Enhanced Technical Guidelines for Design of Debris-resisting Barriers

GEO Report No. 333

J.S.H. Kwan & R.C.H. Koo

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
February 2018

Foreword

Reviews of the prevailing guidelines of design of debris-resisting barriers have been undertaken by Dr Julian S. H. Kwan and Mr Raymond C. H. Koo under my supervision. Enhanced design guidelines are also recommended. The reviews and recommendations were presented in two separate discussion papers. This Technical Note documents these two discussion papers.

Ms Carie L. H. Lam carried out debris mobility analyses and a review of landslide mapping reports of the case histories for the study of the design retention volume of debris-resisting barriers. Many individuals in the GEO and various Works Departments, and different LPM Consultants provided comments on the discussion papers. The Drafting Unit of the S&T Division assisted in formatting this report. Contributions from all parties are acknowledged.

Y.K. Shiu
Chief Geotechnical Engineer/Standards & Testing

Abstract

Improved guidelines for design of rigid and flexible debris-resisting barriers are proposed. It is recommended that variation of debris velocity at the location of a barrier can be taken into account for determining the design debris velocity with the consideration of multiple phases of impact on the barrier. In addition, design considerations for estimating the retention volume for the design of barriers are also recommended.

Contents

1 Introduction

The prevailing guidelines for the design of rigid and flexible debris-resisting barriers are promulgated by GEO (2012) and Kwan & Cheung (2012). Since then, experience in applying the technical guidelines has accrued. Feedback on the design guidelines is received from practitioners from time to time. Driven by the continuous improvement initiatives, a review of the prevailing guidelines has been carried out.

The review focused on design practice in respect of (i) determination of design debris impact velocity, and (ii) estimation of design retention volume. They are pertinent to the design of both rigid and flexible debris-resisting barriers. This report documents details of the review. It also presents enhanced design recommendations and discusses the basis of the recommendations.

2 Determination of Design Debris Impact Velocity

Multiple phases of debris impact are considered in the design of debris-resisting barriers. In the current practice, debris impact force applied in all phases is assumed to be the same. Essentially, this infers a constant design debris velocity in the process of the debris impacting on barriers. Having reviewed available field and laboratory test data (AECOM, 2012; Choi & Ng, 2013), it is recommended that variation of debris velocity at the location of the barriers should be considered in barrier designs. Appendix A presents the review and the recommendations.

3 Estimation of Design Retention Volume

Design retention volume of debris-resisting barriers is usually taken as the total of the landslide source volume and the volume of entrainment yielded in the landslide runout process. Debris mobility analysis and field mapped debris deposition profile of several landslide case histories have been reviewed. Based on the results of the review, guidance on design good practice and key considerations to be made for assessing the design retention volume are recommended. Details are presented in Appendix B.

4 Conclusion

Enhanced guidelines on establishing debris impact velocity and retention volume for the design of debris-resisting barriers are recommended. They are considered to be practical and appropriate for local situation. As the design of debris-resisting barriers for landslide mitigation measures is a relative new subject in Hong Kong, further review on the guidelines would be carried out when more experience and data become available.

5 References

AECOM (2012). *Detailed Study of the 7 June 2008 Landslides on the Hillside above Yu Tung Road, Tung Chung* (GEO Report No. 271). Geotechnical Engineering Office, Hong Kong, 124 p.

Choi, C.E. & Ng, C.W.W. (2013). *Flume Tests to Examine Dynamics of Debris Flows Obstructed by Baffles (Final Report).* Report prepared for Geotechnical Engineering Office, Hong Kong SAR Government. The Hong Kong University of Science and Technology, 110 p.

GEO (2012). *Supplementary Technical Guidance on Design of Rigid Debris-resisting Barriers.* GEO Technical Guidance Note No. 33 (TGN 33). Geotechnical Engineering Office, Hong Kong, 1 p.

Kwan, J.S.H. & Cheung, R.W.M. (2012). *Suggestions on Design Approaches for Flexible Debris-resisting Barriers* (GEO Discussion Note 1/2012). Geotechnical Engineering Office, Hong Kong, 91 p.

Appendix A

Landslide Debris Impact Velocity for Design of Debris-resisting Barriers

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A.1 Background

Landslide debris appears as an "elongated continuum" during its travel on natural hillsides and it impacts on debris-resisting barriers in phases; debris which arrives at a later stage may ride on the debris deposited behind the barrier and hit the barrier at a higher elevation. A landslide debris impact scenario for current design practice of debris-resisting barriers is illustrated in Figure A1.

