; • the width of the channel at the barrier location must be equal to or larger than the 'Minimum Barrier Length' shown in the design tables in Appendix A; and • where the width of a drainage line at the barrier location is greater than the 'Minimum Barrier Length' specified, the barrier is required to be extended to the edges of the drainage line. For barriers with a length that is greater than 1.5 times the 'Minimum Barrier Length' specified, a lower section of 80% of the standardised barrier height that is not longer than the total length of the barrier minus the 'Minimum Barrier Length' could be provided at the two ends of the barrier. The lower sections should be positioned such that any overspilling will not jeopardise the safety of the downhill facilities.

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Table 1 - Summary of Criteria for Application of the Standardised Barriers (Sheet 2 of 2)

Consideration	Criteria for Application
Retention Capacity	- The retention capacity of the barrier shall be at least twice the volume of the design event volume. - The top surface of the landslide debris retained behind the barrier should be assumed to be horizontal in the assessment of the retention capacity of the barrier.
Founding Stratum	<u>Types 1, 2 and 3 Standardised Barriers</u> - These barriers are to be founded on in-situ materials with no dominant weak zones (the design of Types 1, 2 and 3 standardised barriers is based on the assumptions of a material with a shear strength parameters of $c' = 0$ kPa and $\phi' = 35°$ at the founding land). - Subsoil drains may be provided where a high groundwater level is expected. Possible subsurface drainage detailing is shown in Figure 8. - The designer should also check against possible bearing capacity failure and overall slope instability where the barrier is to be constructed on sloping ground. An ultimate bearing pressure of 300 kPa at the founding level over the whole area of the base of the barrier should be considered in the assessment of overall slope stability and bearing capacity. <u>Type 4 Standardised Barrier</u> - The associated foundations and anchorages should be determined by the designer to withstand a debris impact corresponding to the energy rating of the barrier.

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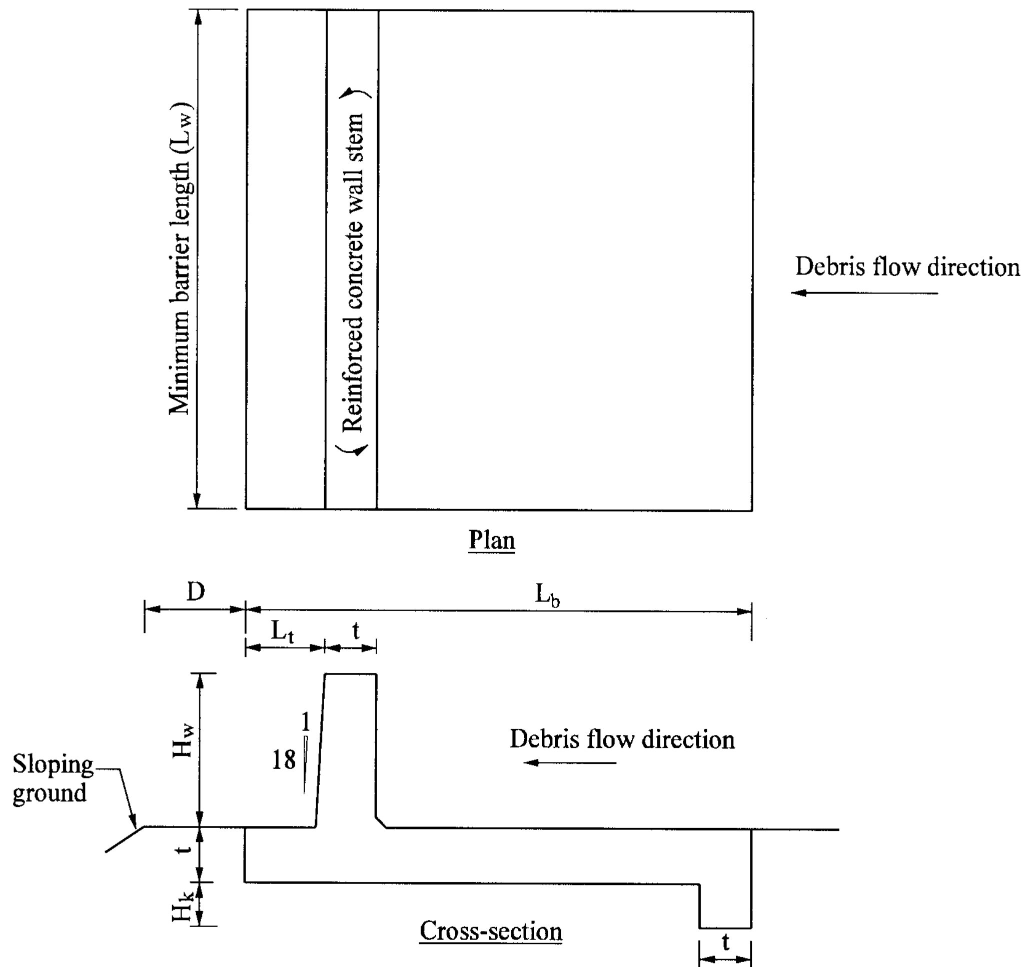

Type 1A Barrier

D	Dimensions (m)					
	H_w	L_w	L_b	L_t	t	H_k
> 4.5 m	3.5	14	10.50	0.75	1.5	0
	4.0	14	12.25	0.75	1.5	0
	4.5	16	14.25	0.75	1.5	0
≤ 4.5 m	3.5	14	11.75	0.75	1.5	0
	4.0	14	13.50	0.75	1.5	0
	4.5	16	15.50	0.75	1.5	0

Type 1B Barrier

D	Dimensions (m)					
	H_w	L_w	L_b	L_t	t	H_k
> 6.5 m	3.5	14	10.25	1.5	1.5	1
	4.0	14	11.00	1.5	1.5	1
	4.5	16	12.25	1.5	1.5	1
≤ 6.5 m	3.5	14	10.50	1.5	1.5	1
	4.0	14	11.25	1.5	1.5	1
	4.5	16	13.00	1.5	1.5	1

Notes :

(1) All dimensions are in mm unless otherwise stated.

(2) All structural concrete shall be grade 40 D. All steel reinforcement shall be grade 460 high yield to BS 4449 (BSI, 1997). Cover to reinforcement shall be 50 mm. All lap and anchorage shall be equal to 46 times bar diameter. 75 mm grade 20 blinding layer shall be provided.

(3) In all cases, dimension 'D' should not be less than 1.5 m.

(4) The barrier is required to be extended to the edges of the drainage line when the width of the drainage line at the barrier location is greater than the minimum barrier length (L_w). For barriers with a length > 1.5 L_w, a lower section of barrier (i.e. 0.8 H_w) that is not longer than the total length of the barrier minus the L_w could be provided at the two ends of the barrier. The lower sections should be positioned such that any overspillling will not jeopardise the safety of the downhill facilities.

(5) Designers may prescribe the provision of a protective layer to the back face of the barriers to minimise potential damage due to debris/boulder impact.

Figure 1 - Reinforced Concrete Barrier (Type 1 Barrier) (Sheet 1 of 2)

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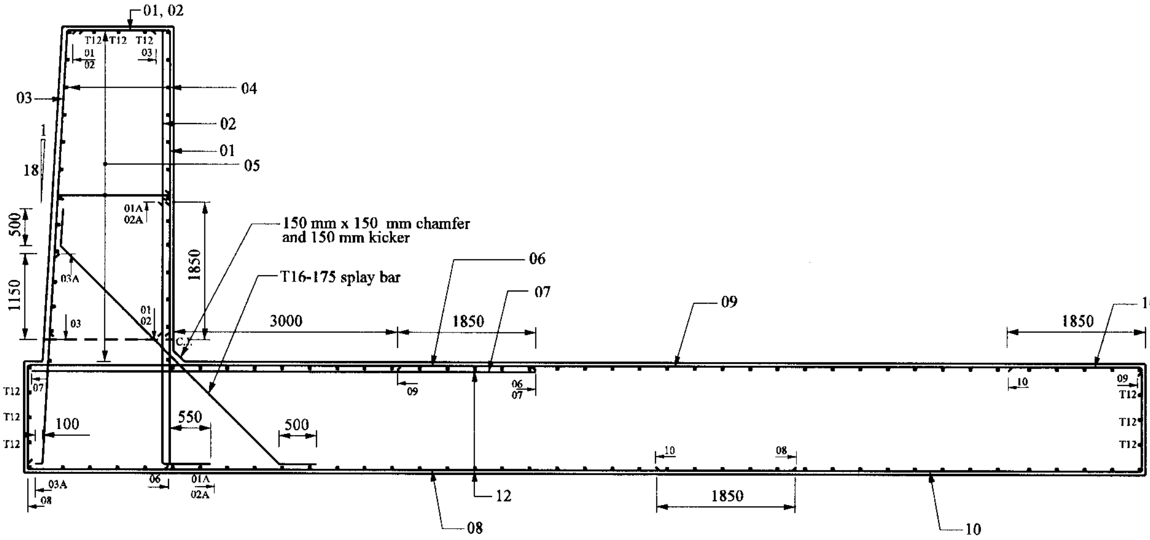
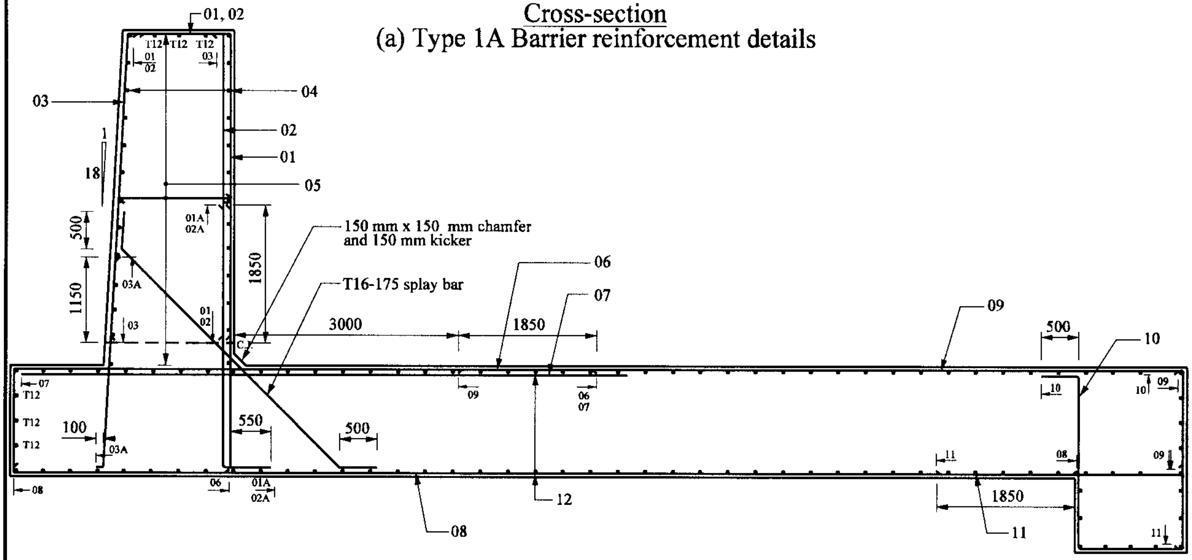


Cross-section
(a) Type 1A Barrier reinforcement details



Cross-section
(b) Type 1B Barrier reinforcement details

Scale 1:100

Bar mark / Wall Height	Wall stem					Wall base and shear key						
	01/01A	02/02A	03/03A	04	05	06	07	08	09	10	11	12
3.5	T40-175	Not required	T20-175	T25-250	T16-250 (both direction)	T40-175	Not required	T32-175	T32-175	T32-175	T32-175	T25-250
4.0	T40-225	T40-225	T25-225	T25-200	T16-200 (both direction)	T40-225	T40-225	T40-225	T40-225	T40-225	T40-225	T25-250
4.5	T40-175	T40-175	T25-175	T25-175	T16-175 (both direction)	T40-175	T40-175	T40-175	T40-175	T40-175	T40-175	T25-250

Figure 1 - Reinforced Concrete Barrier (Type 1 Barrier) (Sheet 2 of 2)

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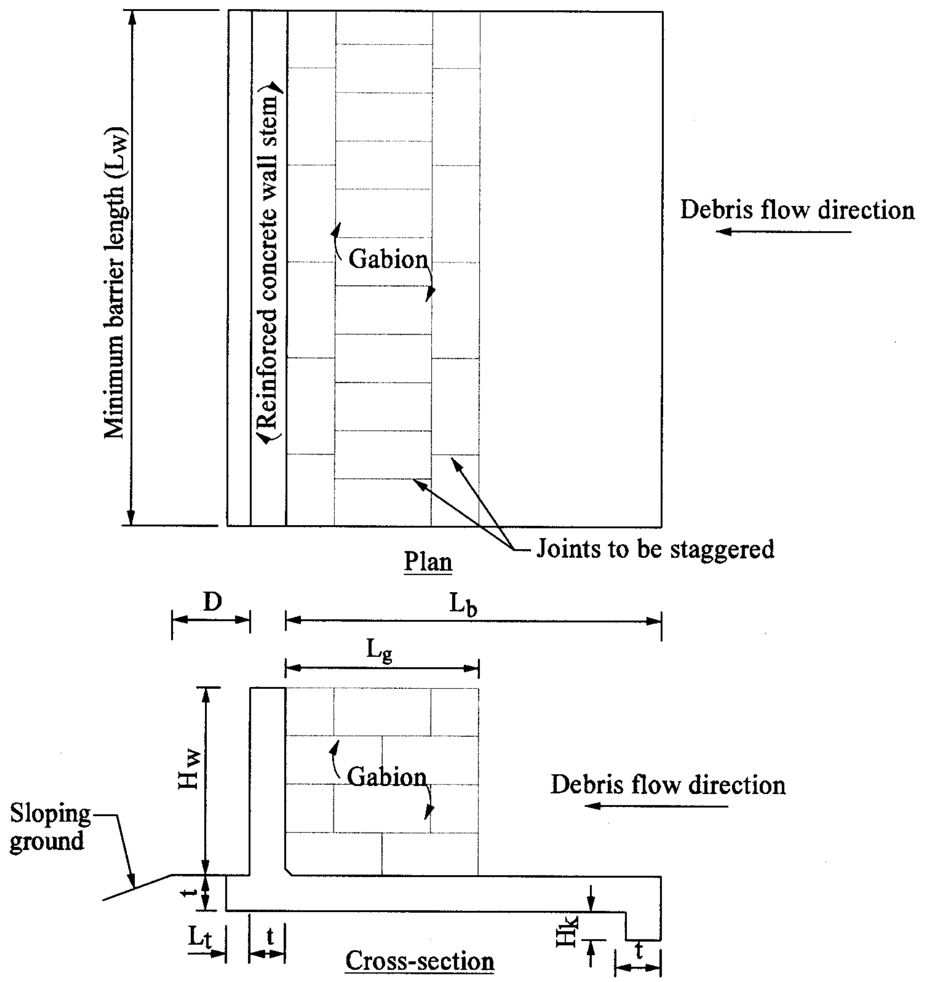

Type 2A Barrier

D	Dimensions (m)						
	H_w	L_w	L_b	L_t	t	L_g	H_k
> 2 m	3.0	10.0	7.75	0.5	0.75	3.0	0
	3.5	10.0	8.75	0.5	0.75	4.0	0
	4.0	11.0	9.25	0.5	0.75	4.5	0
⩽ 2 m	3.0	10.0	8.00	0.5	0.75	3.0	0
	3.5	10.0	9.00	0.5	0.75	4.0	0
	4.0	11.0	9.50	0.5	0.75	4.5	0

Type 2B Barrier

D	Dimensions (m)						
	H_w	L_w	L_b	L_t	t	L_g	H_k
> 4.5 m	3.0	10.0	7.50	1.0	0.75	3.0	1.0
	3.5	10.0	8.50	1.0	0.75	4.0	1.0
	4.0	11.0	9.00	1.0	0.75	4.5	1.0
⩽ 4.5 m	3.0	10.0	7.75	1.0	0.75	3.0	1.0
	3.5	10.0	8.75	1.0	0.75	4.0	1.0
	4.0	11.0	9.25	1.0	0.75	4.5	1.0

Notes :

(1) All dimensions are in mm unless otherwise stated.
(2) All structural concrete shall be grade 40 D. All steel reinforcement shall be grade 460 high yield to BS 4449 (BSI, 1997). Cover to reinforcement shall be 50 mm. All lap and anchorage shall be equal to 46 times bar diameter. 75 mm grade 20 blinding layer shall be provided.
(3) In all cases, dimension 'D' should not be less than 1.5 m.
(4) The barrier is required to be extended to the edges of the drainage line when the width of the drainage line at the barrier location is greater than the minimum barrier length (L_w). For barriers with a length > 1.5 L_w, a lower section of barrier (i.e. 0.8 H_w) that is not longer than the total length of the barrier minus the L_w could be provided at the two ends of the barrier. The lower sections should be positioned such that any overspillling will not jeopardise the safety of the downhill facilities.
(5) Refer to Figure 7 for details of gabions.

