Some Suggested Detailing of Flexible Barriers Traversing a Stream Course for Drainage Purposes

GEO Report No. 344

E.H.Y. Sze & H.W.K. 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.

W.K. Pun
Head, Geotechnical Engineering Office
June 2019

Foreword

This Technical Note presents the results of a study of flexible barriers traversing a stream course. Recommendations pertaining to the proper detailing of flexible barriers are also provided. The study was carried out by Dr E.H.Y. Sze under the supervision of Mr H.W.K. Lam. Landslip Investigation Consultants provided support in the field inspections and record search. Various colleagues in the GEO, Lands Department and LPM Consultants provided insightful comments. The Drafting Unit of the Standards and Testing Division assisted in formatting this report. All contributions are gratefully acknowledged.

Julian S.H. Kwan
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Abstract

This Technical Note documents key observations of a reported flooding incident that occurred at the Shatin Hospital in October 2016. The flooding incident was probably caused by the blockage of stream flow due to presence of a steel flexible barrier which had trapped significant amount of stream loads. This study covers a review of overseas design practice and technical guidance on the use of flexible barriers traversing across a stream course. Based on the findings of this study, preliminary recommendations pertaining to the detailing of flexible barriers that traverse a stream course are provided, with a view to minimising trapping of stream loads.

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1 Introduction

On 19 October 2016, a flooding incident occurred at the premises of the Shatin Hospital during a heavy rainstorm. The flooding incident was probably due to the stream loads trapped by a steel flexible barrier traversing across a natural drainage line adjacent to the Hospital. Subsequent to the incident, GEO initiated a study to identify the lessons learnt with a view to enhancing the serviceability performance of steel flexible barriers which traverse a stream course. This study also reviewed relevant overseas technical guidance and experience on the use of flexible barriers.

This Technical Note documents the findings of the study. Guiding principles on the design of detailing of flexible barriers traversing a stream course are recommended. Some illustrative examples are provided for reference.

2 Background of Flooding Incident at Shatin Hospital

GEO has conducted an investigation on the flooding incident, which entailed field inspections, review of relevant design and construction records of the steel flexible barrier. The flooding incident at Shatin Hospital on 19 October 2016 was probably due to damming of stream flow by a flexible barrier (Feature No. 7SE-A/ND6), which had been unduly trapping a significant amount of stream loads, resulting in over-spillage of stream flow and thereby inundating the downstream areas. Figure 2.1 shows an overview of the flexible barrier after the incident. Details about the flooding incident as well as the findings of site inspection and subsequent desk study are provided in Appendix A.

Based on the records from the Shatin Hospital, similar flooding incidents have repeatedly occurred since the summer season of 2015.

Figure 2.1 Overview of Flexible Barrier Trapped with Stream Loads at Shatin Hospital

3 Trapping of Stream Loads by Flexible Barriers at Other Site

Apart from the case in Shatin Hospital, records of recent inspections of selected flexible barriers that had been installed across a stream course in Hong Kong were reviewed. It was found that stream loads trapped by flexible barriers were also observed in two other locations, one in Kwun Yam Shan (Feature No. 7SE-C/ND3) and one in Fo Tan (Feature No. 7SE-A/ND8). Figure 3.1 shows the general view of the two flexible barriers trapping with stream loads. Some common observations in these two cases as well as the case for the Shatin Hospital are summarised as follows.

(a) The flexible barriers in the three cases are provided with secondary mesh. The principal nets of these barriers are extended down to the base of stream course.

(b) The stream courses in the three cases are perennial where continuous stream flow is observed throughout the year.

(c) The stream loads trapped by the flexible barriers in the three cases comprise mainly sand to boulder-sized materials with fallen leaves or branches.

(a)

(b)

Figure 3.1 Other Cases of Trapping of Stream Loads by Flexible Barriers Traversing across Stream Course at: (a) Kwun Yam Shan; and (b) Fo Tan

4 Review of International Technical Practice and Experience

4.1 Views of Flexible Barrier Suppliers

Views of various flexible barrier suppliers were sought regarding their overseas experience on detailing of flexible barriers installed across a stream course. According to these flexible barrier suppliers, there is no well-established rule on the use of secondary mesh for a flexible barrier. The need of secondary mesh is often project-specific, depending on various factors such as maintenance requirements, design intention, etc. Secondary mesh is commonly provided if the flexible barrier is designed to retain fine-grained materials. Based on their experience, trapping of stream loads by the flexible barriers could occur and more maintenance effort would be required for regular clearance of these trapped materials. Some overseas examples of flexible barriers to mitigate debris flow are shown in Figure 4.1. For example, in Case 1 of Figure 4.1, a secondary mesh was provided with a view to preventing blockage of the downstream culvert by stream loads or fine-grained materials.

For rockfall-resisting barriers, a layer of secondary mesh is commonly provided with a view to arresting flying rock fragments. These barriers are typically energy-rated, proved by full scale tests.

In some overseas projects, a basal opening between flexible barriers and the stream course was allowed to facilitate passage of stream flow. The need of and the size of such basal opening depend on various factors such as the characteristics of stream loads, flow depth, geometry of stream course, the design intent of flexible barriers, etc. For example, in Case 3 of Figure 4.1, a basal opening was provided and it was around 1.5 m high to allow passage of some sizeable driftwood coming along the stream flow. In some situations, the basal opening would be replaced by slitting structures. A proprietary barrier supplier has adopted a basal opening of 0.5 m to 0.8 m in the debris-resisting flexible barriers.

Case 1 - Geobrugg (2009)

Location: California, USA

Installation of a ring net barrier with secondary mesh to retain debris flow material from reaching the culverts

Figure 4.1 Detailing of Debris-resisting Flexible Barriers in Different Countries (Sheet 1 of 3)

Case 2 - Geobrugg (2016)

Location: Rest and be Thankful, Scotland

Installation of a shallow landslide barrier with secondary mesh to retain debris flow material from reaching the highway A83

Case 3 - Trumer (2013b)

Location: Canada

Installation of omega net structure without secondary mesh but basal opening of around 1.5 m to facilitate passage of drift wood under normal stream flow

Figure 4.1 Detailing of Debris-resisting Flexible Barriers in Different Countries (Sheet 2 of 3)

Case 4 - Trumer (2013b)

Location: Leogang, Austria
Installation of omega net structure without secondary mesh but a slitting structure between the barrier base and the stream course

Figure 4.1 Detailing of Debris-resisting Flexible Barriers in Different Countries (Sheet 3 of 3)

4.2 Literature Review

A literature review was carried out on the relation between the size of opening of the principal net and the debris retention capacity of a flexible barrier. Relevant studies indicate that if the size of a net opening is small enough (e.g. less than two times of the maximum clast diameter of debris materials), a plug could be formed when the net is subjected to debris impact. A summary of the literature review is given in Appendix B. As shown in Figure 4.2, a flexible net structure is capable of retaining debris material composing of particles smaller than the net opening soon after a debris plug is formed, probably due to the arching effect.