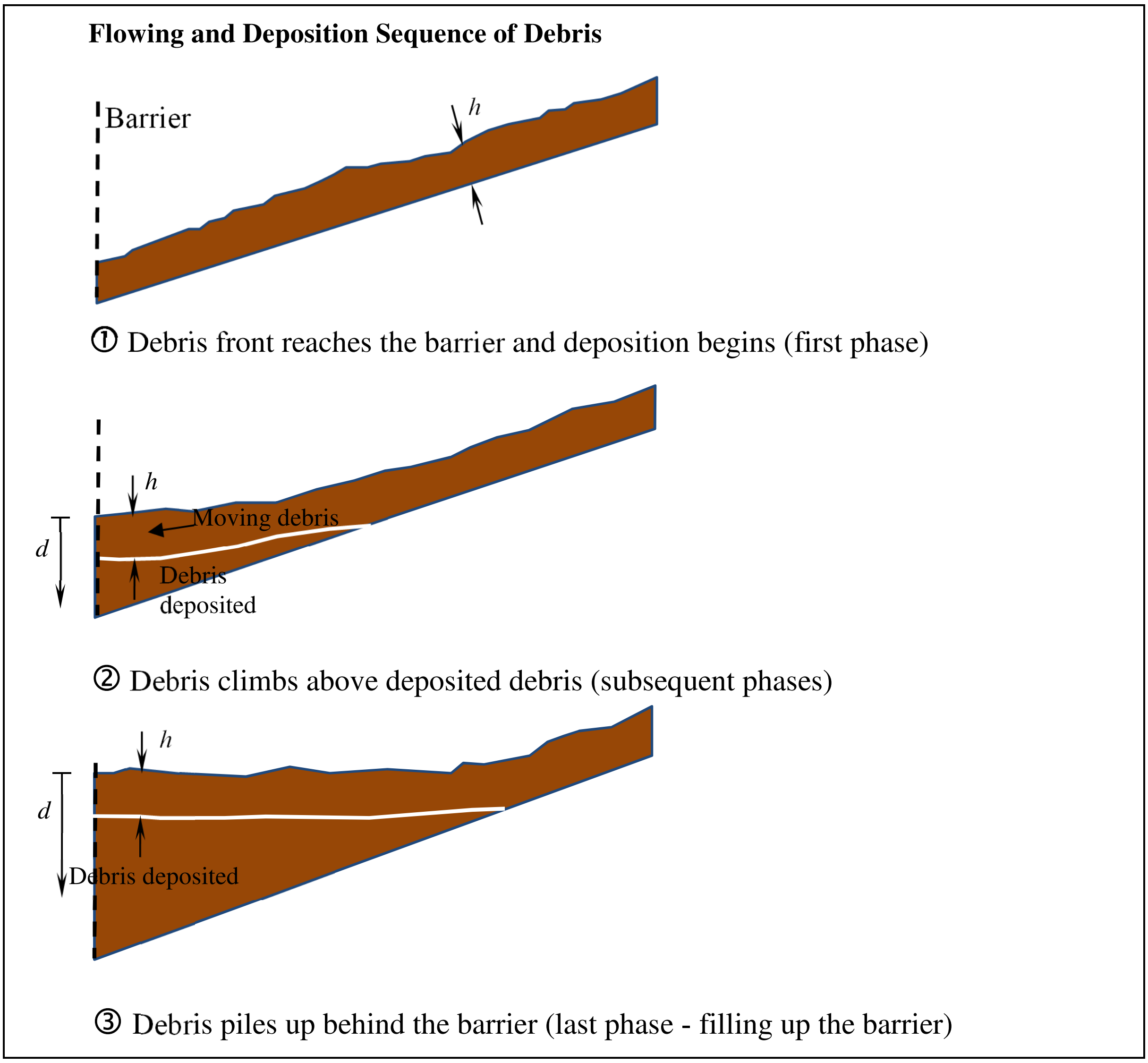


Figure A1 The Landslide Debris Impact Scenario for Design of Debris-resisting Barriers (Kwan, 2012; Kwan & Cheung, 2012)

The design force per unit width (F) acting on a barrier induced by debris impact, perpendicular to the barrier, is calculated based on the hydrodynamic approach:

$$F = \alpha \rho v^2 h \qquad (1)$$

Where	α	=	dynamic pressure coefficient
	ρ	=	density of debris flow (in kg/m^3)
	v	=	debris velocity at impact (in m/s)
	h	=	debris thickness (in m).

The thickness (h) and velocity (v) of the moving debris are usually estimated from debris mobility analysis. The rheological parameters recommended by GEO Technical Guidance Note (TGN) Nos. 29, 34 and 38 are used in the analysis for design purposes.

Debris reaching the barrier at different times may have different combinations of h and v. The current design guidelines recommend that the design debris impact load is taken as the larger of:

(a) the maximum impact load calculated based on the combination of h and v at different times; and

(b) the impact load calculated based on the maximum debris frontal velocity and the average debris thickness at the barrier location.

It is noted that item (a) gives a greater maximum impact force in most cases (Kwan, 2012). From design experience, the debris velocity for establishing the design impact load normally corresponds to the maximum debris velocity at debris front.

The loading calculated above is applied to all phases for design of debris-resisting barriers, i.e. debris impact velocity of all phases is assumed to be the same. However, observations of local landslide cases and physical flume test results suggest that debris velocity drops behind the debris frontal portion (see also Annex A-A), which indicates that debris impact load reduces in subsequent phases. In addition to the above, reference has been made to Lam (2013), who systematically reviewed and back analysed over 150 open hillside failures (OHF) based on field mapping records (some of those OHF could be considered as debris flows in topographic depressions, following the guidelines of GEO (2014) promulgated recently). The results of the velocity hydrograph in the back analyses show that the landslide debris velocity would attenuate more than 50% toward the rear portion of the landslide debris.

A.2 Proposed Enhancement

The current method of establishing the design debris impact load described in the above paragraph neglects the variation in debris velocity. To optimise the design of debris-resisting barriers, it is suggested taking the velocity variation into account in the debris impact load calculation by representing the velocity hydrograph using a step function (see Figure A2).