Figure 2 - Reinforced Gabion Barrier with a Reinforced Concrete Frame (Type 2 Barrier) (Sheet 1 of 2)

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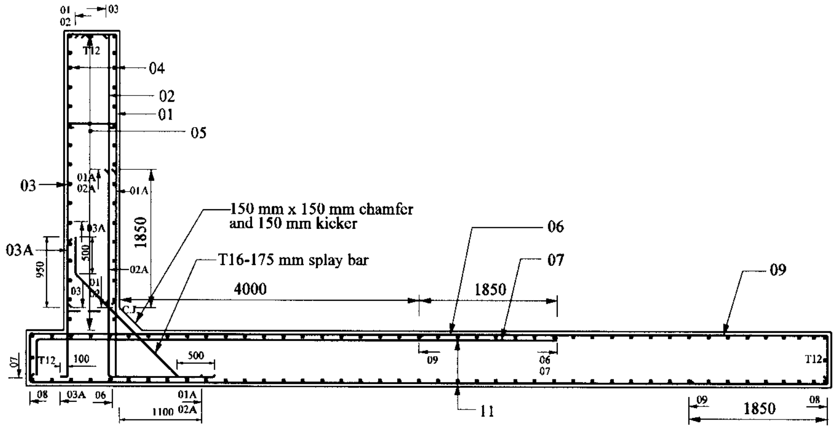
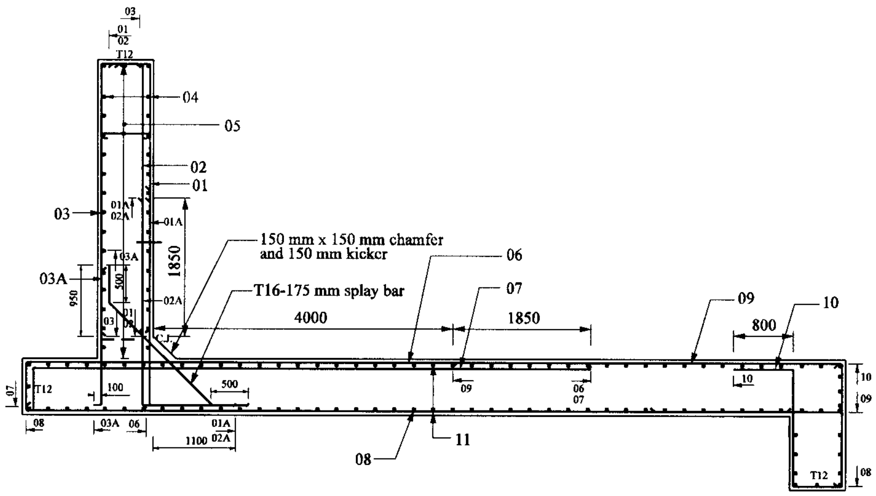


Cross-section
(a) Type 2A Barrier reinforcement details



Cross-section
(b) Type 2B Barrier reinforcement details

Scale 1:100

Bar mark / Wall Height	Wall stem					Wall base and shear key					
	01/01A	02/02A	03/03A	04	05	06	07	08	09	10	11
3.0	T40-175	Not required	T20-175	T16-200	T12-link (200 - V 350 H)	T40-175	Not required	T32-175	T32-175	T32-175	T16-200
3.5	T40-200	T40-200	T20-200	T16-200	T12-link (200 - V 400 H)	T40-200	T40-200	T40-200	T40-200	T40-200	T16-200
4.0	T40-175	T40-175	T20-175	T16-200	T16-link (400 - V 300 H)	T40-175	T40-175	T40-175	T40-175	T40-175	T16-200

Figure 2 - Reinforced Gabion Barrier with a Reinforced Concrete Frame (Type 2 Barrier) (Sheet 2 of 2)

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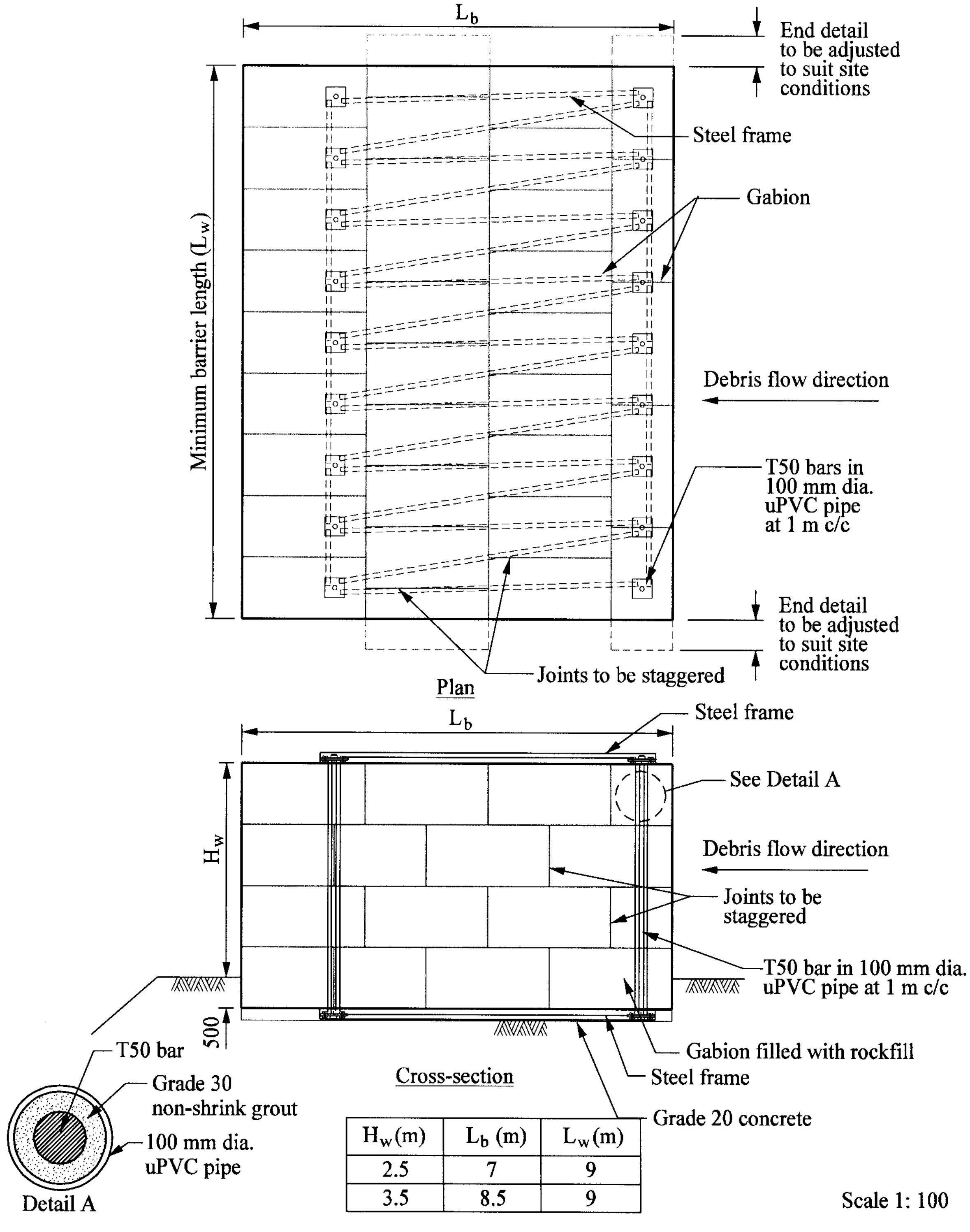

H_w(m)	L_b (m)	L_w(m)
2.5	7	9
3.5	8.5	9

Notes :
(1) Refer to Figure 5 and Figure 7 for details of steel frame and gabions respectively.
(2) The barrier is required to be extended to the edges of the drainage line when the width of the drainage line at the barrier location is greater than the minimum barrier length (L_w). For barriers with a length > 1.5 L_w, a lower section of barrier (i.e. 0.8 H_w) that is not longer than the total length of the barrier minus the L_w could be provided at the two ends of the barrier. The lower sections should be positioned such that any overspillling will not jeopardise the safety of the downhill facilities.

Figure 3 - Reinforced Gabion Barrier (Type 3A Barrier)

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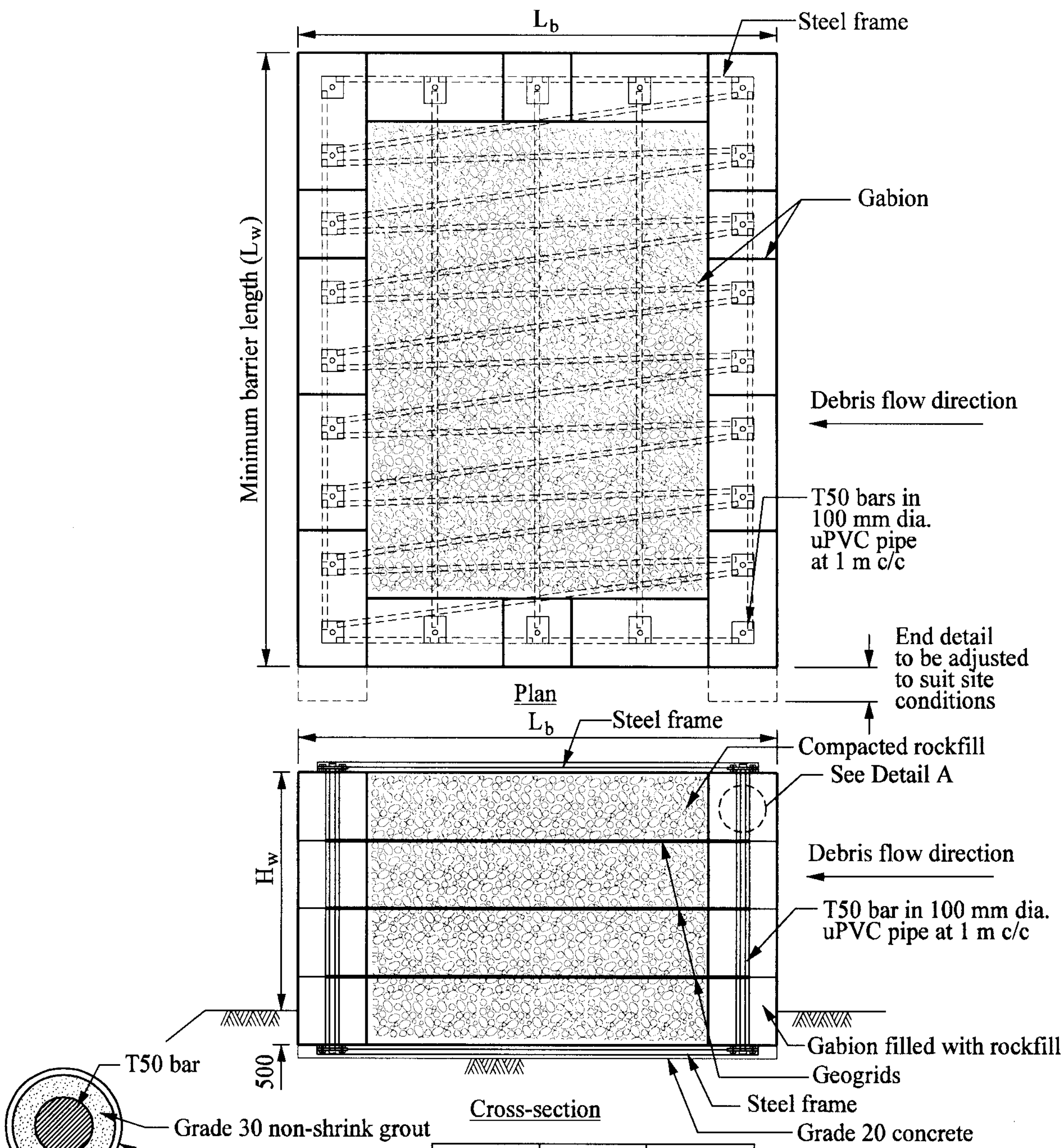

H_w(m)	L_b (m)	L_w(m)
2.5	7	9
3.5	8.5	9

Notes :

(1) Refer to Figure 5 and Figure 7 for details of steel frame and gabions respectively.

(2) Geogrids shall comply with ASTM D4595 (ASTM, 2001) with a minimum yield strength of 40 N/mm² in both direction.

(3) Geogrids shall be binded to gabions with binding wires at 250 mm spacing. Details of looping shall refer to Note (3) of Figure 7.

(4) The barrier is required to be extended to the edges of the drainage line when the width of the drainage line at the barrier location is greater than the minimum barrier length (L_w). For barriers with a length > 1.5 L_w, a lower section of barrier (i.e. 0.8 H_w) that is not longer than the total length of the barrier minus the L_w could be provided at the two ends of the barrier. The lower sections should be positioned such that any overspillling will not jeopardise the safety of the downhill facilities.

Figure 4 - Reinforced Gabion/Rockfill Barrier (Type 3B Barrier)

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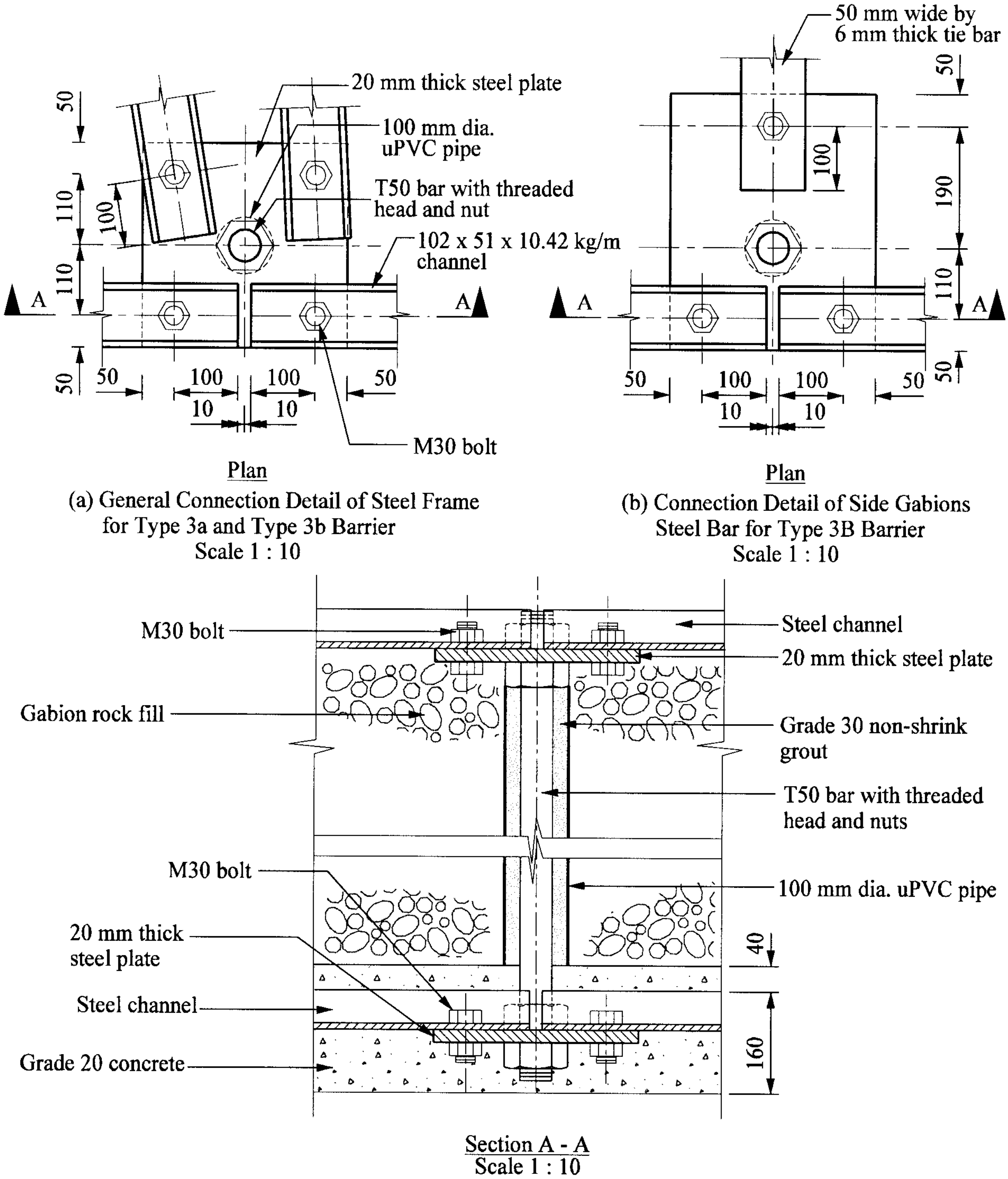

Notes :

(1) All dimensions in mm unless otherwise stated.
(2) All structural steel used shall be Grade 43.
(3) All bolts used shall be 30 mm diameter Grade 4.6.
(4) All steel members / bar shall be hot-dip galvanized to BS EN ISO 1461:1999.
(5) For the T50 reinforcement bar without hot-dip galvanised coating on either the lock nuts or the threads ends, heat-shrinkable sleeve of a proprietary type as approved by the Engineer shall be used as an alternative to hot-dip galvanization as a corrosion protection measure.

Figure 5 - Details of Steel Frame and Tie Bars for Type 3 Barrier

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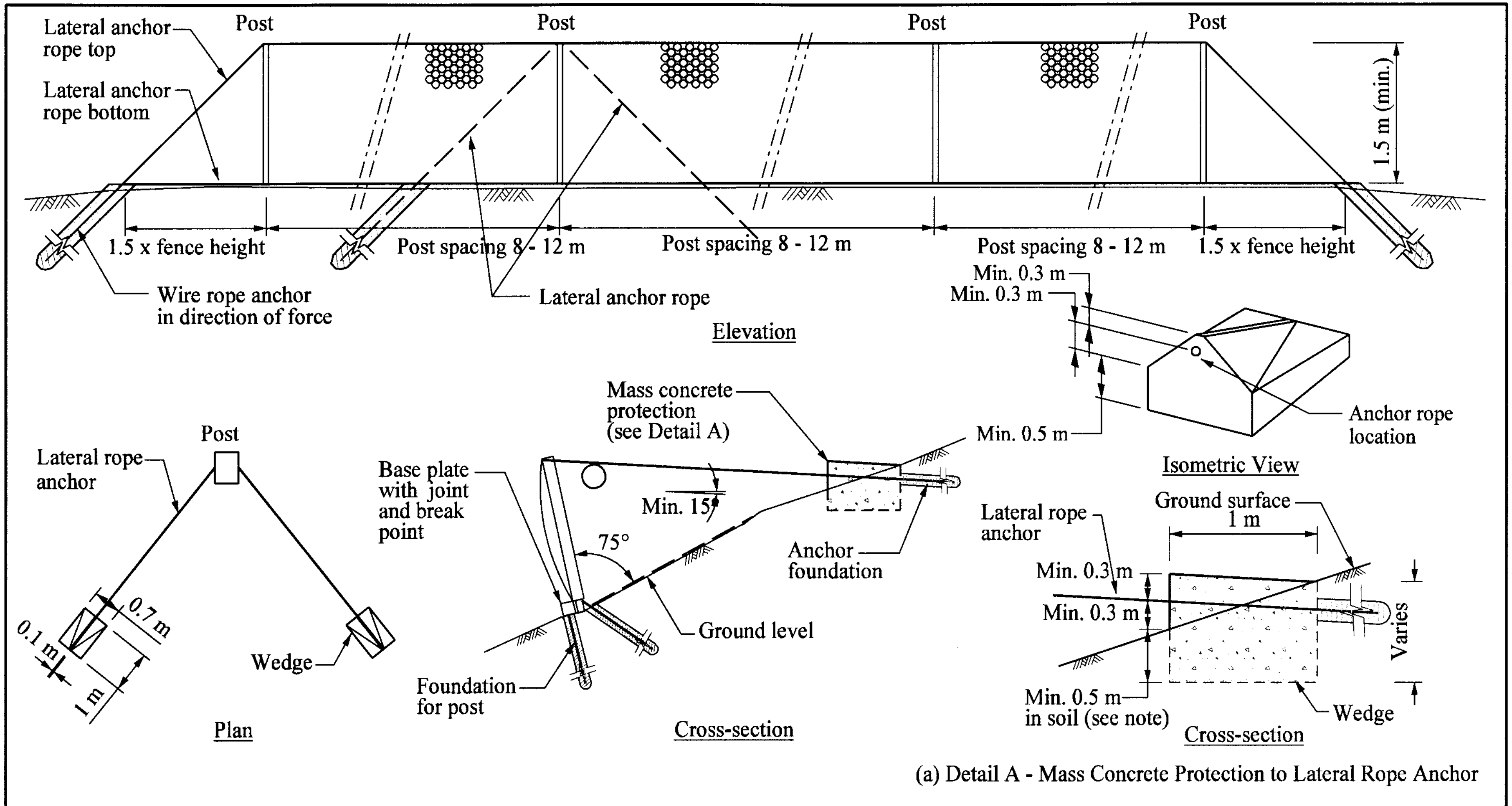

Notes :

(1) The depth of the mass concrete block may be reduced where rockhead is shallower than 1 m depth, provided that 'L' shaped dowels are used for anchorage.
(2) Where proprietary products are used, reference may be made to any special details for the foundations as recommended by the suppliers.
(3) The associated foundations and anchorages shall be determined by the designer to withstand a debris impact corresponding to the energy rating of the tensioned wire mesh fence.