(a) Tabata et al (2004)

(b) Suwa et al (2009)

(c) Geobrugg (2007)

Figure 4.2 Examples where the Flexible Net Structure could Retain Debris Material Composed of Particles Smaller than the Net Opening

5 Review of Local Technical Practice and Experience

In Hong Kong, proprietary energy-rated flexible barriers are commonly adopted to resist landslide debris. Kwan & Cheung (2012) discussed that the use of secondary mesh can reduce the amount of debris passing through the flexible barrier and thus provide an added protection to the downstream facilities.

As discussed in Section 4, from the technical perspective, considerations should be given to the following two key factors in determining the need of secondary mesh for flexible barriers:

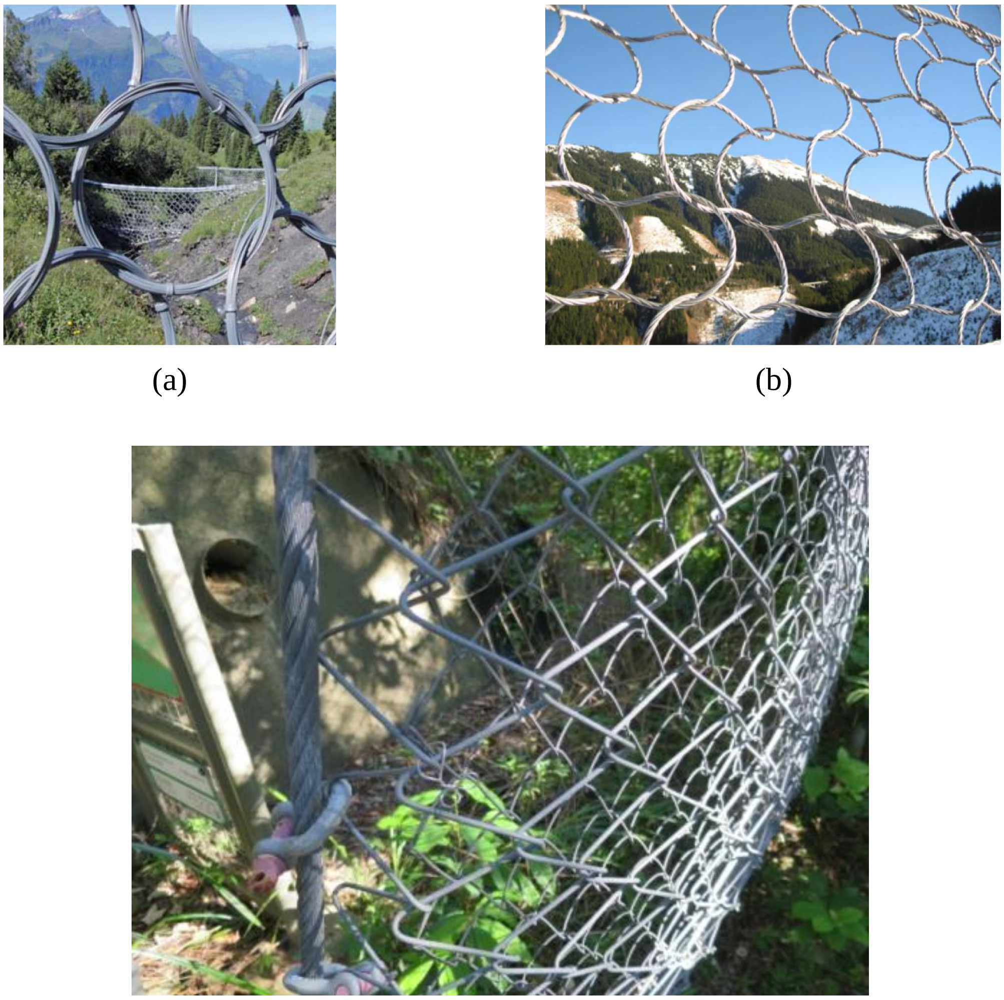
(a) the opening size of principal net adopted, and

(b) the coarse fraction of the landslide debris.

A review of the above two factors pertinent to the situations in Hong Kong is given in the following section.

5.1 Principal Net of Flexible Barriers

Different types of principal nets that are commonly used in Hong Kong are shown in Figure 5.1. In general, the opening size of these principal nets ranges from 80 to 420 mm (in diameter or in-circle diameter) as given in Table 5.1



(a) (b) (c)

Figure 5.1 Different Types of Principal Nets Commonly Used in Hong Kong: (a) Ring Net (Geobrugg, 2009); (b) Omega Net (Trumer, 2013a); and (c) Steel Wire Mesh

Table 5.1 Summary of Principal Nets Commonly Used in Hong Kong

Supplier	Energy Rating	Principal Net	In-circle Diameter (mm)
Geobrugg	1,000 kJ	TECCO G80/4	80
	2,000 kJ	SPIDER S4-130	130
	3,000 kJ	TECCO G80/4 SPIDER S4-130	80 130
	5,000 kJ	ROCCO 16/3/350	350
	8,000 kJ	ROCCO 19/3/300	300
Maccaferri	1,000 kJ	RMC GS 3/7	80
	2,000 kJ	ASM 3-4-350/200	350
	3,000 kJ	ASM 3-4-350/300	350
	5,000 kJ	ASM 3-4-420/500	420
	8,600 kJ	ASM 3-4-420/850	420
Trumer	1,000 kJ	Omega/9.0 mm/MW185	185
	1,500 kJ	Omega/9.0 mm/MW180	180
	2,000 kJ	Omega/9.0 mm/MW180	180
	3,000 kJ	Omega/9.0 mm/MW180	180
	5,000 kJ	Omega/10.5 mm/MW180	180

5.2 Debris Front Characteristics of Channelized Debris Flow

Field mapping reports of about 50 selected channelized debris flows (maximum active volume ranges from < 50 m^3 to > 2,000 m^3) that occurred in June 2008 in Hong Kong provide useful information on the composition of local debris flows (see Appendix C). Bouldery deposits were observed in many of these channelized debris flows as shown in Figure 5.2. A significant portion (> 10%) of frontal debris materials for these landslides was coarse-grained (i.e. > 200 mm in size), with a maximum clast diameter ranging from 0.3 to 5 m (or typically 1 m to 2 m). The maximum clast diameter appears to be much larger than the mesh size of the principal net that are commonly used in Hong Kong (i.e. 80 mm to 420 mm in diameter, see also Table 5.1).