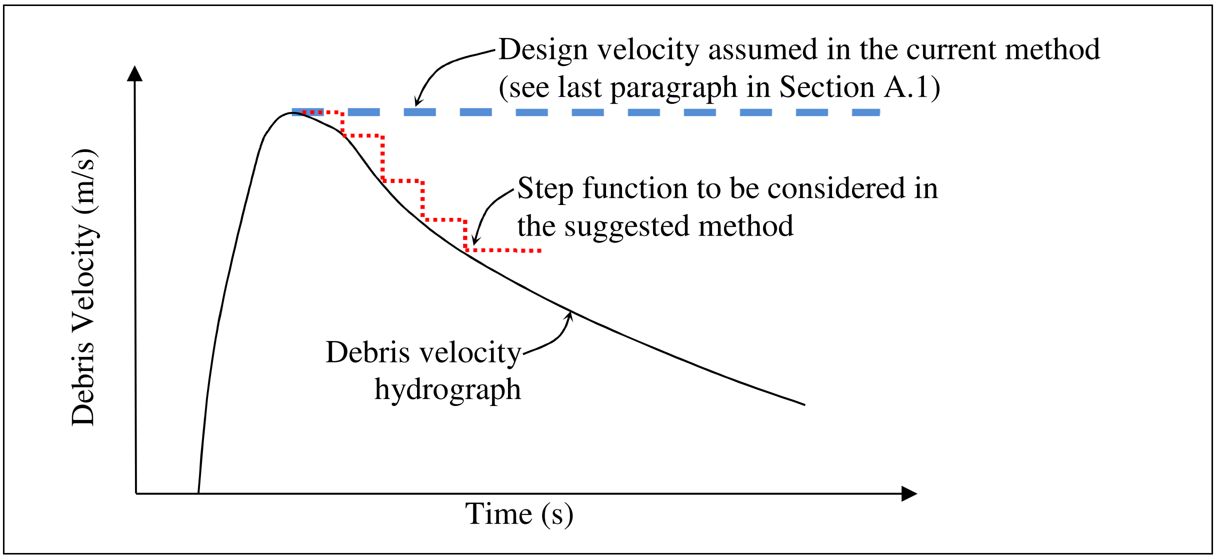


Figure A2 Velocity Hydrographs Considered in Establishing the Design Debris Impact Load

The step function may be established with the consideration of the volume of debris deposited after each phase. Geometry of debris deposition behind a debris-resisting barrier can be assumed to be triangular in shape (see Figure A3(a)). Based on the assumed geometry, the volume of each phase stopped by the barrier can be calculated. Having calculated the deposition volumes of different phases, the time intervals of the phases can be read off from the cumulative debris volume hydrograph at the barrier location (see Figure A3(b)). Debris velocity corresponding to each phase can also be determined based on the time interval from velocity hydrograph (see Figure A3(c)) for design purposes. This velocity can also be applied to establishing boulder impact load, if consideration of boulder impact is relevant to the barrier design.

The following restrictions are suggested in order to ensure robustness of design:

(a) the maximum debris velocity in each phase should be used in establishing the design impact load of the corresponding phase,

(b) a limit should be set on the amount of reduction of impact debris velocity to be adopted in design (considering the uncertainties involved in the debris mobility analysis and the need for robust design, a limit of not more than 30% of the calculated maximum debris velocity of the hydrograph, i.e. the design impact velocity of any phase should not be less than 70% of the maximum debris velocity of the hydrograph, is appropriate), and

(c) the debris impact direction should be perpendicular to the barrier.