Figure 6 - Tensioned Wire Mesh Fence (Type 4 Barrier)

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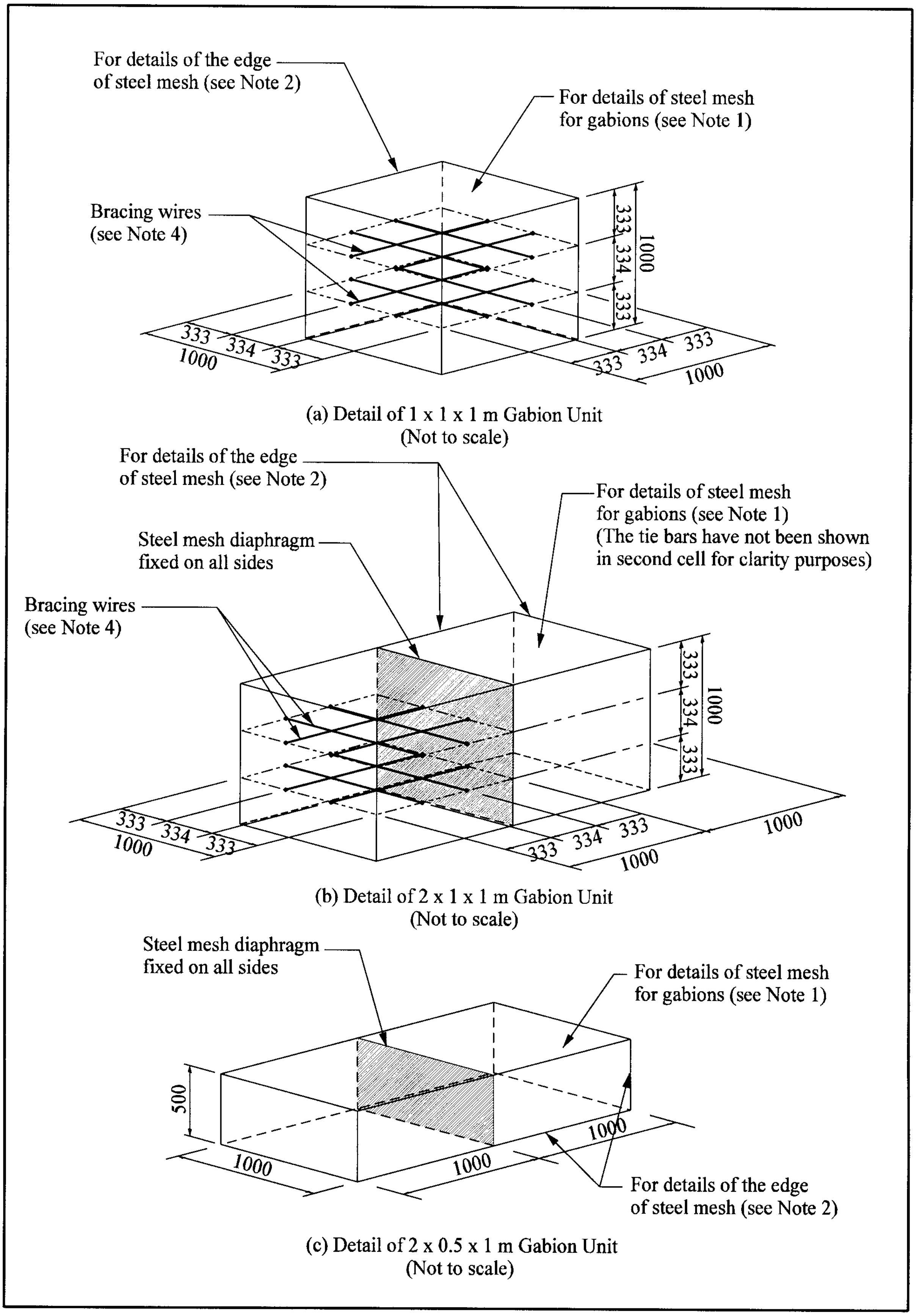

Figure 7 - Details of Gabion Construction (Sheet 1 of 2)

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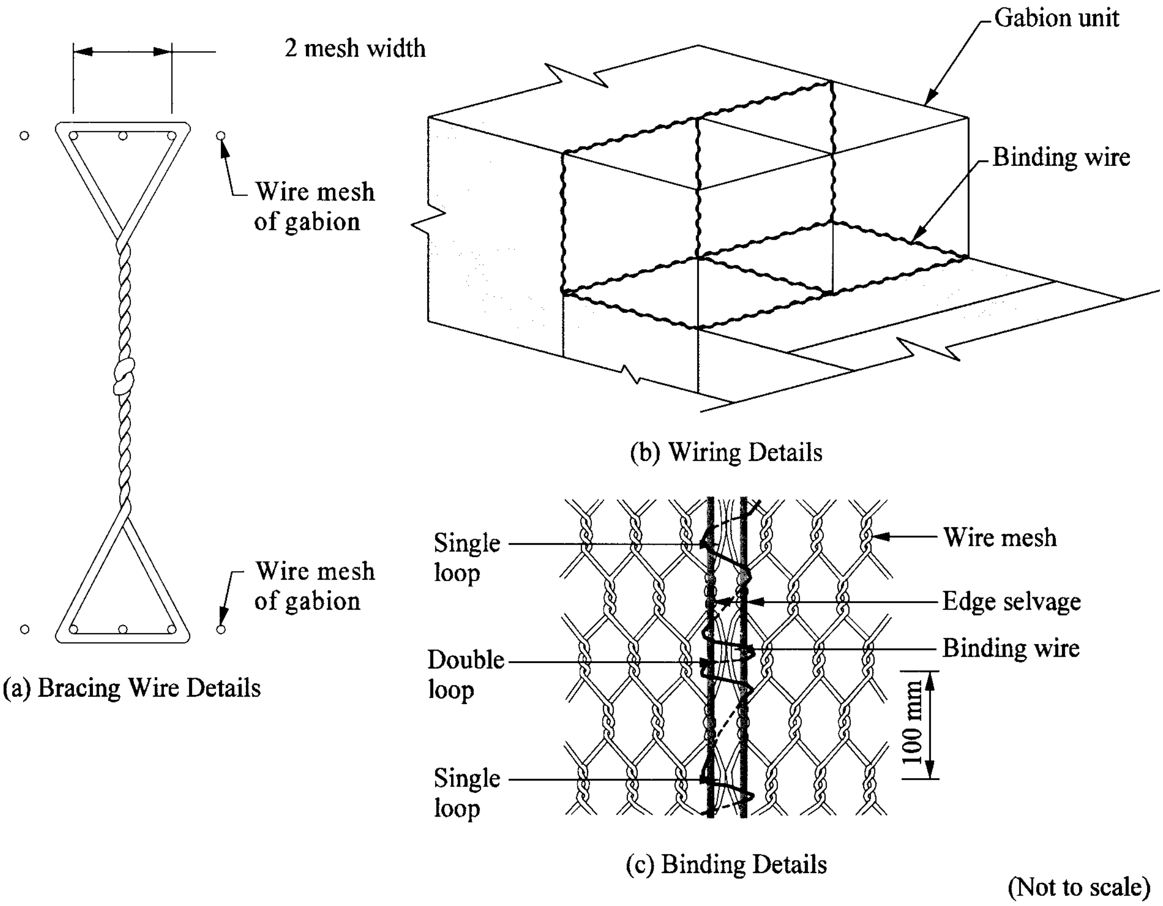

Notes :

(1) All dimensions in mm unless otherwise stated.
(2) Steel wire mesh for gabions shall consist of 100 × 125 mm hexagonal mesh made with 2.7 mm diameter PVC-coated, galvanised high tensile steel wire.
(3) The wire used for the wire-mesh should be high tensile steel wire to BS 1052 (BSI, 1980) with a minimum tensile strength of 350 N/mm².
(4) Binding wire, bracing wire and wire for edge selvage used for gabion construction should be of the same quality as the wires used for the wire-mesh.
(5) The galvanisation of the wires shall comply with BS443 (BSI, 1982).
(6) The PVC coating should be at least 0.5 mm thick and comply with BS4102 (BSI, 1990).
(7) The edges of the mesh and the gabion units should be selvaged with wires of a diameter of about 1.5 m times that of the wire-mesh (i.e. 3.9 mm min.) to prevent unravelling. The wire should be galvanised and PVC-coated.
(8) Binding wires shall be laced around selvages with single loops and double loops in turn at 100 mm intervals. The end of the binding wires shall have a return loop of 100 mm. Individual ties of binding wire shall not be used.
(9) Rockfill used to fill gabion units shall consist of sound, clean, well-graded hard/durable rock fragments showing no discoloration or other evidence of decomposition.
(10) The maximum size of the rock used should not exceed two-thirds the depth of the gabion to be filled or 300 mm, whichever is less.
(11) The smallest dimension of the rock should at least be twice the largest dimension of the mesh aperture.
(12) The gabion units should be tightly infilled in order to achieve minimum voids and maximum density.

Figure 7 - Details of Gabion Construction (Sheet 2 of 2)

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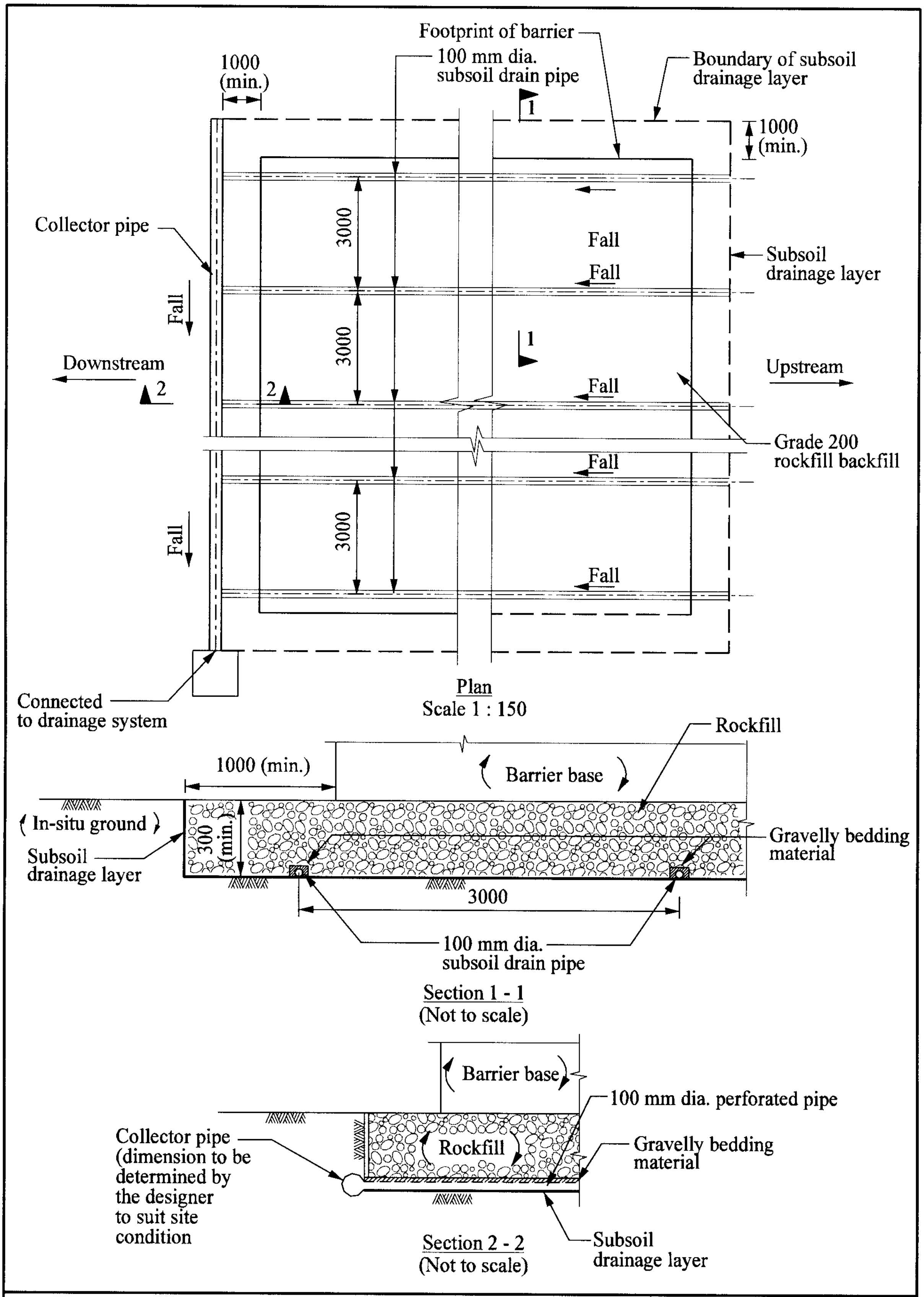

Note : All dimensions in mm unless otherwise stated.

Figure 8 - Typical Details of Barrier Base Drainage

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APPENDIX A

DETERMINATION OF THE DESIGN DEBRIS RUNOUT PROFILE AND POTENTIALLY SUITABLE BARRIER LOCATIONS FOR CHANNELISED DEBRIS FLOWS

CONTENTS

A.1 INTRODUCTION

This Appendix describes the procedures and compliance conditions for selection of the Design Debris Runout Profiles that are representative of the site-specific ground profile under consideration and the potentially suitable barrier locations within the runout area. Tables A1 to A3 show the upper-bound runout distance in lower segment (i.e. commenced from Node Point No. 1, see Figures A1 and A2) for channelised debris flow for respective landslide volumes based on historical data of natural terrain landslides in Hong Kong. Beyond these distances, barriers are generally not required for the respective design volume. A set of tables (A4 to A34), shown in this Appendix, has been prepared in which the minimum acceptable distance from the start of the runout area and minimum barrier width are provided for a given Design Debris Runout Profile. Worked examples that illustrate the selection and positioning of barrier are given in Appendix C.

A.2 GLOSSARY OF TERMS

The terms used in this Appendix relating to the determination of the Design Debris Runout Profiles are defined as follows:

Design Debris Runout Profile. The Design Debris Runout Profile is an idealised debris runout profile to assist the selection of a suitable barrier from the design tables given in this Appendix. The Design Debris Runout Profile comprises an upper segment of 34° steep, and middle and lower segment that vary in inclination as shown in Figures A1 and A2. Any combination of segments that can be fitted to the ground profile, and which meets the conditions for 'template fitting' as shown in Figures A1 and A2, may constitute a Design Debris Runout Profile.

Template. A set of Design Debris Runout Profiles with two different lengths of the middle segment (50 m for Template A and 25 m for Template B) to assist the selection of a simplified Design Debris Runout Profile to represent the actual ground profile for the purposes of assessment of standardised barrier requirements (see Section A.3).

A.3 METHODOLOGY FOR DETERMINING SUITABLE LOCATION OF BARRIER

The method for determining acceptable segments of the ground profile for position of barriers involves the application of the Three-segment profile to produce a simplified Design Debris Runout Profile from a 'best-fit' of the actual ground profile.

To select a Design Debris Runout Profile to represent the actual ground profile, the standard Template is moved along the ground profile while keeping Node Point No. 1 (which marks the start of the runout area) co-incident with the ground profile.

The application of the Three-segment profile for an actual drainage line profile is demonstrated in Examples 1 to 4 in Figures A3 to A9. The compliant portions within the lower segment runout area are highlighted in blue in the Figures.

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Example No. 1 shows a case where there are no acceptable segments of the ground profile because the overall inclination of the ground profile in the upper segment area is steeper than that allowed for in the standardised barrier framework (see Figure A3).

Example No. 2 shows a case where the overall inclination of the ground profile beneath the upper segment and middle segment is acceptable and where a short length of the lower segment is also acceptable for the location of a barrier (Segment A). In this case, the inclination of the middle segment is the same as the upper segment and so the length of the middle segment can be taken as zero for the purposes of determining a suitable barrier from the design tables (see Figures A4 and A5).

Example No. 3 shows a case where there are no acceptable portion of the lower segment because the overall inclination of the ground profile in the middle segment area is steeper than that allowed for in the standardised barrier framework (see Figures A6 and A7).