5.3 Effectiveness of Secondary Mesh in Retaining Landslide Debris

The effectiveness of retaining landslide debris by principal net and secondary mesh can be demonstrated by a local landslide case that occurred in Jordan Valley in 2008 where the landslide debris was successfully retained by a flexible rockfall barrier (Kwan & Koo, 2015). The landslide volume was about 110 m^3. The debris retained behind the net consisted of matrix-supported debris mixed with rounded to sub-rounded boulders and vegetation. The barrier comprised of ring-nets of 350 mm in diameter and a secondary mesh with an aperture of 25 mm x 25 mm. As reported by Kwan & Koo (2015), the landslide debris, including fine grains, was largely arrested by the barrier (see Figure 5.3).

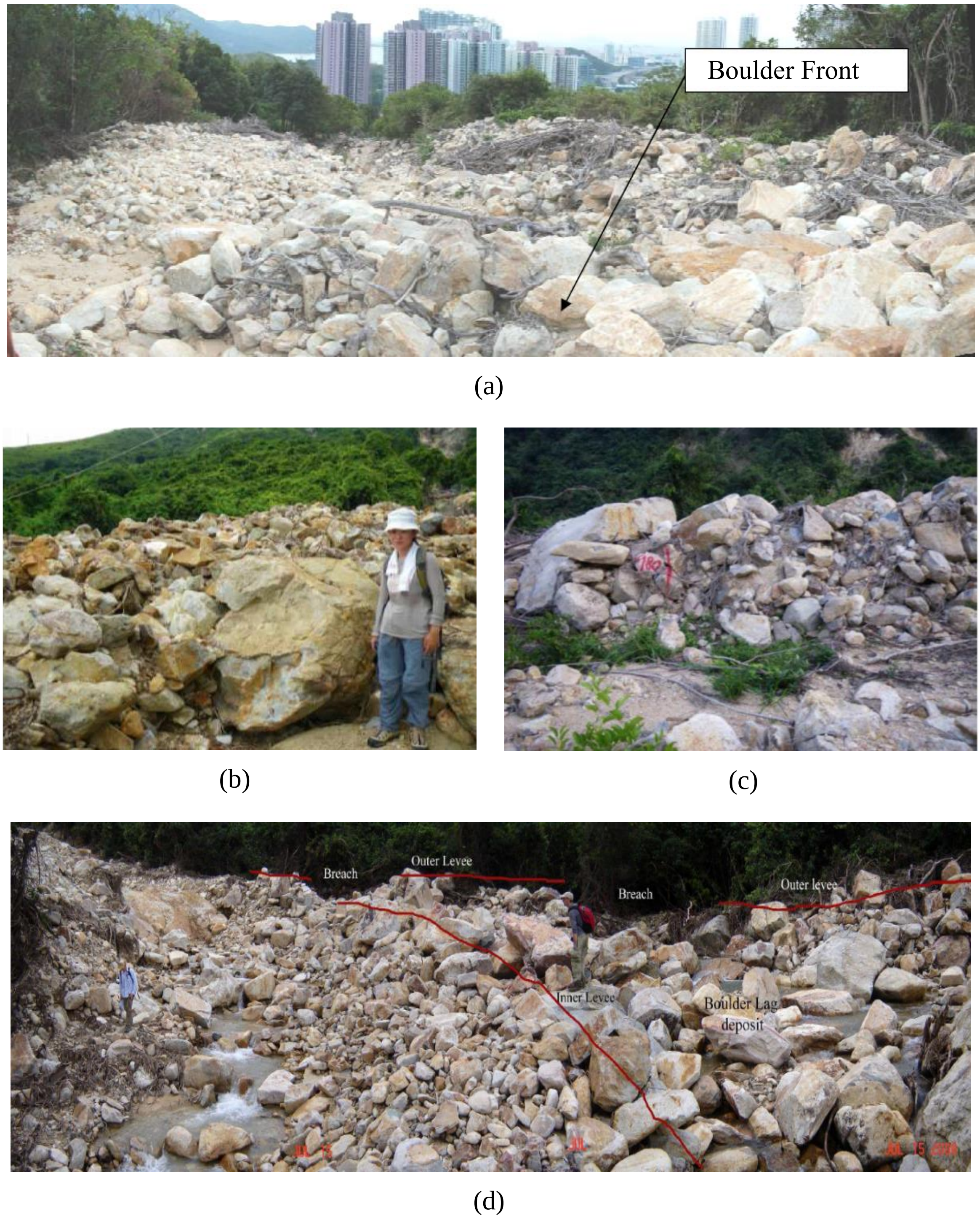


Figure 5.2 Examples of Boulder Front Deposition Observed in 2008 at: (a) Yu Tung Road; (b) Yi O Village; (c) Shek Mun Kap; and (d) Shek Pik 2

Figure 5.3 Capturing of Landslide Debris by a Flexible Barrier with Secondary Mesh in Jordan Valley (Kwan & Koo, 2015)

Overseas field tests involving soil debris hitting flexible barriers were reviewed. In one of the large-scale tests where fine-grained soil debris was released and impacted onto a flexible barrier, it was observed that some 15% (by volume) of soil could pass through the flexible barrier, even though a secondary mesh was provided (see Table 5.2 and Figure 5.4 for the details of the field test). The fine-grained soil which passed through the principal net did not travel a long distance downstream in the test.

Table 5.2 Extracts of Information from a Large-scale Field Test (Isofer, 2012)

Principal net size	250 × 250 mm
Secondary mesh size	80 × 100 mm
Debris material description	mainly fine-grained materials and sand with gravel and some stones, 20% water content
Debris source volume	50 m^3
Volume of debris retained by the barrier	32 m^3
Volume of debris passed through the barrier	6 m^3 (i.e. 15% of debris reaching the barrier)

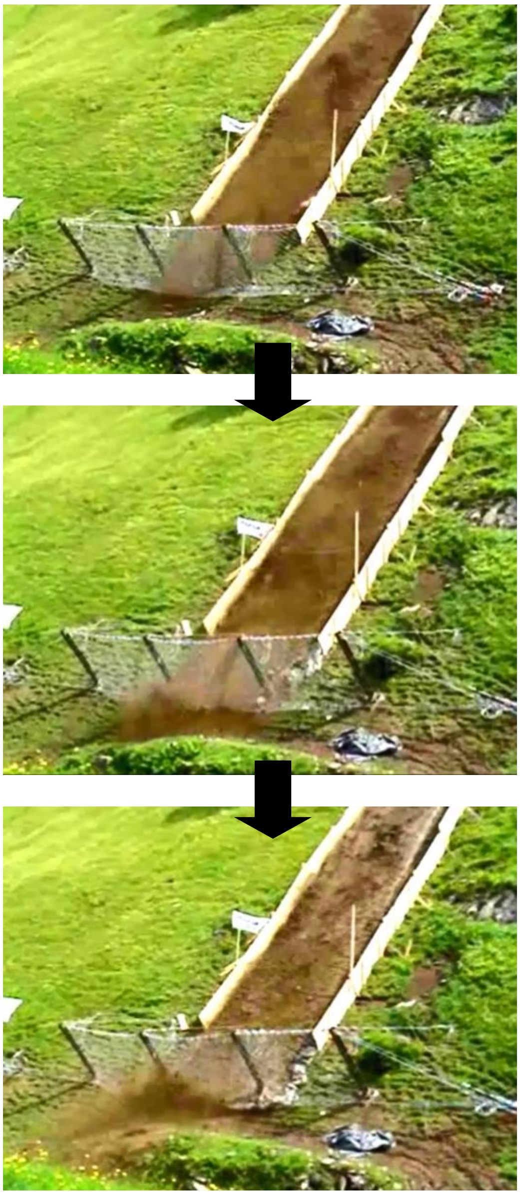


Figure 5.4 Finer Fraction of Debris Passing through a Flexible Barrier with Secondary Mesh in a Large-scale Field Test (Isofer, 2012)