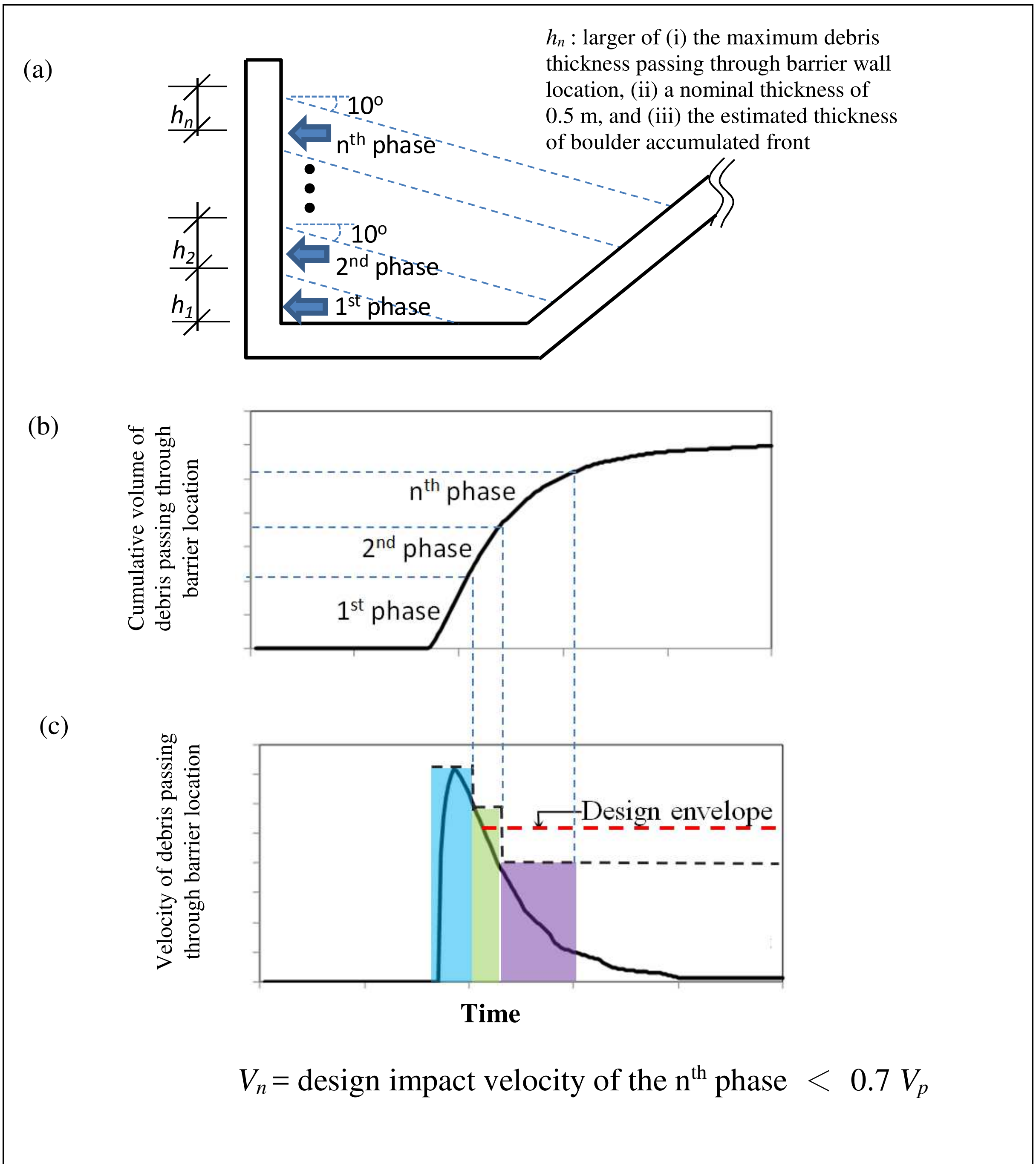


Figure A3 The Suggested Debris Impact Scenario for Design of Barriers: (a) Number of Phases, (b) Design Cumulative Volume, and (c) Design Envelope of Velocity Profile

Hungr (2000) points out that most of the debris mobility models do not account for discharge magnification due to the building of a frontal boulder accumulation. To account for such a frontal accumulation, the design debris impact thickness should be taken as the larger of (i) the maximum thickness of landslide debris that would pass through the barrier location in the free field condition, (ii) a nominal thickness of 0.5 m, and (iii) the estimated thickness of the boulder accumulated front. The inclination of the ramp of the wedge shape deposition can be assumed to be 10° (Kwan & Cheung, 2012). Consideration of the abundance of boulders should be given when determining the design debris thickness (*h*). The value of *h* in the first phase or the first few phases of impact could be controlled by the thickness of the boulder accumulated front while subsequent phases may not.

It should be noted that retention capacity of a barrier should be established based on the final debris deposition profile as discussed in Section 2.1 of GEO TN 3/2013 (see also Figure 2.1 of the TN). The debris deposition wedges shown in Figure A3(a) depict the assumed deposition profiles during the filling up process of the barrier. They do not represent the final debris deposition profile, and thus should not be used for the calculation of the overall barrier retention capacity.

A.3 A Preliminary Study of Optimization

Barrier designs in the following projects have been repeated using the procedures suggested in Section A.2:

(a) Rigid barrier design for:

  (i) Yu Tung Road,

  (ii) Conduit Road,

  (iii) Example in Appendix C of GEO Report No. 270, and

  (iv) Shek Pai Wan Road.

(b) Flexible barrier design for:

  (i) Ap Lei Chau Road, and

  (ii) Castle Peak Road.

Tables A1 and A2 compare the maximum forces of barriers induced by the design debris impacts calculated using the current method (in Section A.1) and the suggested procedures in Section A.2. Reductions in design forces ranging from about 15% to 30% are noted, except the cable force in the Castle Peak Road project in which the cable force, due to the control by the characteristics of the brake element, is minimal.

Table A1 Design of Rigid Barriers - Comparisons between Current Method and the Suggested Method (Sheet 1 of 4)

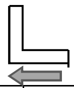
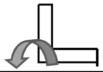
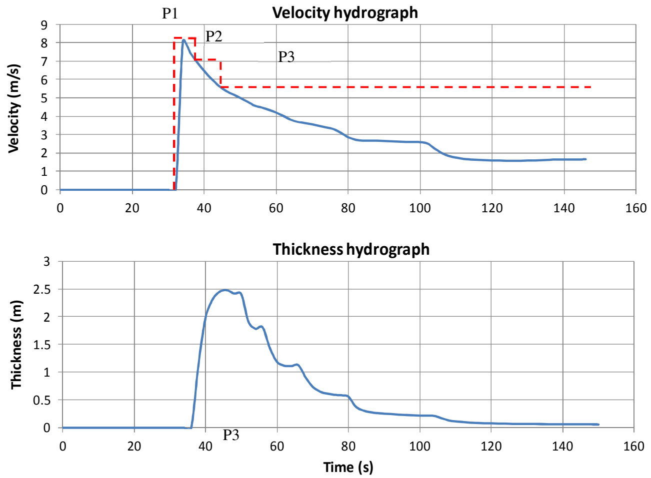
Case	Design volume (m^3)	Design no. of phases	Design thickness (m)	Debris velocity and thickness hydrographs	Maximum disturbing shear (kN/m) 		Maximum overturning moment (kNm/m) 	
					Current method	Suggested method (% diff.)	Current method	Suggested method (% diff.)
Yu Tung Road	3,300	3	2.5		1,032	899 (-13%)	4,836	3,405 (-30%)