Example No. 4 shows a case where the overall ground profile above Node Point No. 1 is acceptable. A significant portion of the ground profile within the lower segment runout area is also acceptable for the location of a barrier. The acceptable segments (Segments B, C, D and E) are located where the inclinations of the overall and local ground profile within the lower segment area are equal to or flatter than the inclination of one of the particular lower segments that can be used to form the Design Debris Runout Profile. In this case, the irregularities and steps in the lower segment area lead to different inclinations of segment being applicable at different distances from the commencement of the runout area (i.e. Node Point No. 1). For this example, all four Design Debris Runout Profiles have a common middle segment of 26°.

Worked examples of determining the minimum distance of the barrier from the commencement of the runout area are shown in Appendix C.

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LIST OF TABLES

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Table A1 - Upper-bound Runout Distance in Lower Segment for Channelised Debris Flow (Design Volume = 150 m^3)

Upper-bound Runout Distance (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	70	80	80	80	80	80	80	80	90	90	90
	5°	75	80	80	85	85	85	90	90	90	90	90
	7.5°	85	90	90	90	95	95	95	95	100	100	100
	10°	95	105	105	105	105	105	110	110	110	110	110
	12.5°	110	120	120	120	120	120	125	125	130	130	130

Table A2 -Upper-bound Runout Distance in Lower Segment for Channelised Debris Flow (Design Volume = 300 m^3)

Upper-bound Runout Distance (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	90	100	110	110	120	120	120	120	120	120	120
	5°	100	110	120	120	120	120	130	130	130	130	130
	7.5°	110	120	120	130	130	130	130	130	130	130	130
	10°	125	135	135	140	140	140	140	150	150	150	150
	12.5°	150	160	160	160	160	160	160	170	170	170	170

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Table A3 - Upper-bound Runout Distance in Lower Segment for Channelised Debris Flow (Design Volume = 450 m^3 and 600 m^3)

Upper-bound Runout Distance (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	120	140	150	150	160	160	160	160	170	170	170
	5°	130	150	160	160	170	170	170	170	180	180	180
	7.5°	150	160	170	170	170	170	180	180	190	190	190
	10°	170	180	180	180	190	190	190	190	200	200	200
	12.5°	220	220	220	225	225	225	225	225	225	225	225

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Table A4 - 4.5 m High Type 1 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	0	0	0	2	2	4	4	6	6	6	6
		16	16	16	16	16	16	16	16	16	16	16
	5°	0	0	0	2	4	4	6	6	6	7	7
		16	16	16	16	16	16	16	16	16	16	16
	7.5°	0	0	0	4	4	6	6	7	7	9	9
		16	16	16	16	16	16	16	16	16	16	16
	10°	0	0	0	4	6	7	7	9	9	9	11
		16	16	16	16	16	16	16	16	16	16	16
	12.5°	0	0	0	6	6	7	9	9	11	11	12
		16	16	16	16	16	16	16	16	16	16	16

Table A5 - 4.5 m High Type 1 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	7	11	11	14	12	16	14	16	16	17	17
		16	16	16	16	16	16	16	16	16	16	16
	5°	9	12	12	14	14	17	17	19	19	19	19
		16	16	16	16	16	16	16	16	16	16	16
	7.5°	11	14	14	17	17	19	19	21	21	23	23
		16	16	16	16	16	16	16	16	16	16	16
	10°	12	16	16	19	19	23	23	24	26	26	28
		16	16	16	16	16	16	16	16	16	16	16
	12.5°	14	19	19	21	23	26	28	29	31	31	33
		16	16	16	16	16	16	16	16	16	16	16

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Table A6 - 4.5 m High Type 1 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	17	20	18	24	22	24	24	25	25	25	25
		16	16	16	16	16	16	16	16	16	16	16
	5°	20	24	22	27	25	29	29	31	31	31	31
		16	16	16	16	16	16	16	16	16	16	16
	7.5°	24	29	25	33	31	36	36	37	36	38	40
		16	16	16	16	16	16	16	16	16	16	16
	10°	29	36	34	41	39	42	42	42	42	43	47
		16	16	16	16	16	16	16	16	16	16	16
	12.5°	39	46	44	46	46	49	49	51	50	51	57
		16	16	16	16	16	16	16	16	16	16	16

Table A7 - 4.5 m High Type 1 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	29	34	33	38	34	39	38	39	38	39	40
		16	16	16	16	16	16	16	16	16	16	16
	5°	34	39	36	43	41	46	45	46	46	48	48
		16	16	16	16	16	16	16	16	16	16	16
	7.5°	43	48	46	53	53	56	55	59	56	60	62
		16	16	16	16	16	16	16	16	16	16	16
	10°	60	65	60	67	66	69	66	69	68	70	73
		16	16	16	16	16	16	16	16	16	16	16
	12.5°	78	79	78	81	81	84	86	86	87	87	90
		16	16	16	16	16	16	16	16	16	16	16

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Table A8 - 4.0 m High Type 1 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	0	4	4	6	6	7	7	7	7	9	9
		14	14	14	14	14	14	14	14	14	14	14
	5°	0	4	4	6	7	7	7	9	9	11	11
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	0	4	6	7	7	9	9	11	11	12	12
		14	14	14	14	14	14	14	14	14	14	14
	10°	0	6	6	9	9	11	11	12	12	14	14
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	0	6	7	9	11	12	12	14	16	16	17
		14	14	14	14	14	14	14	14	14	14	14

Table A9 - 4.0 m High Type 1 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	12	16	16	17	17	19	19	21	21	21	21
		14	14	14	14	14	14	14	14	14	14	14
	5°	16	19	16	19	19	23	23	23	24	24	24
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	17	21	21	24	24	26	26	26	28	28	31
		14	14	14	14	14	14	14	14	14	14	14
	10°	21	24	24	28	28	31	33	34	36	36	36
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	26	31	28	34	36	41	45	45	50	50	50
		14	14	14	14	14	14	14	14	14	14	14

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Table A10 - 4.0 m High Type 1 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	33	36	34	36	34	36	35	37	35	37	38
		14	14	14	14	14	14	14	14	14	14	14
	5°	38	42	40	42	42	43	42	43	42	43	43
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	48	49	48	50	48	54	49	54	50	54	54
		14	14	14	14	14	14	14	14	14	14	14
	10°	59	61	60	61	60	61	60	61	61	62	65
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	84	85	84	85	84	85	85	86	86	86	95
		14	14	14	14	14	14	14	14	14	14	14

Table A11 - 4.0 m High Type 1 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	45	50	48	53	50	53	51	53	51	53	53
		14	14	14	14	14	14	14	14	14	14	14
	5°	55	61	61	63	61	63	63	63	63	63	63
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	73	73	73	74	73	74	74	75	74	75	75
		14	14	14	14	14	14	14	14	14	14	14
	10°	88	90	90	91	90	91	91	92	92	93	94
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	Standardised Barrier Not Applicable										

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Table A12 - 3.5 m High Type 1 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	4	7	7	9	9	11	11	11	11	12	12
		14	14	14	14	14	14	14	14	14	14	14
	5°	6	7	7	11	11	11	12	12	12	14	14
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	6	9	9	11	12	12	14	14	16	16	16
		14	14	14	14	14	14	14	14	14	14	14
	10°	7	11	11	12	14	16	16	17	19	19	19
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	9	12	12	16	16	17	19	21	24	24	24
		14	14	14	14	14	14	14	14	14	14	14

Table A13 - 3.5 m High Type 1 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	19	21	19	23	23	24	24	26	26	26	26
		14	14	14	14	14	14	14	14	14	14	14
	5°	19	23	23	26	26	28	28	29	31	31	33
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	23	28	28	33	33	33	34	34	35	36	37
		14	14	14	14	14	14	14	14	14	14	14
	10°	28	36	36	37	37	41	41	42	42	42	46
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	40	46	48	50	51	53	54	55	56	56	64
		14	14	14	14	14	14	14	14	14	14	14

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Table A14 - 3.5 m High Type 1 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	34	36	34	36	34	36	35	37	36	38	41
		14	14	14	14	14	14	14	14	14	14	14
	5°	38	42	40	42	42	43	43	43	44	44	45
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	48	49	48	50	48	54	49	54	50	54	55
		14	14	14	14	14	14	14	14	14	14	14
	10°	61	61	63	65	63	65	65	67	66	67	83
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	113	115	117	119	119	121	122	124	124	124	136
		14	14	14	14	14	14	14	14	14	14	14

Table A15 - 3.5 m High Type 1 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	46	50	50	54	53	54	53	54	54	55	55
		14	14	14	14	14	14	14	14	14	14	14
	5°	57	63	61	63	63	63	63	63	63	65	65
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	75	77	75	78	75	78	75	78	76	78	79
		14	14	14	14	14	14	14	14	14	14	14
	10°	90	101	100	109	111	120	125	127	131	139	179
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	Standardised Barrier Not Applicable										

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Table A16 - 4.0 m High Type 2 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	0	4	4	6	6	7	7	7	7	9	9
		11	11	11	11	11	11	11	11	11	11	11
	5°	0	4	4	6	7	7	7	9	9	11	11
		11	11	11	11	11	11	11	11	11	11	11
	7.5°	0	4	6	7	7	9	9	11	11	12	12
		11	11	11	11	11	11	11	11	11	11	11
	10°	0	6	6	9	9	11	11	12	12	14	14
		11	11	11	11	11	11	11	11	11	11	11
	12.5°	0	6	7	9	11	12	12	14	16	16	17
		11	11	11	11	11	11	11	11	11	11	11

Table A17 - 4.0 m High Type 2 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	14	17	17	19	19	21	21	23	22	23	23
		11	11	11	11	11	11	11	11	11	11	11
	5°	16	19	17	23	21	24	24	26	26	26	26
		11	11	11	11	11	11	11	11	11	11	11
	7.5°	19	23	21	26	26	28	29	31	31	31	33
		11	11	11	11	11	11	11	11	11	11	11
	10°	23	26	26	31	31	38	38	38	39	41	41
		11	11	11	11	11	11	11	11	11	11	11
	12.5°	31	36	35	39	43	46	51	52	52	52	53
		11	11	11	11	11	11	11	11	11	11	11

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Table A18 - 4.0 m High Type 2 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	33	36	34	36	34	36	35	37	36	38	40
		12	12	12	11	11	11	11	11	11	11	11
	5°	40	42	41	42	43	43	43	44	43	44	45
		12	12	12	11	11	11	11	11	11	11	11
	7.5°	48	49	48	51	49	54	50	54	51	54	54
		12	12	12	11	11	11	11	11	11	11	11
	10°	59	61	60	61	61	62	62	63	63	64	70
		12	12	12	11	11	11	11	11	11	11	11
	12.5°	86	87	86	87	87	88	88	89	89	89	116
		12	12	12	11	11	11	11	11	11	11	11

Table A19 - 4.0 m High Type 2 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	45	51	48	53	50	53	51	53	51	53	53
		13	13	13	13	12	12	12	12	12	12	12
	5°	56	63	61	64	61	64	63	64	64	64	64
		13	13	13	13	13	12	12	12	12	12	12
	7.5°	73	75	73	76	73	76	74	76	74	76	77
		13	13	13	13	13	12	12	12	12	12	12
	10°	90	91	90	93	91	93	91	93	92	93	103
		13	13	13	13	13	12	12	12	12	12	12
	12.5°	Standardised Barrier Not Applicable										

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Table A20 - 3.5 m High Type 2 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	4	7	7	9	9	11	11	11	11	12	12
		10	10	10	10	10	10	10	10	10	10	10
	5°	6	7	7	11	11	11	12	12	12	14	14
		10	10	10	10	10	10	10	10	10	10	10
	7.5°	6	9	9	11	12	12	14	14	16	16	16
		10	10	10	10	10	10	10	10	10	10	10
	10°	7	11	11	12	14	16	16	17	19	19	19
		10	10	10	10	10	10	10	10	10	10	10
	12.5°	9	12	12	16	16	17	19	21	24	24	24
		10	10	10	10	10	10	10	10	10	10	10

Table A21 - 3.5 m High Type 2 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	23	24	24	25	24	26	26	26	26	28	28
		11	11	11	10	10	10	10	10	10	10	10
	5°	28	29	28	30	28	31	29	33	33	33	34
		11	11	11	10	10	10	10	10	10	10	10
	7.5°	33	34	33	34	34	39	39	39	39	39	41
		11	11	11	10	10	10	10	10	10	10	10
	10°	43	43	43	43	43	45	46	49	50	50	50
		11	11	11	10	10	10	10	10	10	10	10
	12.5°	51	53	51	53	55	55	57	57	59	59	65
		11	11	11	11	10	10	10	10	10	10	10

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Table A22 - 3.5 m High Type 2 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	38	39	42	42	42	42	42	42	42	42	42
		12	12	12	11	11	11	11	11	11	11	11
	5°	47	49	47	49	49	51	50	51	51	51	52
		12	12	12	11	11	11	11	11	11	11	11
	7.5°	53	56	54	56	56	57	57	58	57	58	58
		12	12	12	11	11	11	11	11	11	11	11
	10°	76	77	76	77	77	78	77	78	77	78	84
		12	12	12	11	11	11	11	11	11	11	11
	12.5°	Standardised Barrier Not Applicable										

Table A23 - 3.5 m High Type 2 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	58	60	58	61	58	64	59	64	60	64	64
		13	13	13	13	12	12	12	12	12	12	12
	5°	69	70	70	71	70	71	70	71	71	71	71
		13	13	13	13	13	12	12	12	12	12	12
	7.5°	80	83	81	84	83	85	84	85	85	86	86
		13	13	13	13	13	12	12	12	12	12	12
	10°	Standardised Barrier Not Applicable										
	12.5°											

Table A24 - 3.0 m High Type 2 Barrier (Design Volume = 150 m^3)

Inclination of Lower Segment	Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)	Inclination 14°, Segment Length 50 m	Inclination 14°, Segment Length 25 m	Inclination 18°, Segment Length 50 m	Inclination 18°, Segment Length 25 m	Inclination 22°, Segment Length 50 m	Inclination 22°, Segment Length 25 m	Inclination 26°, Segment Length 50 m	Inclination 26°, Segment Length 25 m	Inclination 30°, Segment Length 50 m	Inclination 30°, Segment Length 25 m	Inclination 34°, Segment Length 0 m
2.5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	9	11	11	12	12	14	14	16	16	16	16
	Minimum Barrier Length (m)	10	10	10	10	10	10	10	10	10	10	10
5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	9	12	12	14	16	16	17	17	17	17	19
	Minimum Barrier Length (m)	10	10	10	10	10	10	10	10	10	10	10
7.5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	11	14	14	17	17	19	19	21	23	23	23
	Minimum Barrier Length (m)	10	10	10	10	10	10	10	10	10	10	10
10°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	14	17	17	19	21	24	26	26	26	26	28
	Minimum Barrier Length (m)	10	10	10	10	10	10	10	10	10	10	10
12.5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	17	21	23	26	28	28	31	31	32	32	34
	Minimum Barrier Length (m)	10	10	10	10	10	10	10	10	10	10	10

Table A25 - 3.0 m High Type 2 Barrier (Design Volume = 300 m^3)

Inclination of Lower Segment	Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)	Inclination 14°, Segment Length 50 m	Inclination 14°, Segment Length 25 m	Inclination 18°, Segment Length 50 m	Inclination 18°, Segment Length 25 m	Inclination 22°, Segment Length 50 m	Inclination 22°, Segment Length 25 m	Inclination 26°, Segment Length 50 m	Inclination 26°, Segment Length 25 m	Inclination 30°, Segment Length 50 m	Inclination 30°, Segment Length 25 m	Inclination 34°, Segment Length 0 m
2.5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	31	33	31	34	33	34	33	34	33	34	34
	Minimum Barrier Length (m)	11	11	11	10	10	10	10	10	10	10	10
5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	36	39	36	39	36	41	38	41	38	41	41
	Minimum Barrier Length (m)	11	11	11	10	10	10	10	10	10	10	10
7.5°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	46	48	48	49	48	50	48	50	48	50	50
	Minimum Barrier Length (m)	11	11	11	10	10	10	10	10	10	10	10
10°	Minimum Distance of Barrier Downslope of Node Point No. 1 (m)	59	60	59	60	59	60	59	60	61	61	71
	Minimum Barrier Length (m)	11	11	11	10	10	10	10	10	10	10	10
12.5°		Standardised Barrier Not Applicable										

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Table A26 - 3.0 m High Type 2 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	47	47	47	48	48	49	48	49	48	49	49
		12	12	12	11	11	11	11	11	11	11	11
	5°	64	65	65	67	66	67	67	68	67	69	69
		12	12	12	11	11	11	11	11	11	11	11
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

Table A27 - 3.0 m High Type 2 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	66	69	66	69	66	69	66	69	66	69	69
		13	13	13	13	12	12	12	12	12	12	12
	5°	85	86	85	86	85	86	85	86	85	86	86
		13	13	13	13	13	12	12	12	12	12	12
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

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Table A28 - 3.5 m High Type 3 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	4	9	9	11	11	14	12	14	14	14	14
		9	9	9	9	9	9	9	9	9	9	9
	5°	6	11	9	11	11	16	14	16	16	17	17
		9	9	9	9	9	9	9	9	9	9	9
	7.5°	6	12	11	16	14	17	17	19	19	21	21
		9	9	9	9	9	9	9	9	9	9	9
	10°	7	14	12	17	17	21	23	23	24	26	26
		9	9	9	9	9	9	9	9	9	9	9
	12.5°	9	17	14	19	23	28	28	31	33	35	36
		9	9	9	9	9	9	9	9	9	9	9

Table A29 - 3.5 m High Type 3 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	34	38	38	41	39	43	43	45	44	45	45
		11	11	11	10	10	10	10	10	10	10	10
	5°	41	46	43	49	47	51	51	51	51	51	52
		11	11	11	10	10	10	10	10	10	10	10
	7.5°	54	55	56	58	58	58	58	59	60	60	63
		11	11	11	10	10	10	10	10	10	10	10
	10°	67	67	68	70	71	72	74	74	78	78	80
		11	11	11	10	10	10	10	10	10	10	10
	12.5°	Standardised Barrier Not Applicable										

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Table A30 - 3.5 m High Type 3 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	50	51	51	52	51	52	51	52	52	52	52
		12	12	12	11	11	11	11	11	11	11	11
	5°	67	67	67	68	67	68	68	68	68	69	69
		12	12	12	11	11	11	11	11	11	11	11
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