6 Recommendations

Stream loads refer to transport of sediments and fallen leaves by hydraulic actions of the stream flow in a natural drainage line. Stream loads which do not adversely affect the safety of developments are not natural terrain hazards. Flexible barriers installed across a natural stream course should be designed to resist landslide debris and passageways for stream loads should hence be provided as far as practicable. Figure 6.1 shows detailing adopted for such a purpose. Illustrative examples are also provided in Appendix D.

(a)

(b)

Figure 6.1 Examples of Detailing to Facilitate Passing of Stream Loads by Provision of: (a) Drainage; and (b) Enlarged Net Opening near the Bottom (Maccaferri, 2009)

In essence, detailing for flexible barriers traversing a stream course for drainage purposes should be designed on a case-by-case basis with consideration given to the following factors:

(a) Flexible barriers are designed and constructed to arrest mainly the coarse particles within landslide debris. The normal stream flow should be maintained. Passage of stream loads should be allowed to avoid blockage to the stream course as far as practicable.

(b) Secondary mesh for flexible barriers should be used with cautions. Judgement should be exercised when deciding the need and extent of secondary mesh for a flexible barrier, with due consideration mainly given to the opening size of principal net and composition of debris (especially the coarse-grained portion at the debris front) for the design landslide event (see Section 4.2 for reference), the type and proximity of the downslope facilities being affected, depth of the stream flow and size of stream loads, etc. In general, as a good practice, for flexible barriers including those installed on an open hillside, if a secondary mesh is considered necessary, a clearance of maximum 300 mm between the skirt of the secondary mesh and the ground surface should be provided to prevent trapping of fallen leaves/debris carried by surface runoff.

(c) If the opening size of principal net is small (i.e. equivalent to the opening size of a secondary mesh), the secondary mesh can be omitted.

(d) In case that the stream flow is perennial, it may be prudent to allow a suitably-sized basal opening for the barrier to prevent trapping stream loads and impedance of stream flow. However, such basal opening must not be excessive as it could be a potential gap for the passage of debris in case of landslides. The size of the basal opening could be determined with due regard to the depth of the stream flow (prevailing stream flow in wet season), size of stream loads, the designed debris flow thickness, the geometry of stream course, the type and proximity of the downslope facilities being affected, the consequence of debris leaking through the basal opening, the environmental/ecological considerations (e.g. free passage of fauna in the stream course), etc.

(e) Proper detailing and/or drainage measures, where appropriate, should be adopted for the flexible barriers that traverse across a stream course, for example, providing properly-designed drainages/slitting structures, etc. Examples are given in Appendix D.

(f) Regular inspection and clearance of trapped stream loads on flexible barriers installed across a stream course are important. In this regard, proper maintenance access to the upslope side of the flexible barrier should be provided as far as practicable.

7 Conclusions

Flexible barriers traversing a stream course could trap stream loads based on some international and local experience. Detailing for drainage purposes of these flexible barriers should be designed on a case-by-case basis. These barriers should be regularly maintained to avoid impedance of the stream flow. Guiding principles on the design of detailing of flexible barriers to enhance the serviceability performance of the barriers are recommended in this report. Some illustrative examples are provided for reference. As the use of flexible barriers to mitigate debris flow hazards is an emerging subject in local practice, the recommendations in this Note should be enhanced when more experience and insight accrue.

8 References

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Appendix A

Background of Flooding Incident at Shatin Hospital

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A.1 Background of Flooding Incident at Shatin Hospital

In the afternoon of 19 October 2016 when a Black Rainstorm Warning Signal was in effect, a flooding incident occurred at the Shatin Hospital. According to the record from the Shatin Hospital, a large amount of surface water was discharged from a natural hillside adjoining to the premises of the Hospital, flowing down to the downslope area. As a result, some of the carpark area and road outside the main building of the Hospital was flooded.

Subsequent to this incident, GEO inspected the natural hillside and identified that a significant amount of stream loads was trapped by a flexible barrier (Feature No. 7SE-A/ND6) installed across a natural stream course. A location plan is shown in Figure A1. These trapped stream loads included some soil sediments (about 2 m deep) that were accumulated at the stream course behind the flexible barrier. Some fallen leaves and branches were found trapped by the lower portion of the barrier (up to a level of 1.2 m above the top of soil sediments accumulated). Figures A2 (a) to A2 (e) show the conditions of the flexible barrier after the incident.

It was probable that, at the time of heavy rainstorm, the stream flow could have been obstructed by the trapped stream loads, resulting in over-spillage of stream flow undermining the adjacent footpath as shown in Figures A2 (f) and A2 (g). Immediately downstream of the flexible barrier is a box culvert that receives stream flow (see Figure A2 (h)). At the time of the incident, the stream flow could have been diverted to adjacent grounds and bypassed the box culvert, thereby inundating the downstream areas. The probable flow path is indicated in Figure A1.

Based on the records from the Shatin Hospital, before the subject flooding incident, similar flooding incidents repeatedly occurred since the summer season of 2015. This suggests that the observed trapping of stream loads to the current condition could have been developed progressively in the past two to three years.