Table A1 Design of Rigid Barriers - Comparisons between Current Method and the Suggested Method (Sheet 2 of 4)

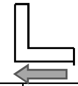
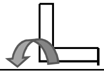
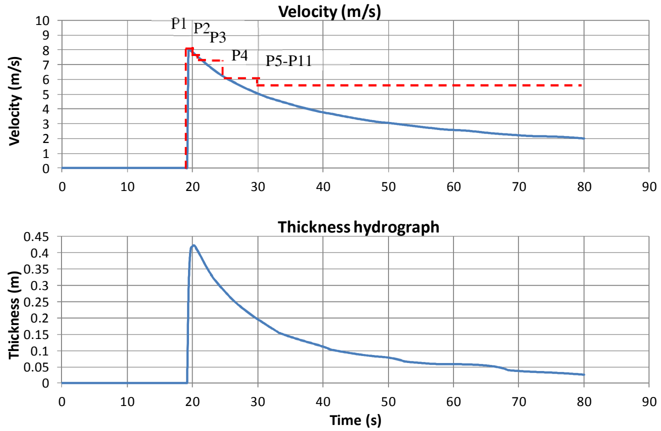
Case	Design volume (m^3)	Design no. of phases	Design thickness (m)	Debris velocity and thickness hydrographs	Maximum disturbing shear (kN/m) 		Maximum overturning moment (kNm/m) 	
					Current method	Suggested method (% diff.)	Current method	Suggested method (% diff.)
Conduit Road	450	11	0.5		457	388 (-15%)	1,392	1,039 (-25%)

Table A1 Design of Rigid Barriers - Comparisons between Current Method and the Suggested Method (Sheet 3 of 4)

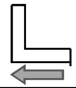
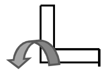
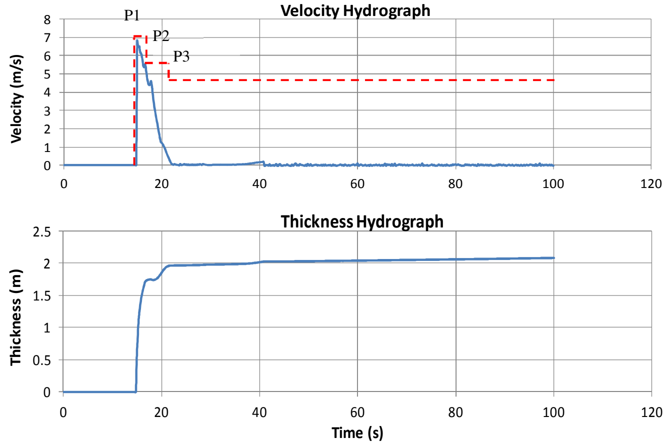
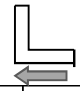
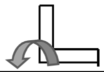
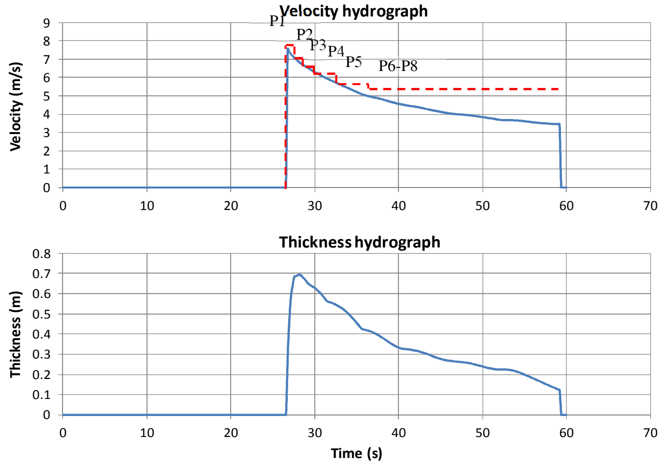
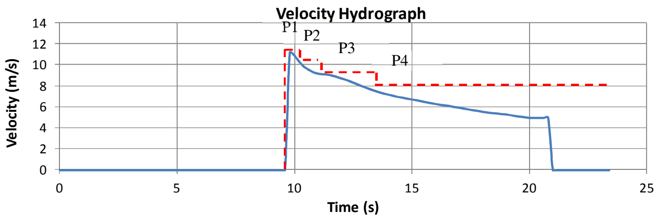
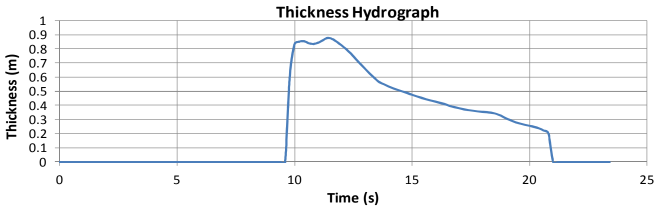
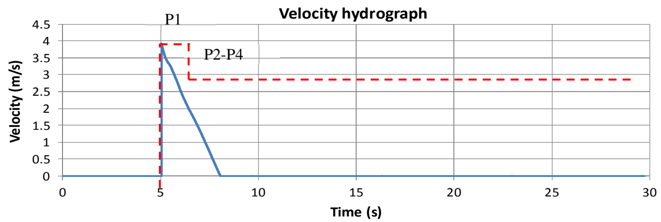
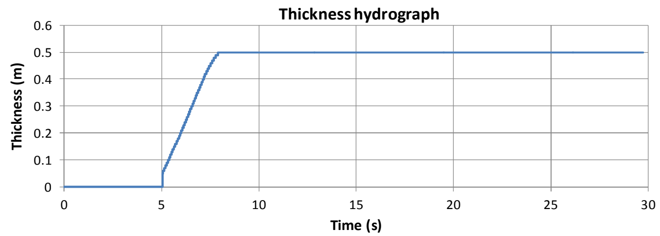
Case	Design volume (m^3)	Design no. of phases	Design thickness (m)	Debris velocity and thickness hydrographs	Maximum disturbing shear (kN/m) 		Maximum overturning moment (kNm/m) 	
					Current method	Suggested method (% diff.)	Current method	Suggested method (% diff.)
Example in GEO Report No. 270	630	3	2.0		610	524 (-14%)	1,629	1,092 (-28%)