Table A31 - 3.5 m High Type 3 Barrier (Design Volume = 600 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	71	74	71	74	71	74	71	74	71	74	74
		13	13	13	13	12	12	12	12	12	12	12
	5°	97	98	97	98	97	98	97	98	97	98	98
		13	13	13	13	13	12	12	12	12	12	12
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

Table A32 - 2.5 m High Type 3 Barrier (Design Volume = 150 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	17	21	19	21	21	23	21	23	23	23	23
		9	9	9	9	9	9	9	9	9	9	9
	5°	21	24	24	26	26	28	28	28	28	28	29
		9	9	9	9	9	9	9	9	9	9	9
	7.5°	28	31	31	31	31	33	33	34	33	34	34
		9	9	9	9	9	9	9	9	9	9	9
	10°	38	38	39	39	39	40	40	40	40	40	43
		9	9	9	9	9	9	9	9	9	9	9
	12.5°	51	54	56	57	58	59	59	60	60	61	63
		9	9	9	9	9	9	9	9	9	9	9

Table A33 - 2.5 m High Type 3 Barrier (Design Volume = 300 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	47	48	47	48	48	48	48	49	50	50	
		11	11	11	10	10	10	10	10	10	10	
	5°	68	71	68	71	68	71	68	71	68	71	
		11	11	11	10	10	10	10	10	10	10	
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

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Table A34 - 2.5 m High Type 3 Barrier (Design Volume = 450 m^3)

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	68 / 12	69 / 12	69 / 12	71 / 11	69 / 11	72 / 11	70 / 11	72 / 11	71 / 11	72 / 11	72 / 11
	5°	130 / 12	133 / 12	131 / 12	133 / 11	131 / 11	133 / 11	131 / 11	133 / 11	131 / 11	133 / 11	
	7.5°	Standardised Barrier Not Applicable										
	10°											
	12.5°											

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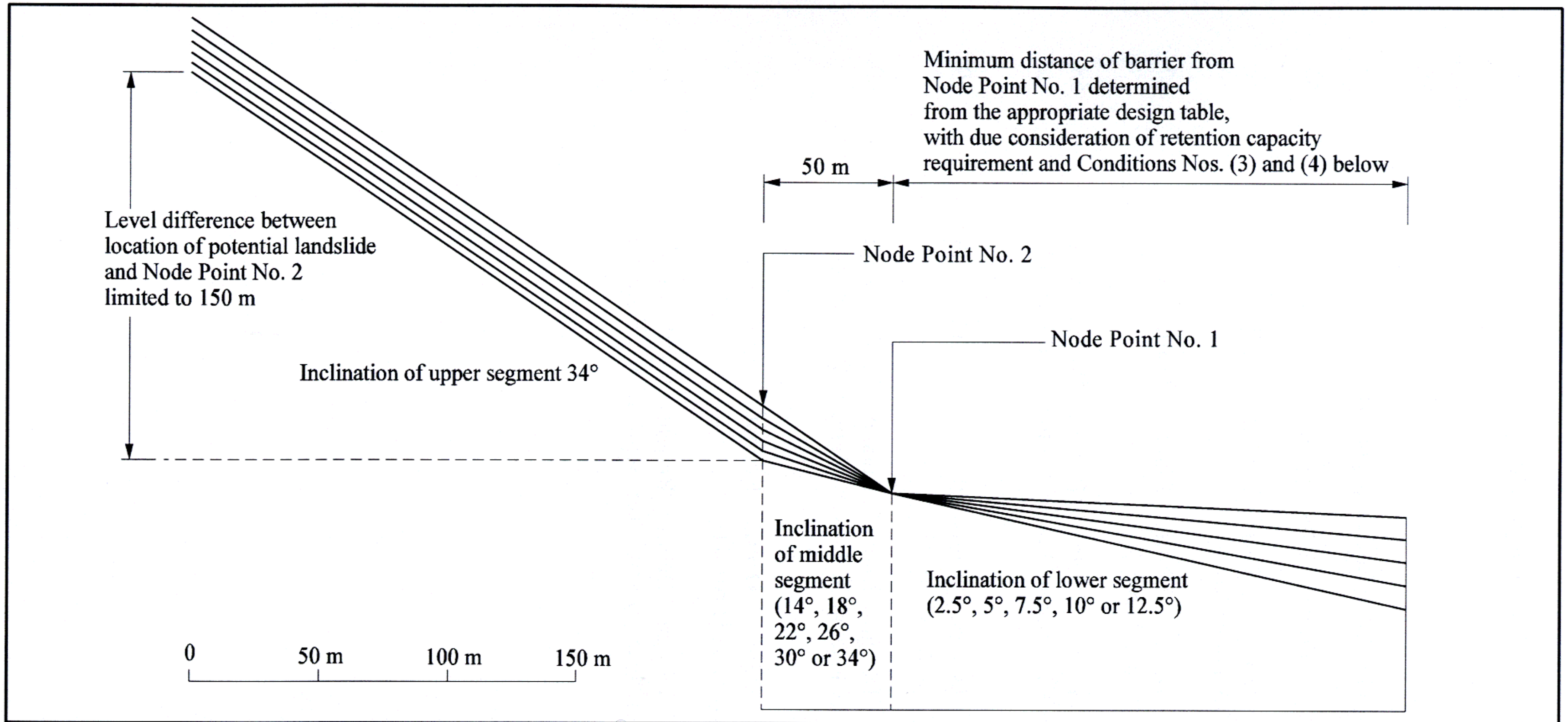

Conditions for Template Fitting:

(1) No parts of the upper or middle segment lines shall be below the ground profile (upper segment length to be extended as far as the crown of the potential landslide).

(2) Node Point No. 1 (which marks the start of the runout area and lies at the intersection of the lower and middle segments) must coincide with the actual ground profile.

(3) The lower segment over which a barrier can be positioned must lie below the ground profile and must have an inclination that is steeper than or equal to the gradient of the local ground profile.

(4) Steps in the ground profile in the lower segment area are allowable provided that Condition No. (3) above is complied with and that the distance of the barrier from the toe of the step is not less than the vertical height of the step.

Figure A1 - Template A (50 m Long Middle Segment)

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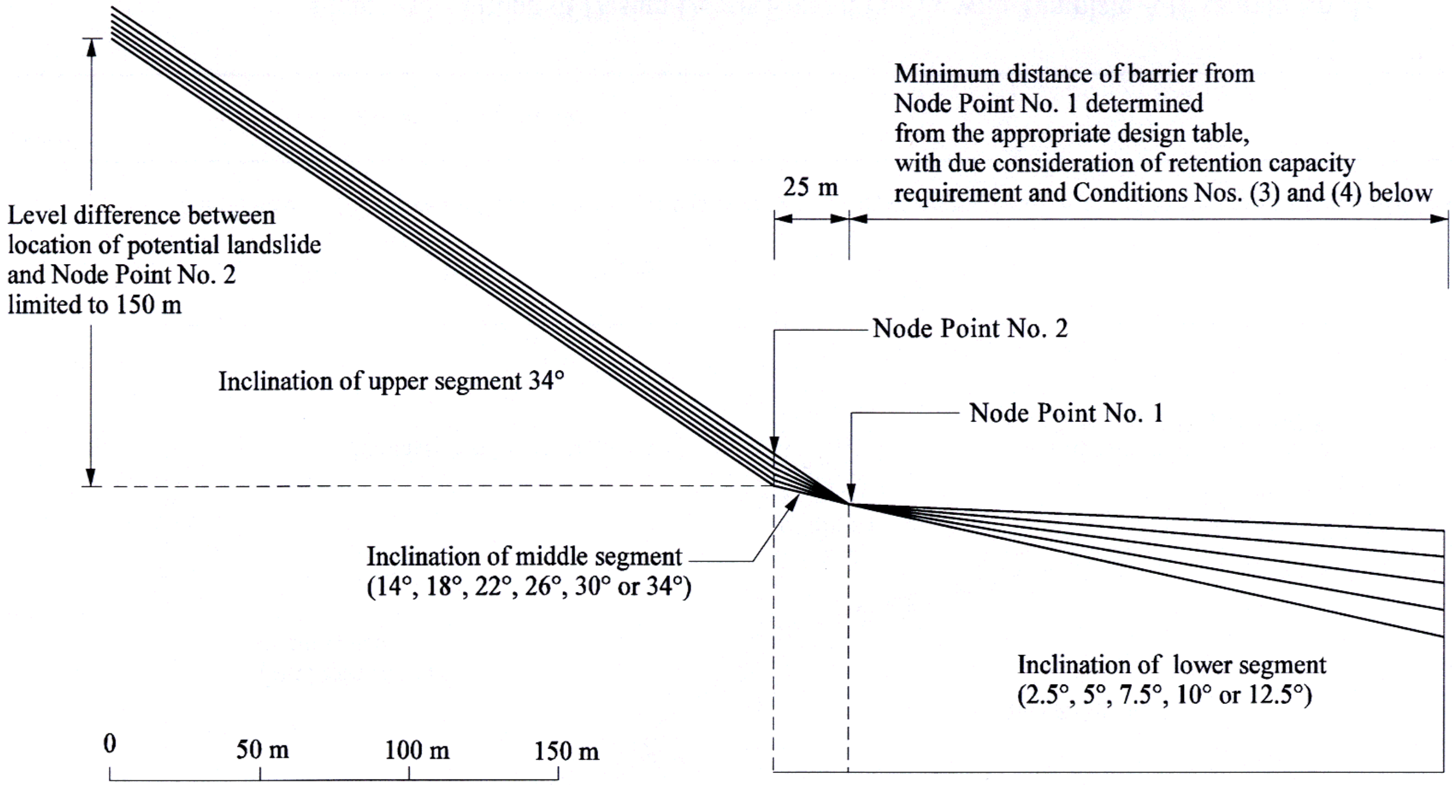

Conditions for Template Fitting:

(1) No parts of the upper or middle segment lines shall be below the ground profile (upper segment length to be extended as far as the crown of the potential landslide).

(2) Node Point No. 1 (which marks the start of the runout area and lies at the intersection of the lower and middle segments) must coincide with the actual ground profile.

(3) The lower segment over which a barrier can be positioned must lie below the ground profile and must have an inclination that is steeper than or equal to the gradient of the local ground profile.

(4) Steps in the ground profile in the lower segment area are allowable provided that Condition No. (3) above is complied with and that the distance of the barrier from the toe of the step is not less than the vertical height of the step.

Figure A2 - Template B (25 m Long Middle Segment)

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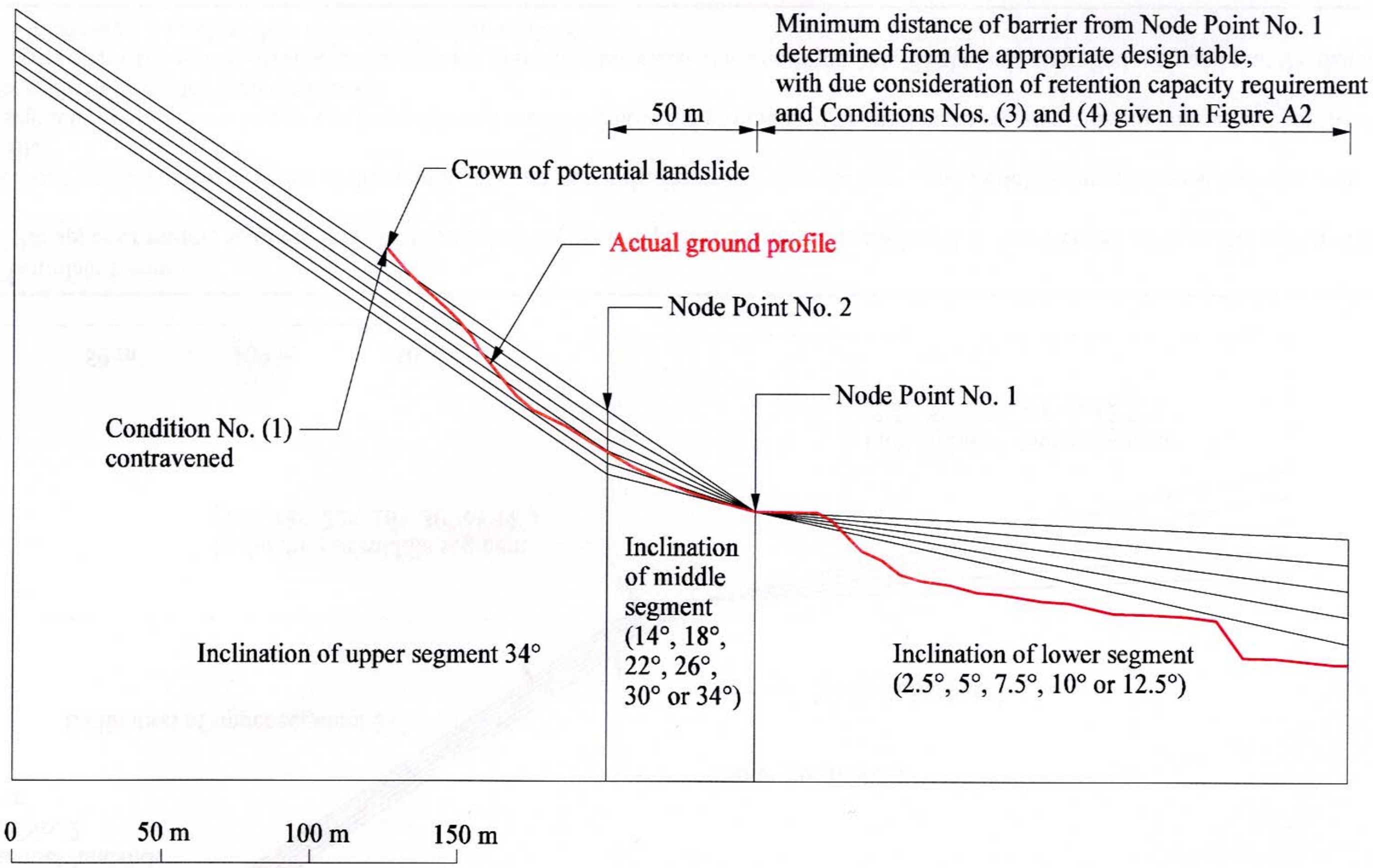

Compliance: NO, because Condition No. (1) contravened, i.e. upper segment not extended to the crown of potential landslide

Legend :

Actual ground profile

Figure A3 - Fitting of Design Debris Runout Profile with Template A (Example No. 1)

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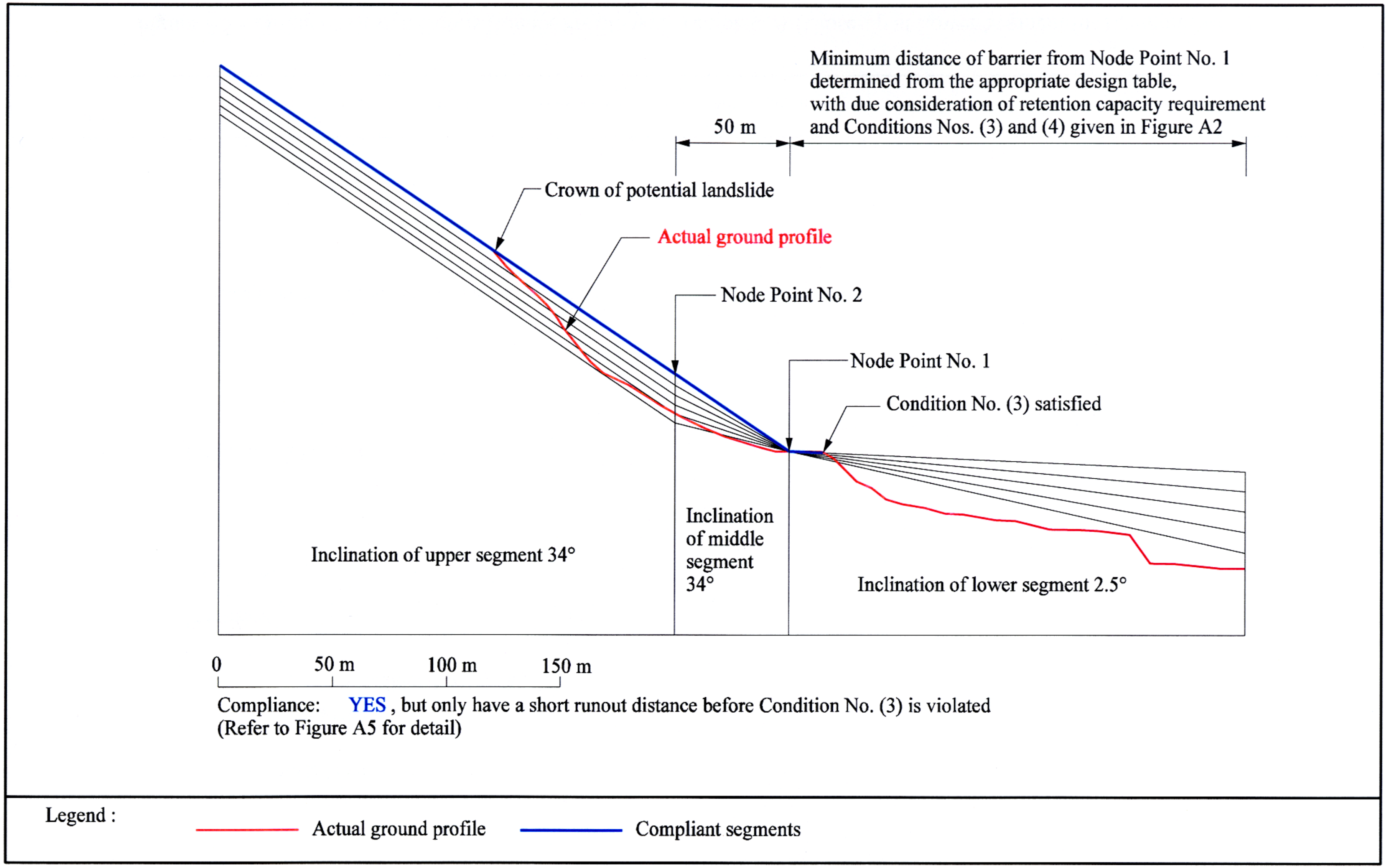

Figure A4 - Fitting of Design Debris Runout Profile with Template A (Example No. 2)