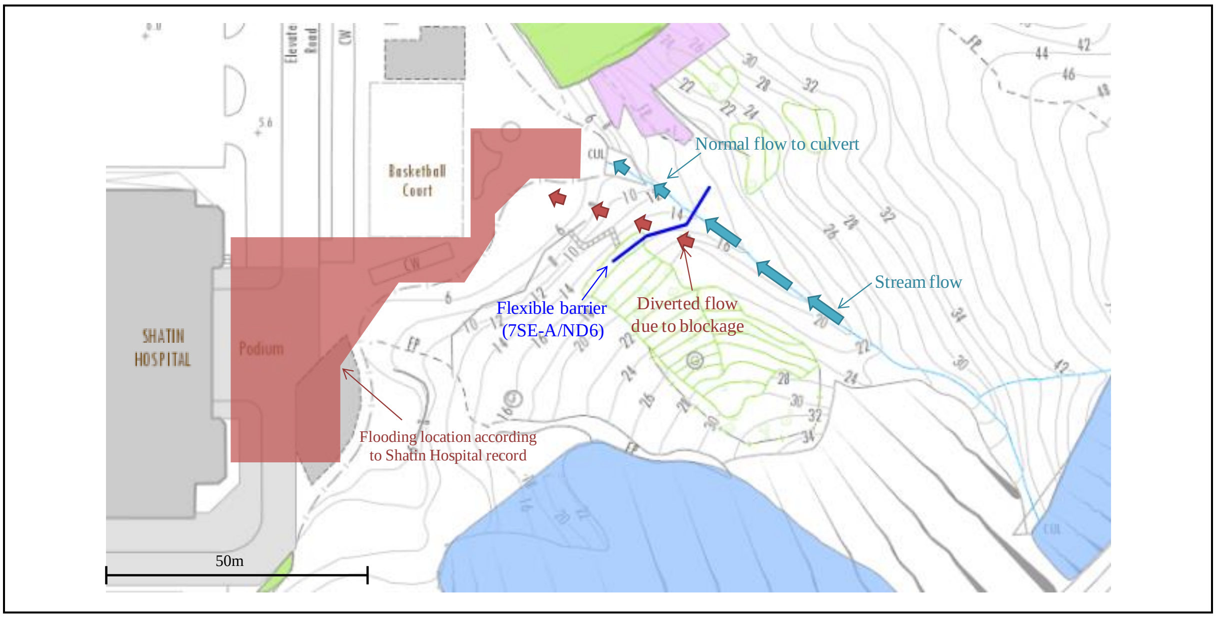

Figure A1 Location Plan of the Flooding Incident at Shatin Hospital

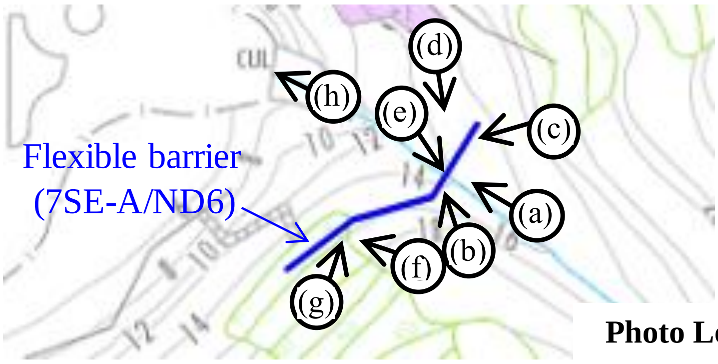

Photo Location Plan

(a)

(b)

(c)

Figure A2 Site Inspection Photos (Sheet 1 of 2)

(d)

(e)

(f)

(g)

(h)

Figure A2 Site Inspection Photos (Sheet 2 of 2)

A.2 Details of the Flexible Barrier

The subject flexible barrier was constructed under the Landslip Prevention and Mitigation Programme (LPMitP) in 2012. According to the Stage 3(H) study (Halcrow, 2011), it was designed to mitigate the channelized debris flow hazard of a design volume of 200 m^3 arising from the natural hillside upslope. According to the as-built record, the flexible barrier was a proprietary rockfall barrier with an energy rating of 5,000 kJ. It was about 5 m high and 24 m long comprising three panels supported by four steel posts. The principal net layer was composed of 350 mm diameter ring-net. Attached to the upslope side of the principal net was a layer of secondary mesh with a mesh size of 60 mm x 80 mm.

The flexible barrier was installed across a major stream course, which is relatively broad (about 8 m to 12 m wide) with the presence of a 1.9 m wide and 1.8 m deep gully running along the middle of the stream course. Figure A3 shows the design cross-section of the channel at the barrier location. At the location of the gully, an additional panel of net was provided below the flexible barrier. This additional panel composed of principal net only and was anchored to the stream bed. The secondary mesh was extended to the top of the gully. An overview of the flexible barrier after construction and the netting details within the gully are shown in Figure A4.

The installation of the flexible barrier, including the additional panel of net, was completed in late 2012. The flexible barrier was handed over to the Lands Department for maintenance since 2013.

The catchment of the stream course is sizeable, about 480,000 m^2 on plan. Based on the most severe hourly rainfall of about 120 mm/hr that occurred in the catchment area since the erection of the flexible barrier, the estimated flow rate of the stream course could be up to around 16 m^3/s, which corresponded to a flow depth of about 1 m from the base of the gully, assuming that the stream flow at the gully had been unobstructed.

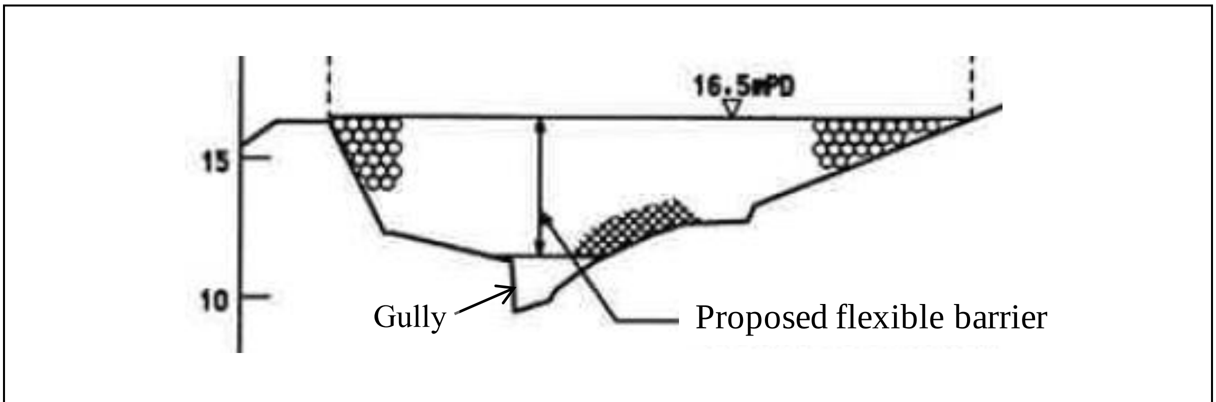

Figure A3 Design Cross-section of the Stream Course (Extracted from Stage 3(H) report)

(a)

(b)

Figure A4 Photos of (a) the Flexible Barrier; and (b) Netting Details after Construction

A.3 Findings after Completion of Remedial Works

The remedial works was completed in July 2017. A total of about 10 m^3 of stream loads was removed. The lower portion of the trapped stream loads (primarily within the gully) was found to be mainly boulders of irregular shape with an average size of about 300 to 500 mm (Figure A5 (a)). The upper portion of the trapped stream loads was uniformly-graded soil sediments (about 0.4 m thick). Turbulent flow in the stream was observed (Figure A5 (b)).