Table A1 Design of Rigid Barriers - Comparisons between Current Method and the Suggested Method (Sheet 4 of 4)

Case	Design volume (m^3)	Design no. of phases	Design thickness (m)	Debris velocity and thickness hydrographs	Maximum disturbing shear (kN/m) 		Maximum overturning moment (kNm/m) 	
					Current method	Suggested method (% diff.)	Current method	Suggested method (% diff.)
Shek Pai Wan Road	300	8	0.7		684*	546* (-20%)	2,595*	1,883* (-27%)

Note: *Controlled by boulder impact load.

Table A2 Design of Flexible Barriers - Comparisons between Current Method and the Suggested Method

Case	Design volume (m^3)	Design no. of phases	Design thickness (m)	Debris velocity and thickness hydrographs	Calculated forces of key structural components: Current method	Calculated forces of key structural components: Suggested method (% diff.)
Ap Lei Chau Road	230	4	0.9	 	Maximum cable force 290 kN Maximum post compressive force 2,250 kN Maximum post shear force 500 kN	Maximum cable force 243 kN (-16%) Maximum post compressive force 1,720 kN (-24%) Maximum post shear force 400 kN (-20%)
Castle Peak Road	100	4	0.5	 	Maximum cable force 316 kN	Maximum cable force 311 kN (nil)

A.4 Recommendations

The suggested calculation method in Section A.2 are to be adopted in design of rigid debris-resisting barriers and design of flexible debris-resisting barriers using force approach.

Impact Loads due to debris flow (and isolated boulder(s) as appropriate, subject to the abundance of boulders) hitting the very top of barriers and the effects of debris flow overtopping of the barriers should be assessed as good practice. The design debris velocity of the phase hitting the crest portion of the barriers and the design debris thickness stated in Section A.2 are relevant for the assessments.

A.5 References

GEO (2014). *Guidelines on Enhanced Approach for Natural Terrain Hazard Studies.* GEO Technical Guidance Note No. 36 (TGN 36). Geotechnical Engineering Office, Hong Kong, 18 p.

Hungr, O. (2000). Analysis of debris flow surges using the theory of uniformly progressive flow. *Earth Surface Processes and Land-forms*, 25:1-3.

Kwan, J.S.H. (2012). *Supplementary Technical Guidance on Design of Rigid Debris-resisting Barriers (GEO Report No. 270).* Geotechnical Engineering Office, Hong Kong, 88 p.

Kwan, J.S.H. & Cheung, R.W.M. (2012). *Suggestions on Design Approaches for Flexible Debris-resisting Barriers (DN 1/2012).* Geotechnical Engineering Office, Hong Kong, 90 p.

Lam, C. (2013). *Mobility Modeling of Open Hillslope Failures in Hong Kong*. MSc Thesis, The University of British Columbia, Canada, 262 p.

Annex A-A

Landslide Debris Velocity Hydrographs

The characteristics of landslide debris velocity hydrographs of the following cases have been reviewed:

(a) 2008 Yu Tung Road Debris Flow, and

(b) Dry sand flume test by HKUST.

2008 Yu Tung Road Debris Flow

The maximum active debris volume of the debris flow is about 3,300 m^3. Based on the You Tube video record and field study results (http://youtu.be/R2uTKyK1c9k; AECOM, 2012), debris velocity hydrograph at about Ch 520 has been established. The maximum debris velocity, which occurred at the debris front, was 8.5 m/s at Ch 520. The debris velocity reduced to about 5 m/s after 15 seconds. The debris velocity hydrograph is presented in Figure A-A1.