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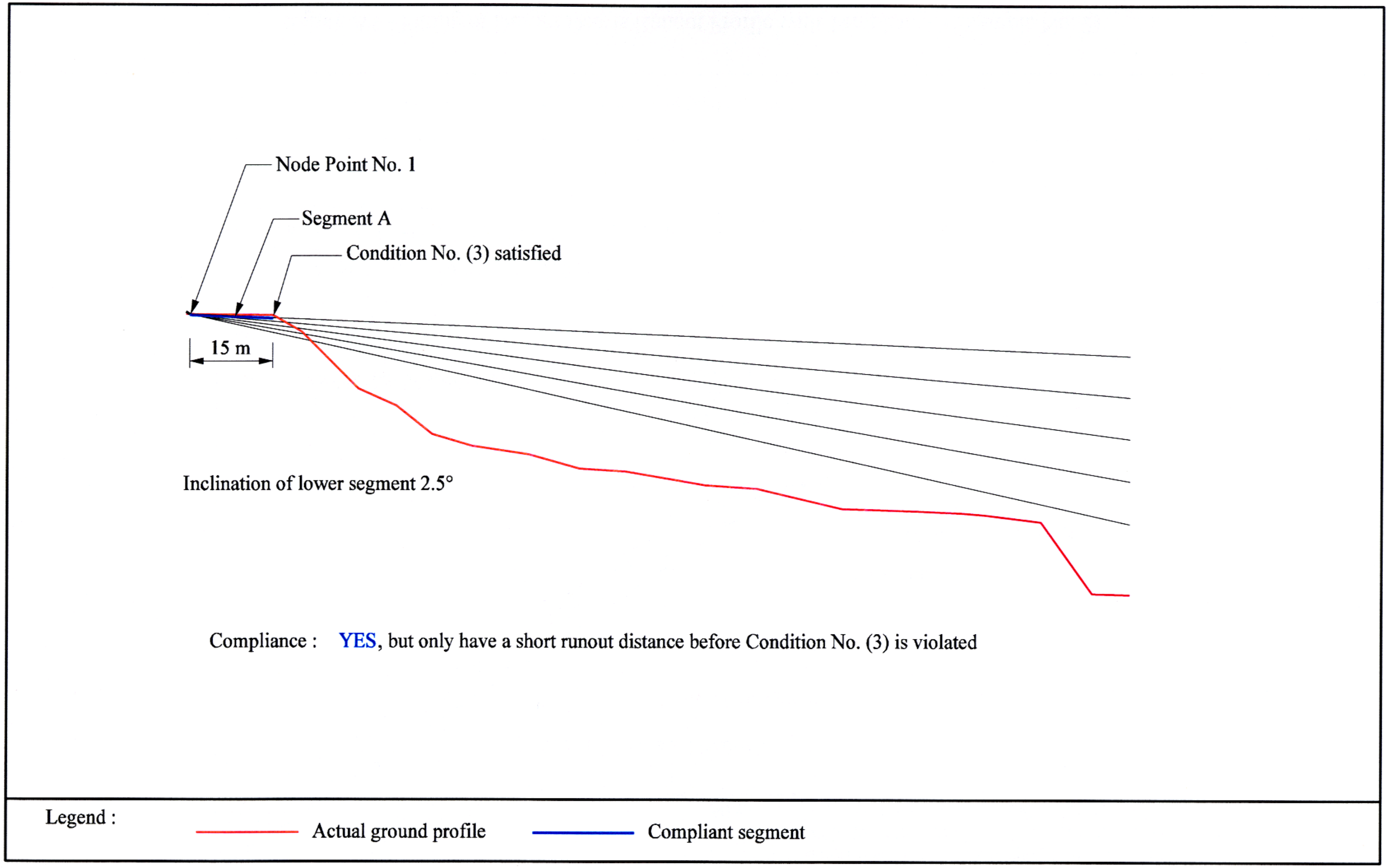
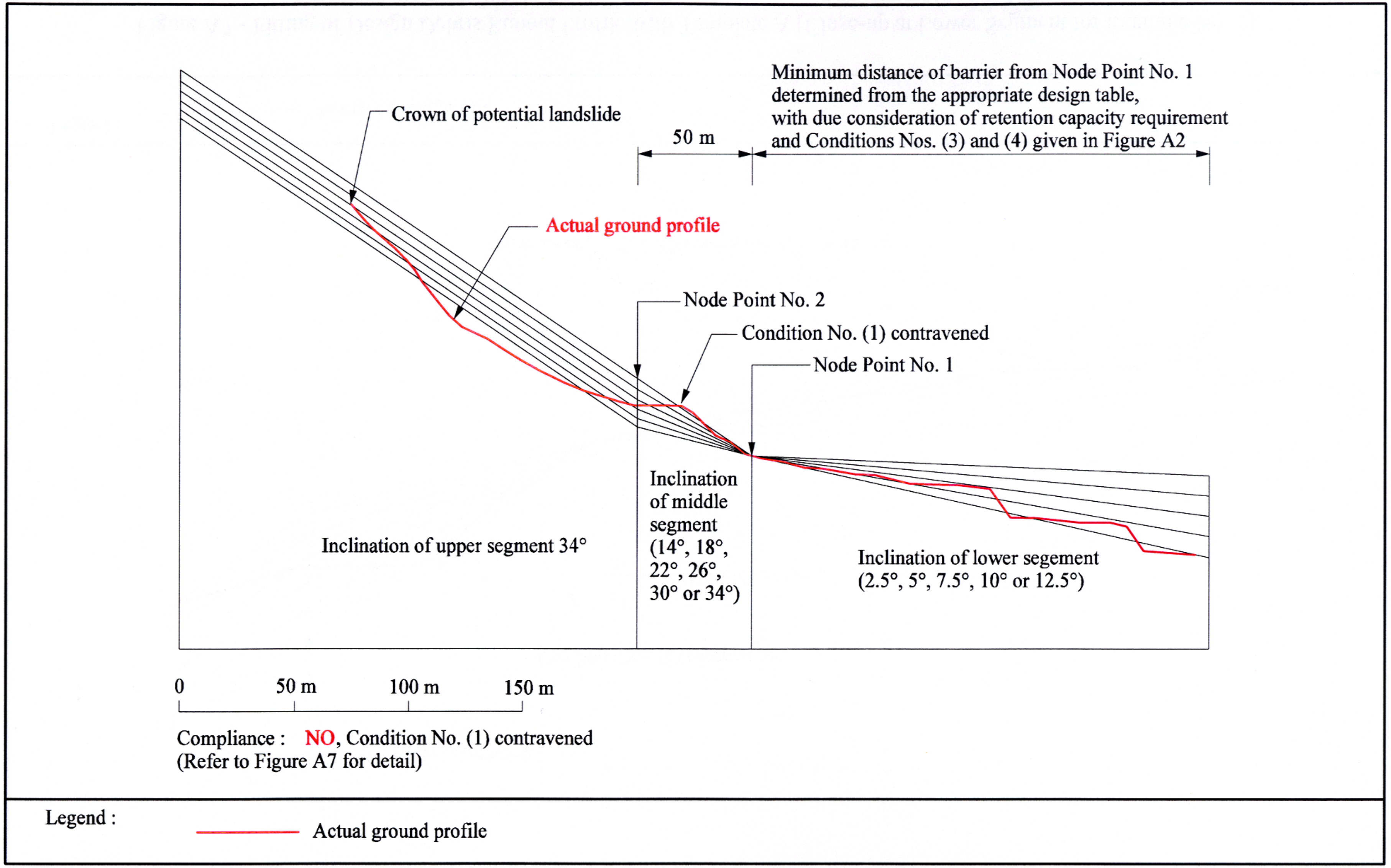


Figure A5 - Fitting of Design Debris Runout Profile with Template A (Close-up at Lower Segment for Example No. 2)



A6 - Fitting of Design Debris Runout Profile with Template A (Example No. 3)

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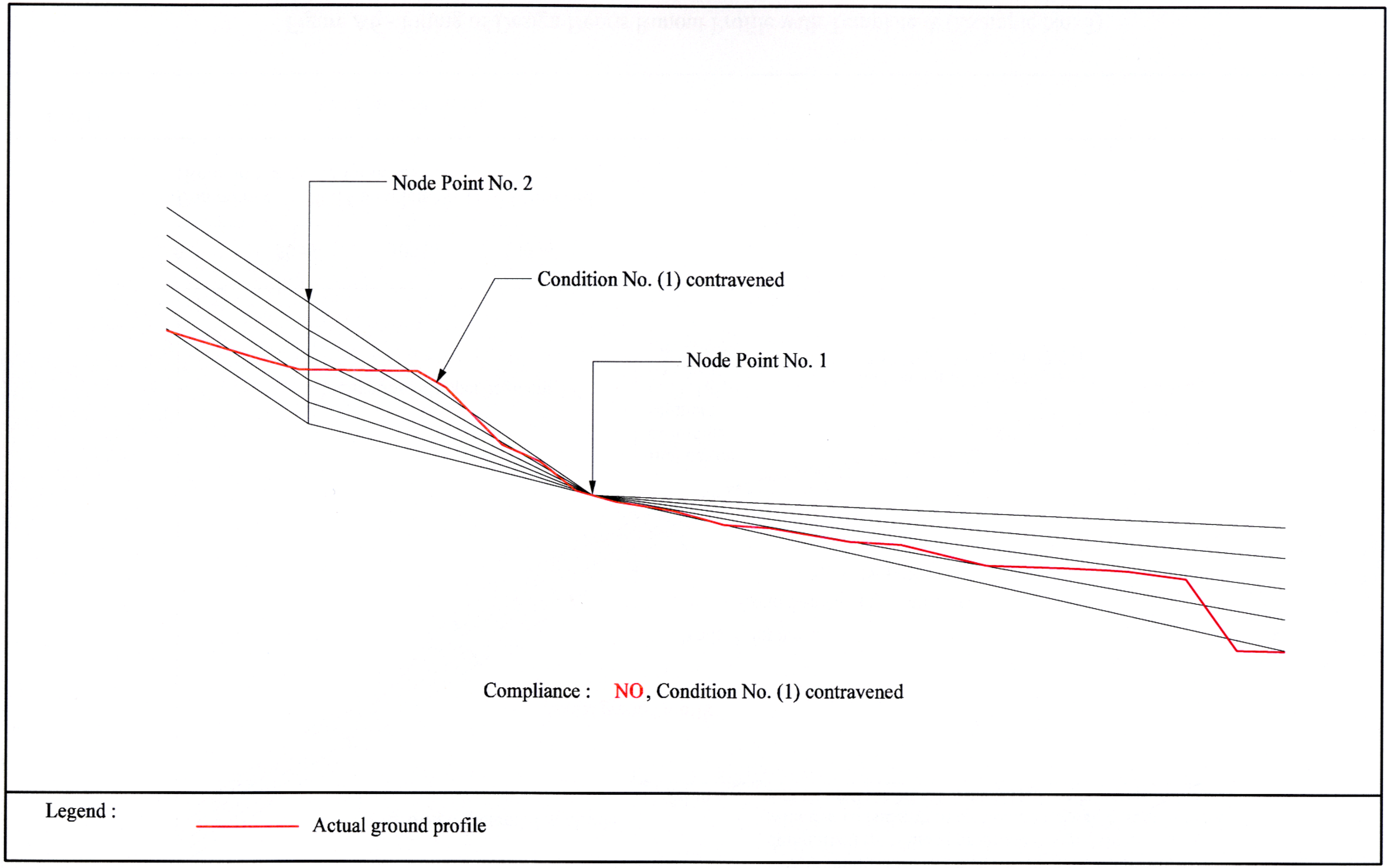

A7 - Fitting of Design Debris Runout Profile with Template A (Close-up at Lower Segment for Example No. 3)

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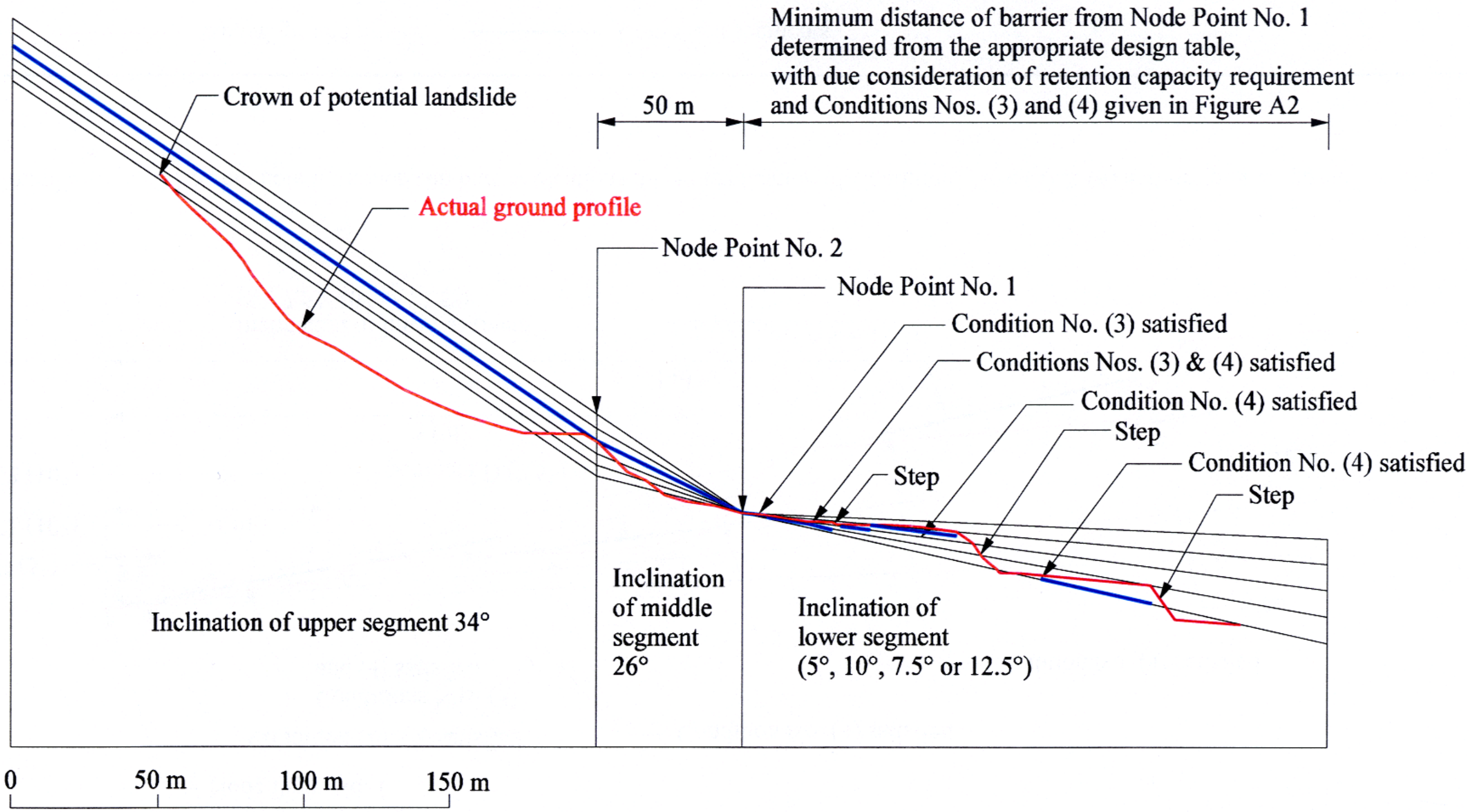

Compliance : YES , but note limitations on barrier locations due to application of Conditions Nos. (3) & (4) and irregularity of ground profile (Refer to Figure A9 for detail)

Legend : Actual ground profile Compliant segments

A8 - Fitting of Design Debris Runout Profile with Template A (Example No. 4)

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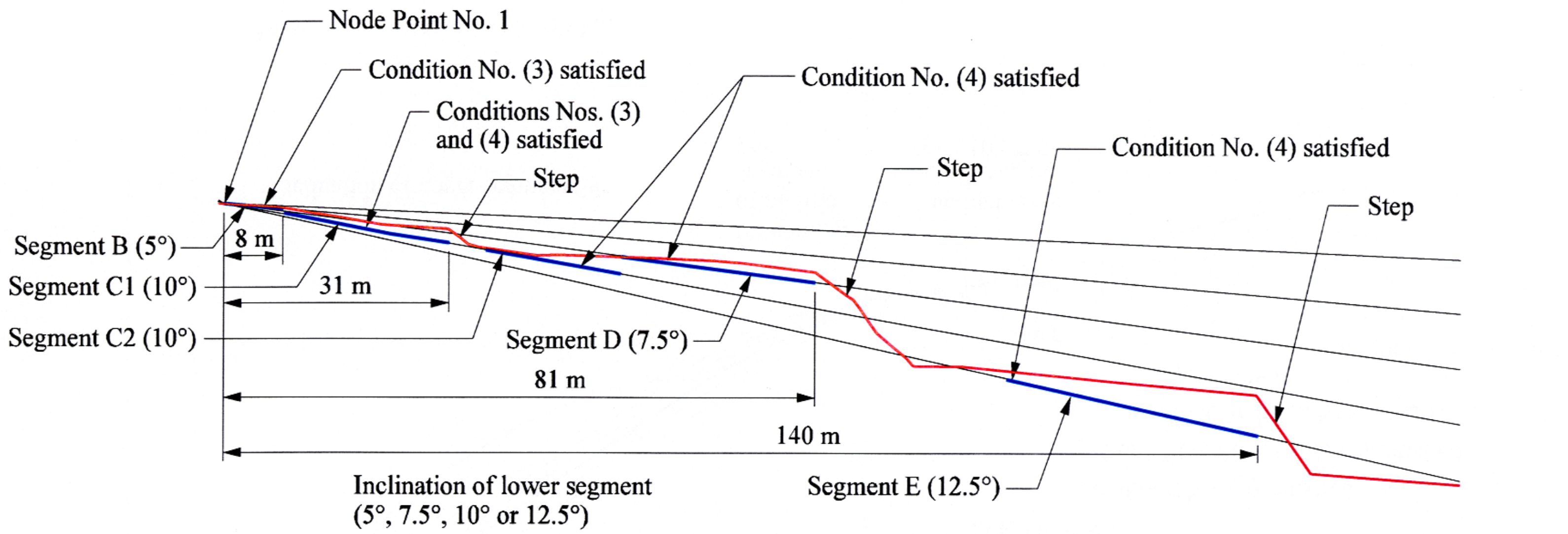

Compliance : YES, but note limitations on barrier locations due to application of Conditions Nos. (3) & (4) and irregularity ground profile

Legend : Actual ground profile Compliant segments

A9 - Fitting of Design Debris Runout Profile with Template A (Close-up at Lower Segment for Example No. 4)

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APPENDIX B

DETERMINATION OF THE DESIGN DEBRIS RUNOUT PROFILE AND POTENTIALLY SUITABLE BARRIER LOCATIONS FOR OPEN HILLSLOPE LANDSLIDES

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CONTENTS

B.1 INTRODUCTION

This Appendix describes the procedures and compliance conditions for selection of the Design Debris Runout Profiles that are representative of the site-specific ground profile under consideration. A set of charts, shown in Table B1, has been prepared in which the minimum acceptable distance of the barrier from the start of the runout area versus design volume and friction angle is given for each Design Debris Runout Profile. Worked examples that illustrate the application of the design charts are given in Appendix D.