(a)

(b)

Figure A5 Photos Taken after Clearance of Trapped Stream Loads: (a) Boulders Removed from the Gully; and (b) Active Stream Flow Observed

A.4 References

Halcrow (2011). *Stage 3(H) Study Report: Study Area No. 7SE-A/SA3 (Hillside Catchment Nos. 7SE-A/DF25 and 7SE-A/DF25a) behind Shatin Hospital, Shatin (S3(H)R 9/2010).* Halcrow China Ltd., 238 p.

Appendix B

Literature Review

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B.1 Literature Review

A literature review was carried out on the relation between the principal net opening and the debris retention capability of a flexible barrier.

According to the laboratory flume study by Wendeler & Volkwein (2015) (see Figure B1), most of the debris material could be retained by the net if the net opening is smaller than the d_{90} grain size, where d_{90} is the maximum diameter of 90% of the particles composing the debris material. Volkwein (2014) also recommended that if the opening size of the principal net of a debris-resisting flexible barrier exceeds the grain fraction d_{90}, a small-sized secondary mesh should be provided.

Mesh size = 3 cm Nearly all debris retained	Mesh size = 4 cm About 80% of debris retained	Mesh size = 6 cm About two-thirds of debris retained
Note: d_{90} grain size of debris material = 3 cm.		

Figure B1 Extracts of Some Test Results from the Laboratory Flume Study by Wendeler & Volkwein (2015)

Wendeler & Volkwein (2015) also found that the basal opening (i.e. the gap between the net and the channel floor) of a flexible barrier having a size of d_{90} grain size could more effectively retain the debris.

PWRI (1988) stated that a permeable dam could retain debris flow if its opening is less than two times of the maximum clast diameter of the debris materials.

Zhou et al (1991) discussed that if the net opening of a flexible net structure was smaller than two times of the maximum clast diameter of the debris material, the debris could form a plug behind the net structure.

B.2 References

PWRI (1988). *Technical Standard for the Measures Against Debris Flow* (Technical Memorandum of PWRI No. 2632) (Draft). Public Works Research Institute, Japan, 45 p.

Volkwein, A. (2014). *Flexible Debris Flow Barriers - Design and Application.* Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Issue 18, 29 p.

Wendeler, C. & Volkwein, A. (2015). Laboratory Tests for the Optimisation of Mesh Size for Flexible Debris-flow Barriers. *Nat. Hazards Earth Syst. Sci*., 15, 2597-2604.

Zhou, B.F. (1991). *泥石流防治指南.* 科學出版社, 206 p (in Chinese).

Appendix C

Summary of Mapping Reports of about 50 Selected Channelized Debris Flow in June 2008

Table C1 Summary of Mapping Reports of about 50 Selected Channelized Debris Flow (CDF) in June 2008 (Sheet 1 of 5)

Location	Debris Front					
	Description/Remarks	Max. Clast Diameter m	Percentage by Volume			
			> 200 mm	60-200 mm	2-60 mm	< 2 mm
Catchment No. 30 above Yu Tung Road, Tung Chung	Grey, angular to sub-angular cobble- and boulder-sized rock fragments with soil matrix of silt/sand	2.5	40	20	20	20
Catchment No. 24 above Yu Tung Road, Tung Chung	Light greenish grey, sub-rounded to sub-angular cobbles with many boulders, some gravels and locally with some silt and sand matrix	1	25	30	30	15
Catchment No. 25 above Yu Tung Road, Tung Chung	Light greyish white, sub-rounded to sub-angular cobbles with some gravels and occasional boulders locally with a silt and sand matrix	1.5	25	30	30	15
Catchment No. 15 above North Lantau Highway, Tung Chung	Soft, pale brown to light reddish brown, silty/clayey gravelly sand with some to many cobbles and boulders of tuff	1.5	30	30	20	20
Catchment No. 15 above North Lantau Highway, Tung Chung	Cobbles and a few boulders of about 0.3 m by 0.3 m	0.3	20	40	30	10
Catchment No. 21 above North Lantau Highway, Tung Chung	Rhyolitic tuff cobbles and boulders	2	20	40	30	10
Catchment No. 19 above North Lantau Highway, Tung Chung	Sub-angular to sub-rounded cobble- and boulder-sized rock fragments with some fines/ matrix, clast supported	0.3	30	40	20	10
Shek Mun Kap	Woody debris and many sizeable boulders, clast supported	1.5	80	10	8	2
On the hillside above Yi O Village	Unsorted subangular boulders (typical 1 - 2 m) and cobbles with a matrix of gravels, sands and finer materials, and a significant amount of vegetation (10%).	4	40-50	20	20	10
South of Yi O Village	No photo shows big boulders at distal end, description provided as heterogeneous, clast supported, boulders, typically < 1.5 m	< 1.5	10	20	20	50
Shek Pik 1	Clastic debris, with matrix, clast-supported.	5	N/A	N/A	N/A	> 10

Table C1 Summary of Mapping Reports of about 50 Selected Channelized Debris Flow (CDF) in June 2008 (Sheet 2 of 5)

Location	Debris Front					
	Description/Remarks	Max. Clast Diameter m	Percentage by Volume			
			> 200 mm	60-200 mm	2-60 mm	< 2 mm
Adjacent to Shek Pik 1	Heterogeneous, clast suppported sub-angular to sub-rounded boulders typically < 1.5 m.	1.5	10	20	20	50
Northeast of Shek Pik	Subrounded cobbles and boulders of slightly decoposed coarse ash tuff, clast supported	1.5	60	40	0	0
WH9-c above Wang Hang	Loose, light brown cobbles and boulders with some silty sand, clast supported	N/A	80	20	0	0
WH9-b above Wang Hang	Merge with "WH9-c" at CH185	N/A	80	20	0	0
WH9X above Wang Hang	Dry, stiff, light brown, sandy clayey silt with some angular gravels, cobbles and boulders (Note: it is a shallow but spatially extensive (42 m wide) failure)	1.5	20	20	40	20
WH9A-e above Wang Hang	Loose, light brown cobbles and boulders with some silty sand, clast supported	1.5	80	20	0	0
Sham Wat	Clast-supported debris, mostly angular to sub-rounded, moderately to highly decomposed cobble- and boulder-sized clasts, with some yellowish brown silty sand	2	30	40	20	10
West facing open hillside above Sham Wat Vilage in West Lantau	Angular to sub-angular cobbles and boulders of MD fine ash tuff, with some angular coarse grvel (Clastic debris)	0.5	30	50	10	10
West facing open hillside above Sham Wat Vilage in West Lantau	Angular to sub-angular, medium to coarse gravel with matrix of silt/sand, clast supported matrix colluvium)	1.2	0	10	60	30
North-northeast facing hill slope to the south of Tai-O road and approximately 600 m southwest of the Kwun Yam temple	Clastic debris flow/avalanche deposit, highly heterogeneous, coarse to very coarse comprising sub-angular to sub-rounded, moderately to highly decomposed coarse ash/lithic crystal tuff, clast supported.	1.5	10	20	20	50