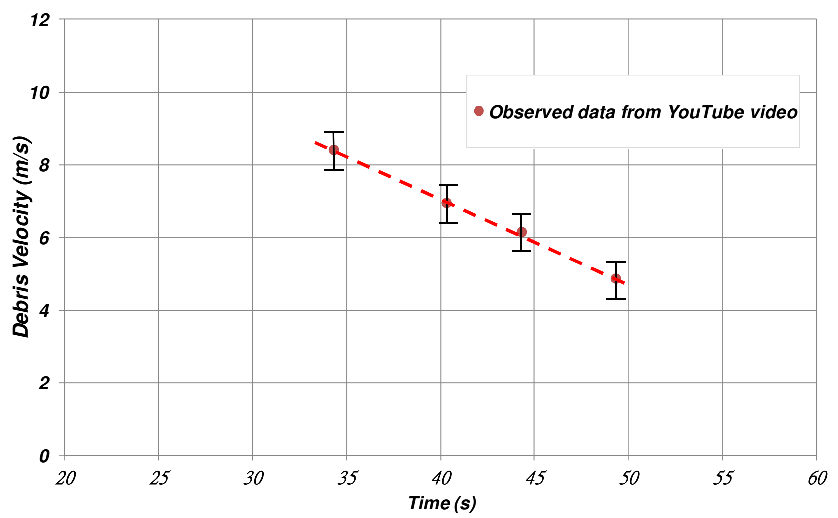


Figure A-A1 Velocity Hydrograph of 2008 Yu Tung Road Debris Flow at Ch 520 (Error Bars are Based on the Resolution of the Measurement from the Screen Captured from the Video)

Dry sand flume test by HKUST

Choi & Ng (2013) carried out a series of flume tests of dry sand flows. The flume used was 5.5 m long and 0.2 m wide. The angle of repose of the sand was 33^o and the friction angle between the sand and flume bed was 23^o. The initial bulk density of the sand mass was about

1,680 kg/m^3. At the top end of the flume was a sand storage tank, and the sand was released into the flume by opening a flip gate of the tank.

The test was recorded with the use of a high-speed camera which could capture 100 images per second. The velocity of the sand flow has been determined using the 'geoPIV' computer package developed by White et al (2003). Figure A-A2 presents the flow velocity hydrograph measured at a distance of 800 mm downstream of the sand storage tank. As part of the flume test, laser sensors were used to measure the flow depth, the flow depth hydrograph measured at the location is also shown in Figure A-A2 for reference.

The debris frontal velocity of about 2.5 m/s attenuated to about 1.0 m/s in 3.0 seconds.

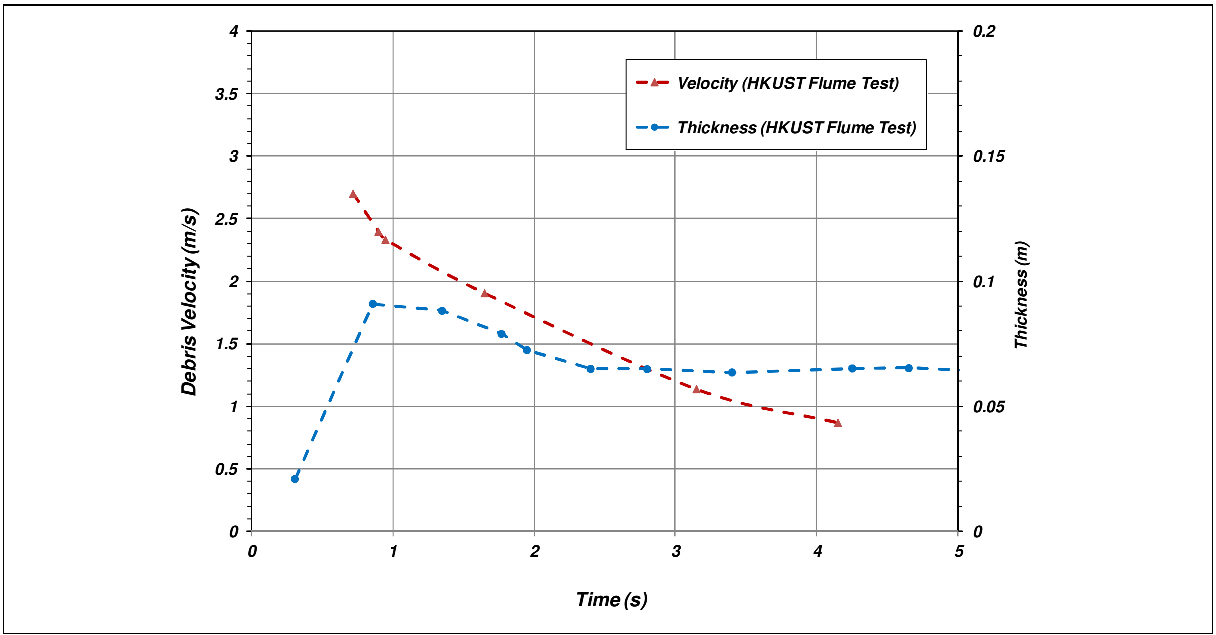


Figure A-A2 Flow Velocity Hydrograph Measured in Flume Test

References

AECOM (2012). *Detailed Study of the 7 June 2008 Landslides on the Hillside above Yu Tung Road, Tung Chung (GEO Report No. 271).* Geotechnical Engineering Office, Hong Kong, 124 p.

Choi, C.E. & Ng, C.W.W. (2013). *Flume Tests to Examine Dynamics of Debris Flows Obstructed by Baffles (Final Report).* Report prepared for Geotechnical Engineering Office, Hong Kong SAR Government. The Hong Kong University of Science and Technology, 110 p.

White, D.J., Take, W.A. & Bolton, M.D. (2003). Soil deformation measurement using particle image velocimetry (PIV) and photogrammetry. *Geotechnique*, 53, pp 619-631.