B.2 GLOSSARY OF TERMS

The terms used in this Appendix relating to the determination of the Design Debris Runout Profiles are defined as follows:

Design Debris Runout Profile. The Design Debris Runout Profile is an idealised debris runout profile to assist the selection of a suitable barrier from the design tables given in this Appendix. The Design Debris Runout Profile comprises an upper segment of 34° steep and a lower segment that varies in inclination as shown in Figure B1. Any combination of segments that can be fitted to the ground profile, and which meets the conditions for 'template fitting' as shown in Figure B1, may constitute a Design Debris Runout Profile.

Template. A set of Design Debris Runout Profiles to assist the selection of a simplified Design Debris Runout Profile to represent the actual ground profile for the purposes of assessment of standardised barrier requirements (see Section B3).

B.3 METHODOLOGY FOR DETERMINING ACCEPTABLE DESIGN DEBRIS RUNOUT PROFILE FOR POSITIONING OF BARRIER

The method relies on the application of the two-segment profile to select a simplified Design Debris Runout Profile from a 'best-fit' of the actual ground profile.

In order to find a Design Debris Runout Profile, the Template is moved along the ground profile while keeping Node Point No. 1 (which marks the start of the runout area and lies at the intersection of the lower segment with the middle segment) co-incident with the ground profile.

The application of the two-segment profile to an actual hillside profile is shown in Figure B2, and follows the same principles as that demonstrated for the upper, middle and lower segments in Examples 1 to 4 as shown in Figures A3 to A9 of Appendix A.

The maximum runout distances (as measured from the lower edge of the source area of potential landslide) to be used for assessment purposes are 75 m and 120 m for open hillslope landslide design events of 50 m^3 and 100 m^3 respectively. Beyond these distances, it is generally not necessary to construct a barrier to arrest the landslide debris. It should be recognised that individual boulders from the debris front may travel further than the distance of the landslide debris. The designer is advised to consider whether the potential hazard of boulder 'roll-out' from the landslide debris is a concern and if so, whether a boulder fence to

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cater for this is warranted or not. For example, Evans & Hungr (1993) suggest that the above hazard should be assessed for a runout path that is steeper than 23° based on their experience with sizeable landslides in Canada. The design of the boulder fence for such scenario, where considered necessary by the designer, is outside the scope of the present framework.

Worked examples of the determination of the minimum distance of the barrier from the commencement of the runout area are shown in Appendix D.

B.4 REFERENCES

Evans, S.G. & Hungr, O. (1993). The assessment of rockfall hazard at the base of talus slopes. Canadian Geotechnical Journal, vol. 30, pp. 620-636.

Lo, D.O.K. (2000). Review of Natural Terrain Landslide Debris-resisting Barrier Design. Special Project Report No. SPR 1/2000, Geotechnical Engineering Office, Hong Kong, 93 p. (GEO Report No. 104)

Sun, H.W., Lam, T.T.M. & Tsui, H.M. (2003). Design Basis for Standardised Modules of Landslide Debris-Resisting Barrier. Technical Note No. TN 4/2003, Geotechnical Engineering Office, Hong Kong, 161 p.

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Table B1 - Minimum Distance from Node Point No. 1 to Type 4 Barrier

50 m^3 Design Volume with Friction Angle of 30° (1000 kJ Tensioned Wire Mesh Fence)						
Inclination of Lower Segment (°)	6	10	14	18	22	26
Distance (m)	6	7	8	11	16	31

50 m^3 Design Volume with Friction Angle of 30° (2000 kJ Tensioned Wire Mesh Fence)						
Inclination of Lower Segment (°)	6	10	14	18	22	26
Distance (m)	3	4	5	7	10	19

100 m^3 Design Volume with Friction Angle of 25° (2000 kJ Tensioned Wire Mesh Fence)					
Inclination of Lower Segment (°)	6	10	14	18	22
Distance (m)	11	14	19	29	67

100 m^3 Design Volume with Friction Angle of 25° (3000 kJ Tensioned Wire Mesh Fence)					
Inclination of Lower Segment (°)	6	10	14	18	22
Distance (m)	10	12	16	25	59

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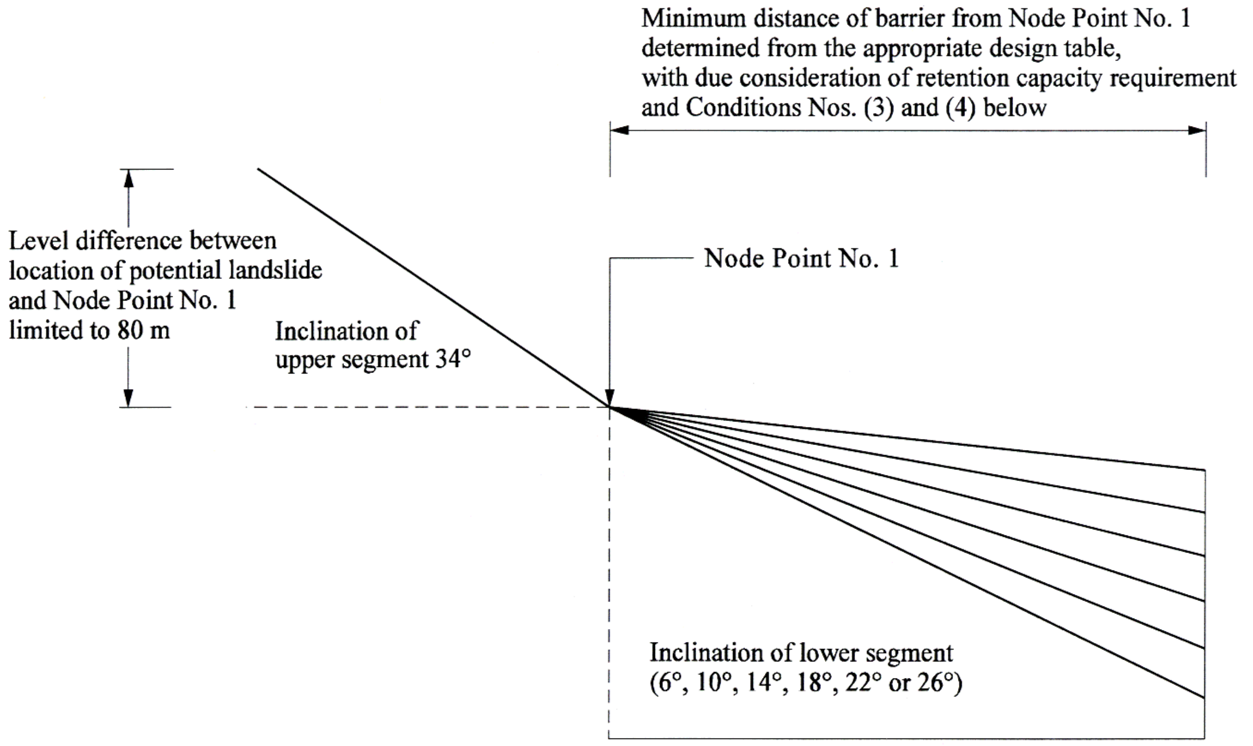

Notes : Conditions for Template Fitting:

(1) No parts of the upper or middle segment lines shall be below the ground profile (upper segment length to be extended as far as the crown of the potential landslide).

(2) Node Point No. 1 (which marks the start of the runout area and lies at the intersection of the lower and middle segments) must coincide with the actual ground profile.

(3) The lower segment over which a barrier can be positioned must lie below the ground profile and must have an inclination that is steeper than or equal to the gradient of the local ground profile.

(4) Steps in the ground profile in the lower segment area are allowable provided that Condition No. (3) above is complied with and that the distance of the barrier from the toe of the step is not less than the vertical height of the step.

Figure B1 - Template for Open Hillslope Landslides

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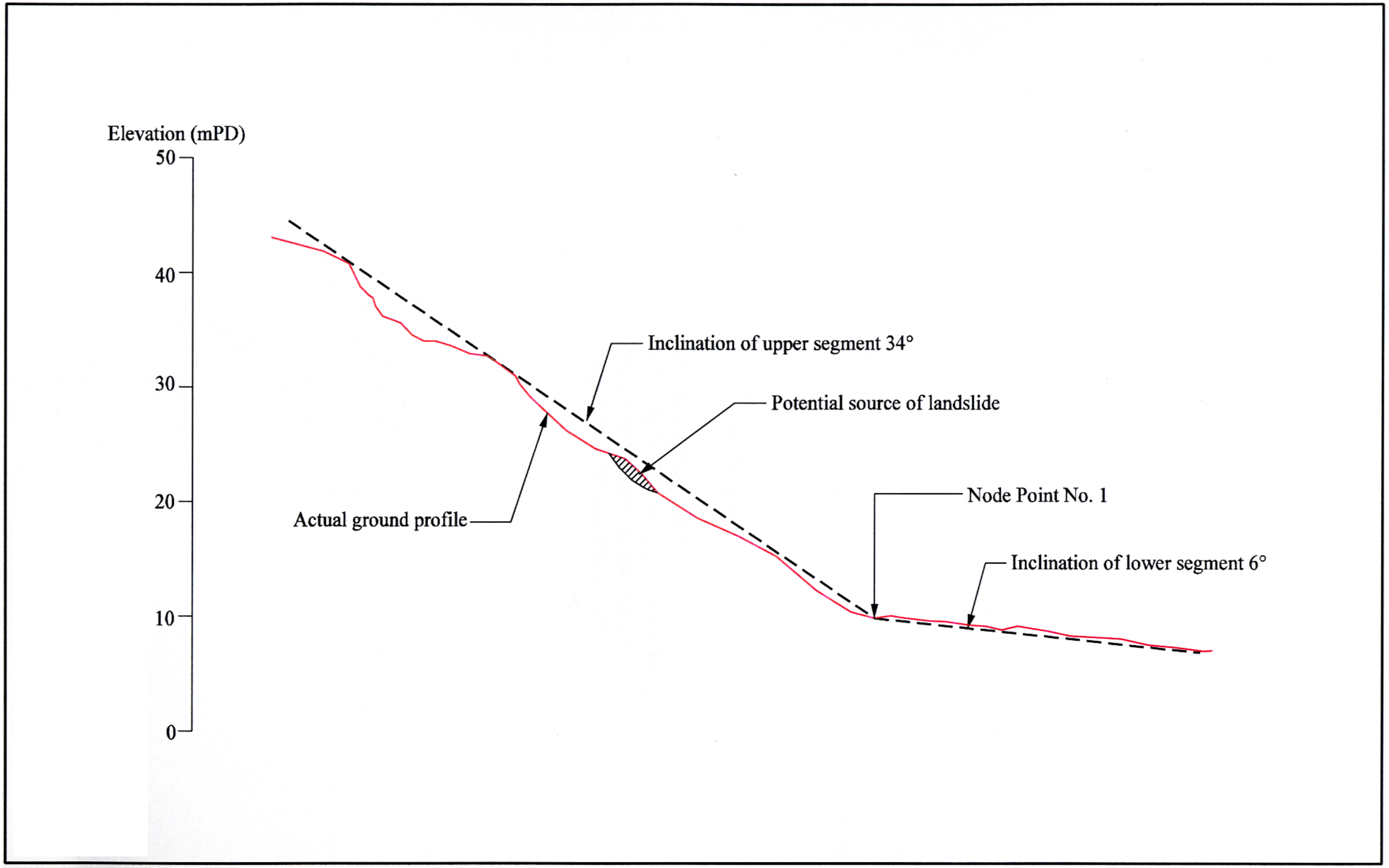

Figure B2 - Application of the Two-segment Profile to Open Hillslope Landslides

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APPENDIX C

WORKED EXAMPLES FOR ASSESSMENT OF THE LOCATION OF STANDARDISED BARRIERS FOR CHANNELISED DEBRIS FLOWS

CONTENTS

C.1 WORKED EXAMPLES FOR CHANNELISED DEBRIS FLOWS

The following worked examples have been applied to Templates A and B which are shown in Figures C1 and C2 respectively.

C.2 TEMPLATE A

With reference to Figure C1, the middle segment length is 0 m and the Design Debris Runout Profile of Segment A has an inclination of lower segment of 2.5°.

For a design event volume of 600 m^3:

(a) For Type 3 Barriers: Table A31 indicates that a 3.5 m high Type 3 barrier could be constructed at a minimum distance of 74 m from Node Point No. 1. The corresponding minimum barrier length is 12 m.

(b) For Type 2 Barriers: Tables A19, A23 and A27 indicate that 4.0 m, 3.5 m and 3.0 m high Type 2 barriers could be constructed at minimum distances of 53 m, 64 m and 69 m respectively from Node Point No. 1. The corresponding minimum barrier length of these barriers is 12 m.

(c) For Type 1 Barriers: Tables A7, A11 and A15 in Appendix A indicate that 4.5 m, 4.0 m and 3.5 m high Type 1 barriers could be constructed in the runout area at minimum distances of 40 m, 53 m and 55 m respectively from Node Point No. 1. The corresponding minimum barrier lengths are 16 m, 14 m and 14 m respectively. The selected figures in relevant design Tables C1, C2 and C3 are circled for reference. The minimum barrier distances from Node Point No. 1 for the Type 1 barriers are also shown in Figure C1.

For the above example, it can be seen that under the standardised barrier framework, all types of barriers (except for a 2.5 m high Type 3 barrier) could serve as mitigation measures for a 600 m^3 design event within the Design Debris Runout Profile. Obviously, if the runout distance for construction of barrier is equal to or more than 74 m, a 3.5 m high Type 3 barrier might be preferable in terms of physical dimensions and construction cost. On the other hand, if the available runout distance is between 40 m and 53 m, then only a 4.5 m high Type 1 barrier would be suitable. In this case, barrier is generally not required where the facility is located at 170 m or more from Node Point No. 1 according to Table A3.

For a design event volume of 150 m^3:

(a) For Type 3 Barriers: Tables A28 and A32 indicate that 3.5 m and 2.5 m high Type 3 barriers could be constructed at minimum distances of 14 m and 23 m respectively from Node Point No. 1. The corresponding minimum barrier length is 9 m.

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(b) For Type 2 Barriers: Tables A16, A20 and A24 indicate that 4.0 m, 3.5 m and 3.0 m high Type 2 barriers could be constructed at minimum distances of 9 m, 12 m and 16 m respectively from Node Point No. 1. The corresponding minimum barrier lengths are 11 m, 10 m and 10 m respectively.

(c) For Type 1 Barriers: Tables A4, A8 and A12 in Appendix A indicate that 4.5 m, 4.0 m and 3.5 m high Type 1 barriers could be constructed in the runout area at minimum distances of 6 m, 9 m and 12 m respectively from Node Point No. 1. The corresponding minimum barrier lengths are 16 m, 14 m and 14 m respectively.

All types of standardised barriers are suitable as mitigation measures for a 150 m^3 design event within the Design Debris Runout Profile. In this case, barrier is generally not required where the facility is located at 90 m or more from Node Point No. 1 according to Table A1.

C.3 TEMPLATE B

With reference to Figure C2, the middle segment is 25 m in length and has an inclination of 26°. The Design Debris Runout Profile has an inclination of lower segment of 12.5°.

For a design event volume of 600 m^3:

(a) For Type 3 Barriers: Table A31 in Appendix A indicates that 3.5 m high Type 3 barrier is unsuitable for this design event volume and Design Debris Runout Profile.

(b) For Type 2 Barriers: Tables A19, A23 and A27 in Appendix A indicate that 4.0 m, 3.5 m and 3.0 m high Type 2 barriers are unsuitable for this design event volume and Design Debris Runout Profile.

(c) For Type 1 Barriers: Table A7 in Appendix A indicate that a 4.5 m high Type 1 barrier could be constructed in the runout area at a minimum distance of 86 m from Node Point No. 1. Tables A11 and A15 indicate that 4.0 m and 3.5 m high Type 1 barriers are unsuitable for this design event volume and Design Debris Runout Profile.

For the above example, it can be seen that under the standardised barrier framework, only the 4.5 m high Type 1 barrier could serve as mitigation measures for a 600 m^3 design event within Design Debris Runout Profile, whereas the other standardised barriers are not suitable. In this case, barrier is generally not required where the facility is located at 225 m or more from Node Point No. 1 according to Table A3.

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For a design event volume of 150 m^3:

(a) For Type 3 Barriers: Tables A28 and A32 indicate that 3.5 m and 2.5 m high Type 3 barriers could be constructed at minimum distances of 31 m and 60 m respectively from Node Point No. 1. The corresponding minimum barrier length is 9 m. The selected figures in relevant design Tables C4 and C5 are circled for reference. The minimum barrier distances from Node Point No. 1 for the Type 3 barriers are also shown in Figure C2.

(b) For Type 2 Barriers: Tables A16, A20 and A24 indicate that 4.0 m, 3.5 m and 3.0 m high Type 2 barriers could be constructed at minimum distances of 14 m, 21 m and 31 m respectively from Node Point No. 1. The corresponding minimum barrier lengths are 11 m, 10 m and 10 m respectively.

(c) For Type 1 Barriers: Tables A4, A8 and A12 in Appendix A indicate that 4.5 m, 4.0 m and 3.5 m high Type 1 barriers could be constructed in the runout area at minimum distances of 9 m, 14 m and 21 m respectively from Node Point No. 1. The corresponding minimum barrier lengths are 16 m, 14 m and 14 m respectively.