Table C1 Summary of Mapping Reports of about 50 Selected Channelized Debris Flow (CDF) in June 2008 (Sheet 3 of 5)

Location	Debris Front					
	Description/Remarks	Max. Clast Diameter m	Percentage by Volume			
			> 200 mm	60-200 mm	2-60 mm	< 2 mm
North-northeast facing hill slope to the south of Tai-O road and approximately 600 m southwest of the Kwun Yam temple	Brown, gravelly silty sand with angular to sub-angular boulders and cobbles	0.5	25	20	15	40
390 m to the west of Keung Shan Road	Poorly-sorted, angular to sub-angular boulders and cobbles of moderately decomposed coarse ash/lithic tuff.	2.2	30	35	20	15
North-facing slope of Mount Davis	Wet loose sandy gravel and cobbles, some boulders, clast supported	3.8	20	40	30	10
North-facing slope of Mount Davis	Loose sandy gravels and cobbles, some boulders, clast supported	1	20	40	30	10
Landslide above Shatin Pass Road affect Tsz Ching Estate	Sub-angular cobbles and boulders, no matrix	1	20	40	30	10
Catchment No. 7 above Nam Chung Tsuen	Angular boulders and cobbles of MDT with a matrix of loose sandy clayey silt	2	60	20	10	10
Catchment No. 1 above Nam Chung Tsuen	Heterogeneous, clast suppported sub-angular to sub-rounded boulders typically < 1.5 m. Terminal debris lobe likely reworked by fluvial processes reduing % of fines	~2	10	40	25	25
Landslide above Leung Uk Tsuen	Loose boulder and cobble debris with some fines, clast supported	1.3	30	50	10	10
South faing slopes between Keung Shan and Tai Long Wan Tsuen	Subangular to subrounded cobbles and boulders of coarse ash tuff with some pockets of loose sand and gravel, clast supported	0.7	20	70	10	0
South faing slopes between Keung Shan and Tai Long Wan Tsuen	Subangular to subrounded cobbles and boulders of coarse ash tuff with some loose sand and gravel, clast supported	0.6	10	50	40	0

Table C1 Summary of Mapping Reports of about 50 Selected Channelized Debris Flow (CDF) in June 2008 (Sheet 4 of 5)

Location	Debris Front					
	Description/Remarks	Max. Clast Diameter m	Percentage by Volume			
			> 200 mm	60-200 mm	2-60 mm	< 2 mm
South facing hillslope near Keung Shan Peak above Tai Long Wan, Lantau Island	Sub-angular to subrounded cobbles and boulders with a little to some gravel and silty clay, clast supported, typical landslide boulder deposits	3	40	30	20	10
South facing hillslope near Keung Shan Peak above Tai Long Wan, Lantau Island	Sub-angular to subrounded cobbles and boulders with a little to some gravel and silty clay, clast supported, typical landslide boulder deposits	2	40	30	20	10
West of Ngong Ping	Gravel, cobble- and boulder-sized fragments of sub-angular rock, generally comprising fine ash tuff (Debris Landslide Material), clast supported	1.4	30	30	30	10
West-facing hillside of Nei Lak Shan, northwest of Ngong Ping	Sub-angular to sub-rounded cobbles and boulder sized rock fragments with some fines/ matrix	0.5	35	25	20	20
South Lantau	Loose, light grayish green, subangular and elongated tuff cobbles and boulders with some sandy matrix, clast supported	0.8	60	20	10	10
Hillside below Nei Lak Shan, to the southeast of Shan Wat Wan / North of Ngong Ping	Heterogeneous, clast suppported sub-angular to sub-rounded boulders typically < 1.5 m. Terminal debris lobe likely reworked by fluvial processes reducing percentage of fines	2.5	15	30	25	30
Hillside below Nei Lak Shan, to the southeast of Shan Wat Wan / North of Ngong Ping	Heterogeneous, clast suppported sub-angular to sub-rounded boulders typically < 1.5 m. Terminal debris lobe likely reworked by fluvial processes reducing percentage of fines	3	15	30	25	30
West of Lantau Peak, south of Po Lin Monastery	Subrounded cobbles and boulders of coarse ash tuff with much vegetation	1.7	60	40	0	0
West facing slopes below Nei Lak Shan, northeast of Po Lin Monastery	Subrounded cobbles and boulders of fine ash tuff with much vegetation, clast supported	0.8	70	30	0	0

Table C1 Summary of Mapping Reports of about 50 Selected Channelized Debris Flow (CDF) in June 2008 (Sheet 5 of 5)

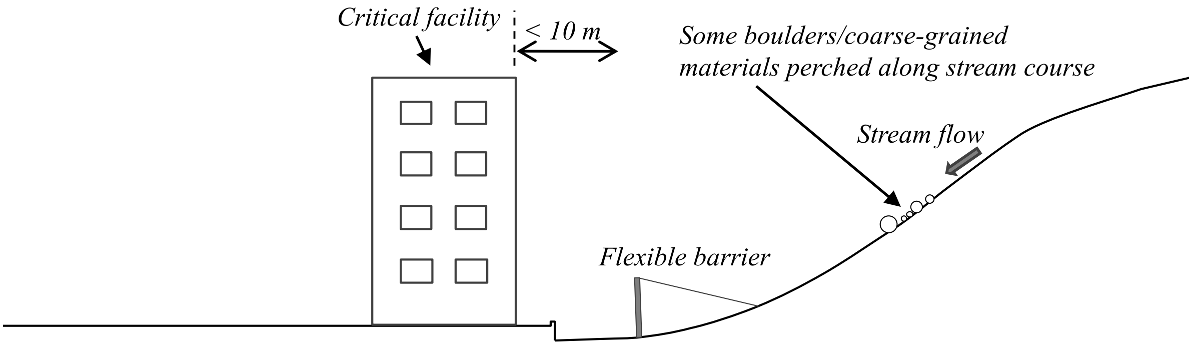
Location	Debris Front					
	Description/Remarks	Max. Clast Diameter m	Percentage by Volume			
			> 200 mm	60-200 mm	2-60 mm	< 2 mm
Below rigdeline of Lantau Peak, within Lantau South Country Park	Heterogeneous, clast supported with boulders typically < 1.5 m	1.5	20	40	30	< 10
Southeasterly facing hillside below Sunset Peak in South Lantau	Loose sandy gravel & cobbles, some boulders in a clast supported matrix	1	20	40	30	10
Southeasterly facing hillside below Sunset Peak in South Lantau	Loose sub-angular cobbles and boulders, with some sands and gravels, boulders typically 0.3-0.6 m	0.9	20	40	25	15
Southeasterly facing hillside below Sunset Peak in South Lantau	No big boulders in frontal deposit	0.4	N/A	N/A	N/A	N/A
North-facing hillside above a WSD reservoir and Chep Lap Kok New Village	Heterogenous, dense grayish brown sandy gravelly vobbles and boulders, clast supported	1	30-60	20-40	10-20	10
West facing catchment in West Lantau, northeast of Tai O Village	Highly heterogeneous, silty and very gravelly sand with many cobbles and some boulders or bouldery cobbles with some to much finer material, clastic debris with > 30% matrix	2	10-20	20-40	20-30	10-40
Northwest facing slopes below Cheung Shan northeast of Tai O	Clastic debris with predominantly angular and subangular boulders and cobbles of eutaxite	1.8	50	50	0	0
Northwest facing slopes below Cheung Shan northeast of Tai O	Debris slide and debris avalanche	3	N/A	N/A	N/A	N/A
Northwest facing slopes below Cheung Shan northeast of Tai O	Clastic debris, predominantly angular to sub-angular eutaxite boulders and cobbles	N/A	50	15	10	25

Notes: (1) Maximum active volume of these landslides ranges from about 50 m^3 up to > 2,000 m^3.
(2) N/A: Information not available.