From the above example, it can be seen that under the standardised barrier framework, any of the barrier types may be feasible as mitigation measures for a 150 m^3 design event within Design Debris Runout Profile. In this case, barrier is generally not required where the facility is located at 125 m or more from Node Point No. 1 according to Table A1.

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Table C1 - Example of Applying Design Table (4.5 m High Type 1 Barrier - Design Volume of 600 m^3) on Template A

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	29 16	34 16	33 16	38 16	34 16	39 16	38 16	39 16	38 16	39 16	40 16
	5°	34 16	39 16	36 16	43 16	41 16	46 16	45 16	46 16	46 16	48 16	48 16
	7.5°	43 16	48 16	46 16	53 16	53 16	56 16	55 16	59 16	56 16	60 16	62 16
	10°	60 16	65 16	60 16	67 16	66 16	69 16	66 16	69 16	68 16	70 16	73 16
	12.5°	78 16	79 16	78 16	81 16	81 16	84 16	86 16	86 16	87 16	87 16	90 16

Table C2 - Example of Applying Design Table (4.0 m High Type 1 Barrier - Design Volume of 600 m^3) on Template A

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	45 14	50 14	48 14	53 14	50 14	53 14	51 14	53 14	51 14	53 14	53 14
	5°	55 14	61 14	61 14	63 14	61 14	63 14	63 14	63 14	63 14	63 14	63 14
	7.5°	73 14	73 14	73 14	74 14	73 14	74 14	74 14	75 14	74 14	75 14	75 14
	10°	88 14	90 14	90 14	91 14	90 14	91 14	91 14	92 14	92 14	93 14	93 14
	12.5°	Standardised Barrier Not Applicable										

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Table C3 - Example of Applying Design Table (3.5 m High Type 1 Barrier - Design Volume of 600 m^3) on Template A

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	46	50	50	54	53	54	53	54	54	55	55
		14	14	14	14	14	14	14	14	14	14	14
	5°	57	63	61	63	63	63	63	63	63	65	65
		14	14	14	14	14	14	14	14	14	14	14
	7.5°	75	77	75	78	75	78	75	78	76	78	79
		14	14	14	14	14	14	14	14	14	14	14
	10°	90	101	100	109	111	120	125	127	131	139	179
		14	14	14	14	14	14	14	14	14	14	14
	12.5°	Standardised Barrier Not Applicable										

Table C4 - Example of Applying Design Table (3.5 m High Type 3 Barrier - Design Volume of 150 m^3) on Template B

Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)		‘Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length		Segment Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
Inclination of Lower Segment	2.5°	4	9	9	11	11	14	12	14	14	14	14
		9	9	9	9	9	9	9	9	9	9	9
	5°	6	11	9	11	11	16	14	16	16	17	17
		9	9	9	9	9	9	9	9	9	9	9
	7.5°	6	12	11	16	14	17	17	19	19	21	21
		9	9	9	9	9	9	9	9	9	9	9
	10°	7	14	12	17	17	21	23	23	24	26	26
		9	9	9	9	9	9	9	9	9	9	9
	12.5°	9	17	14	19	23	28	28	31	33	35	36
		9	9	9	9	9	9	9	9	9	9	9

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Table C5 - Example of Applying Design Table (2.5 m High Type 3 Barrier - Design Volume of 150 m^3) on Template B

Inclination of Lower Segment	Minimum Distance of Barrier Downslope of Node Point No. 1 (m) / Minimum Barrier Length (m)	Middle Segment Characteristics										
		Inclination 14°		Inclination 18°		Inclination 22°		Inclination 26°		Inclination 30°		Inclination 34°
		Length		Length		Length		Length		Length		Length
		50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	50 m	25 m	0 m
2.5°	Minimum Distance	17	21	19	21	21	23	21	23	23	23	23
2.5°	Minimum Barrier Length	9	9	9	9	9	9	9	9	9	9	9
5°	Minimum Distance	21	24	24	26	26	28	28	28	28	28	29
5°	Minimum Barrier Length	9	9	9	9	9	9	9	9	9	9	9
7.5°	Minimum Distance	28	31	31	31	31	33	33	34	33	34	34
7.5°	Minimum Barrier Length	9	9	9	9	9	9	9	9	9	9	9
10°	Minimum Distance	38	38	39	39	39	40	40	40	40	40	43
10°	Minimum Barrier Length	9	9	9	9	9	9	9	9	9	9	9
12.5°	Minimum Distance	51	54	56	57	58	59	59	60	60	61	63
12.5°	Minimum Barrier Length	9	9	9	9	9	9	9	9	9	9	9

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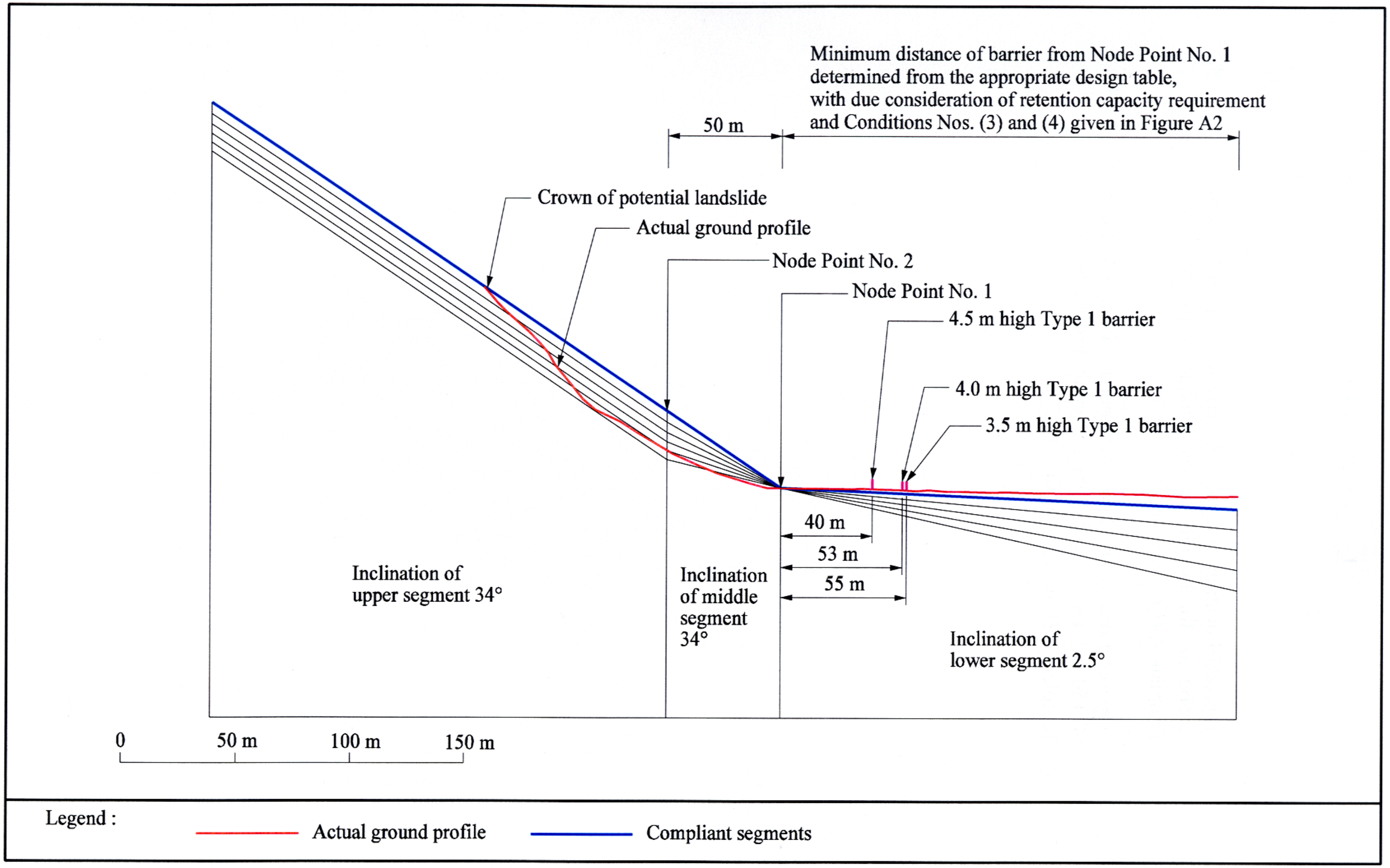

Figure C1 - Proposed Location of Type 1 Barrier for Design Volume of 600 m^3 for Design Debris Runout Profile based on Template A (Lower Segment = 2.5°)

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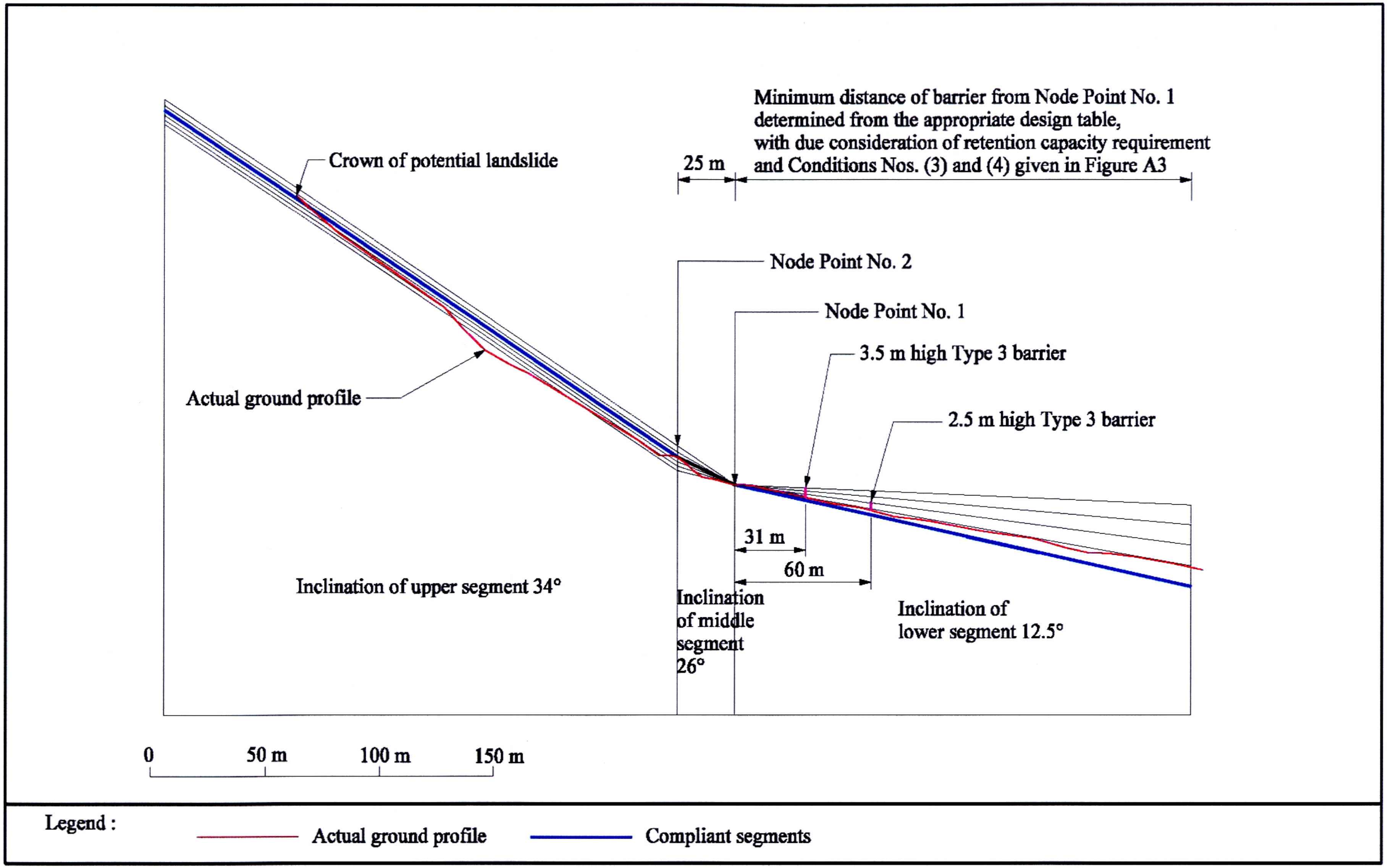

Figure C2 - Proposed Location of Type 3 Barrier for Design Volume of 150 m^3 for Design Debris Runout Profile based on Template B (Lower Segment = 12.5°)

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APPENDIX D

WORKED EXAMPLE FOR ASSESSMENT OF THE LOCATION OF STANDARDISED BARRIERS FOR OPEN HILLSLOPE LANDSLIDES

CONTENTS

D.1 WORKED EXAMPLE FOR OPEN HILLSLOPE LANDSLIDES

An example for an inclination of lower segment of 6° shown in Figure D1, Table D1 indicates that the minimum acceptable barrier distances from Node Point No. 1 are 3 m, 6 m, 10 m and 11 m for design volumes/barrier energy rating of 50 m^3/2000 kJ, 50 m^3/1000 kJ, 100 m^3/3000 kJ and 100 m^3/2000 kJ respectively.

If the inclination of the lower segment is much steeper, say 22°, Table D1 indicates that the minimum acceptable barrier distances from Node Point No. 1 would increase to 10 m, 16 m, 59 m and 67 m respectively for the above four combinations of design volume and barrier energy rating.

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Table D1 - Example of Applying Type 4 Barrier Design Table

50 m^3 Design Volume with Friction Angle of 30° (1000 kJ Tensioned Wire Mesh Fence)						
Inclination of Lower Segment (°)	6	10	14	18	22	26
Distance (m)	6	7	8	11	16	31

50 m^3 Design Volume with Friction Angle of 30° (2000 kJ Tensioned Wire Mesh Fence)						
Inclination of Lower Segment (°)	6	10	14	18	22	26
Distance (m)	3	4	5	7	10	19

100 m^3 Design Volume with Friction Angle of 25° (2000 kJ Tensioned Wire Mesh Fence)					
Inclination of Lower Segment (°)	6	10	14	18	22
Distance (m)	11	14	19	29	67

100 m^3 Design Volume with Friction Angle of 25° (3000 kJ Tensioned Wire Mesh Fence)					
Inclination of Lower Segment (°)	6	10	14	18	22
Distance (m)	10	12	16	25	59

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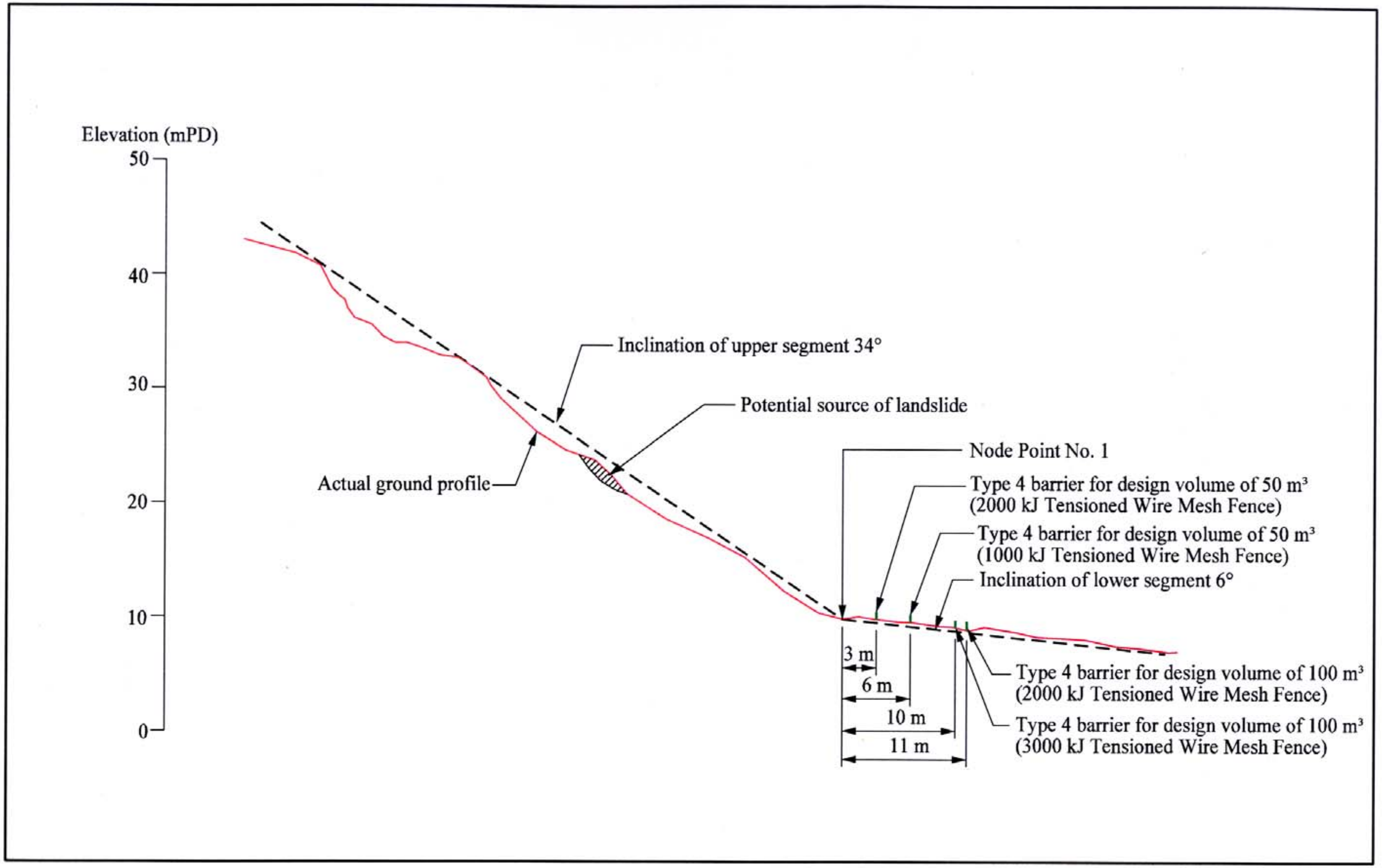

Figure D1 - Proposed Location of Type 4 Barrier for Design Volume of 50 m^3 and 100 m^3 for Design Debris Runout Profile

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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.

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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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GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
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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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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