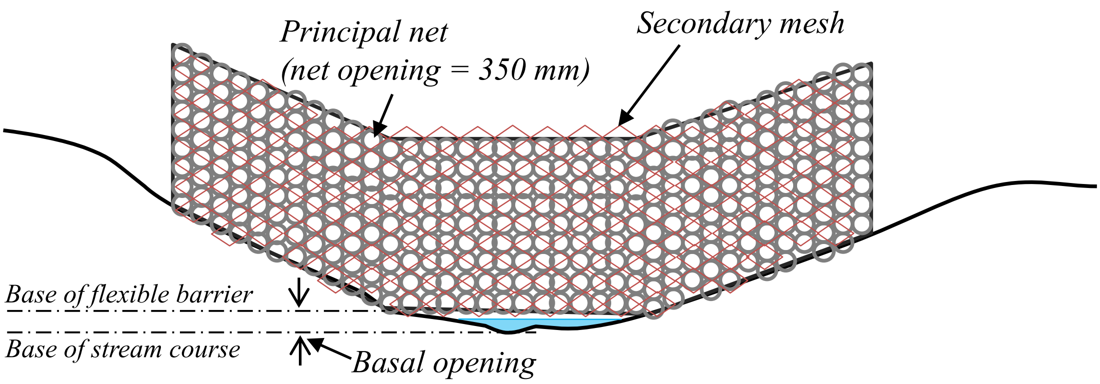
Appendix D

Worked Examples

Case 1 - flexible barrier in close proximity (e.g. < 10 m) to critical facility



Slope profile along stream course



Secondary mesh is provided and a small (up to 300 mm) basal opening (i.e. the clearance between the bottom side of the net and the base of stream course) is allowed to reduce any potential hazard due to leakage of landslide debris.

Remarks:

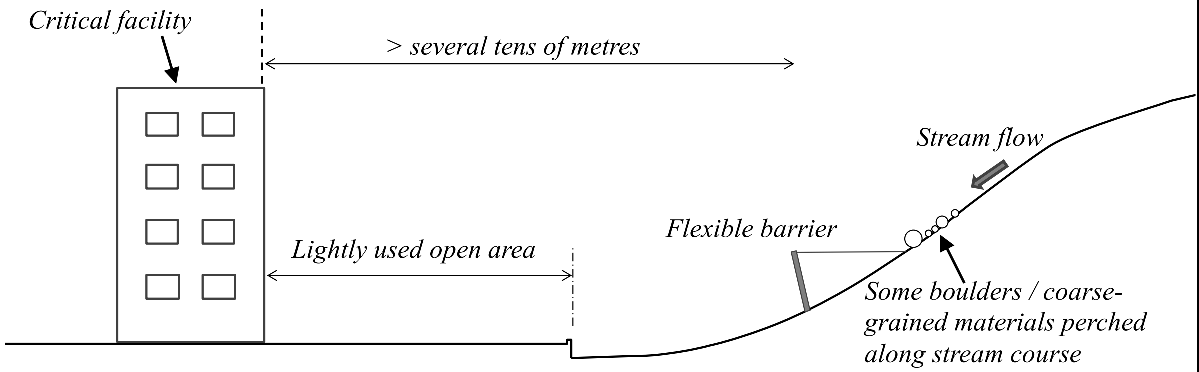
(1) *Judgement should be exercised to determine the size of the basal opening, and the guiding principles given in Section 6(d) of the main text should be followed.*

(2) *In this case, since the secondary mesh and small basal opening would easily trap stream loads, regular inspection and clearance of any stream loads trapped by the flexible barrier are important to facilitate smooth passage of stream flow.*

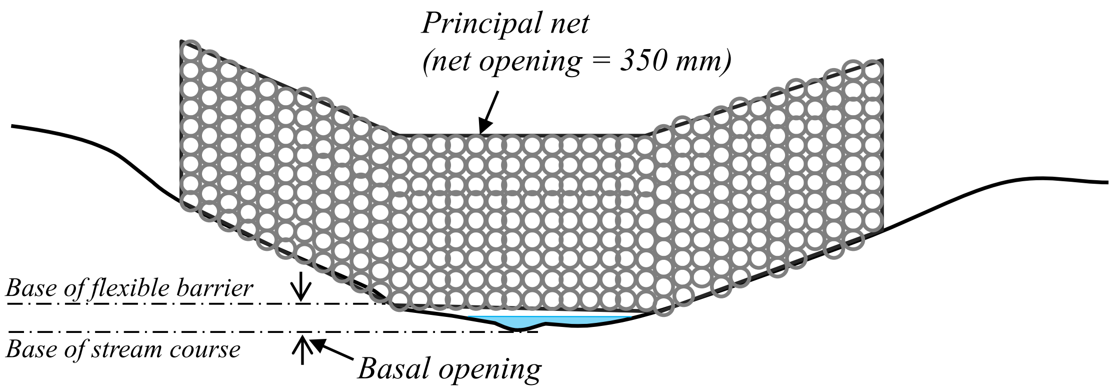
(3) *Where deemed appropriate, the designers may consider the need of measures (e.g. surface drainage or bunds/baffle walls) to divert overflow, if any, back to the stream course in case of blockage of the flexible barrier.*

Proposed detailing of flexible barrier

Case 2 - flexible barrier far away (e.g. several tens meter) from critical facility



Slope profile along stream course



No secondary mesh is provided and a basal opening of 300 mm to 500 mm is allowed in this case.

Remarks:

(1) *The basal opening should be suitably adjusted in some special circumstances. For example, if the envisaged flow depth is large (e.g. due to the presence of an incised gully) or the envisaged stream bed load is large (e.g. up to 0.5 m in diameter in some stream courses in Hong Kong), the size of the basal opening should be suitably increased with a view to preventing the blockage of the net or relieving the impedance of the stream flow as far as possible, so as to reduce the maintenance effort. In any case, the guiding principles given in Section 6(d) of the main text should be followed.*

Proposed detailing of flexible barrier

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