Appendix B

Design of Retention Volume of Debris-resisting Barriers

Contents

B.1 Background

Single debris-resisting barriers or terminal barriers are commonly used to mitigate natural terrain landslide hazards. The volume of landslide debris to be retained by the barriers is assessed as part of the barrier designs with an aim to avoiding debris spilling over the barriers.

There appears to be different views as how the debris retention volume should be determined. Some engineers consider that the debris retention volume should include the total of the design landslide source volume and the entrainment volume, whilst others consider that the retention volume should be based on the results of mobility analyses and the debris assessed to be outside the retention zone can be neglected.

This appendix discusses the key considerations to be made for assessing the design retention volume. The considerations presented in this appendix are generic in nature and should not be taken as exhaustive.

B.2 Design Good Practice

In the prevailing design practice, debris mobility analysis is carried out to determine the landslide debris dynamics for design of debris-resisting barriers. The analysis considers ground detachment from an assumed landslide source area. Results of the analysis include debris velocity and debris thickness, and from which designers can determine the cumulative debris volume passing through any locations along the runout trail.

The landslide source volume, location of potential source zone and amount of entrainment are assessed in accordance with GEO Report No. 138 and GEO TGN 36. The possibility of failures at different vulnerable landslide source locations, and the chance of concurrent (or multiple) failures within a rainstorm should be considered. For hillside catchments where several vulnerable landslide source locations exist, separate debris mobility analysis to account for the different vulnerable landslide source locations should be carried out to determine the design debris retention volume. In the event that concurrent occurrence of failures at different landslide source locations is considered credible (e.g. where there is evidence of such occurrence in the catchment under consideration in past rainstorm(s)), 3-dimensional debris mobility assessments should be carried out. The debris mobility analysis is carried out using models with algorithm agreed by GEO. The debris width is usually established based on the geometry of runout path or by means of three-dimensional debris mobility models. Rheological parameters to be used follow the recommendations of GEO TGN Nos. 29, 34 and 38.

The extent of debris retention zone can be defined based on the retaining height of barriers, ground profile behind barriers and angle of debris deposition. The range of debris deposition angles was calculated based on the observation of flume tests reported by Osti et al (2007) and assumptions of basal resistance of debris flows. The range can serve as a reference for estimation of the angle of debris deposition profile behind barriers. Angles of debris deposition profile recommended by other publications are also summarised in Kwan et al (2013) for reference.

B.3 Debris Mobility Analysis

Performance of the commonly used models of debris mobility analysis, including DMM and DAN/W, has been reviewed (see Annex B-A). Rheological parameters of four notable landslide case histories in Hong Kong with reliable landslide mapping records have been back-calculated based on the reported landslide runout distances. The debris deposition profiles generated by the debris mobility analysis were compared with the field mapping data.

For the landslide cases analysed, most of the landslide debris is assessed to accumulate close to or within a distance behind the distal end of the landslide trail. In contrast, deposition of certain amount of the landslide debris along the landslide trail was observed in the field mapping and deposition started at a considerable distance behind the distal end. This comparative exercise indicates that the cumulative debris volume hydrograph calculated by debris mobility analysis tends to be larger than field observations. If design rheological parameters are used for analyzing these cases, the calculated landslide runout distance will be larger than the observed runout distance and the computed cumulative debris volume will be larger than the field measurements.

B.4 Recommendations

The aggregate volume of landslide source volume and amount of entrainment gives an upper bound estimate of the design debris retention volume. The use of this upper bound value may result in over-sizing the debris retention zone. Designers should make reference to the calculated cumulative debris volume entering the debris retention zone with consideration of an appropriate debris bulking factor to assess the design retention volume.

Debris mobility analysis using suitable computer programmes such as DMM or DAN/W is a useful tool for estimating the amount of debris that could enter the retention zone (i.e. debris retention volume). However, care should be taken when undertaking the analysis; and the following factors/conditions should be considered:

(a) Realistic topographical profiles, inter alia, cross-sectional geometry of the runout path, should be adopted in the debris mobility analysis.

(b) Attention should be made to the need of considering different landslide sources in debris runout assessment. For hillside catchments where several vulnerable landslide source locations exist, separate debris mobility analysis to account for the different vulnerable landslide source locations should be carried out to determine the design debris retention volume. In the event that concurrent occurrence of failures at different landslide source locations is considered credible (e.g. where there is evidence of such occurrence in the catchment under consideration in past rainstorm(s)), 3-dimensional debris mobility assessments (e.g. 3d-DMM) to consider the appropriate combination of different landslide sources should be carried out.

(c) If the results of mobility analysis indicate that some debris would deposit at the upstream of the barrier's retention zone, some allowance should be made to accommodate possible additional volume of the debris that could be washed down to the retention zone, taking into account site-specific factors such as gradient of the runout path, catchment area, etc.

(d) Should the barriers be designed to retain debris flow and additional rock/boulder fall that would occur at the same time, the volume of the additional rock/boulder fall should be allowed for in the design.

B.5 References

Kwan, J.S.H., Koo, R.C.H. & Ko, F.W.Y. (2013). *A Pilot Study on the Design of Multiple Debris-resisting Barriers (TN 3/2013).* Geotechnical Engineering Office, Hong Kong, 70 p.

Osti, R., Itoh, T. & Egashira, S. (2007). Control of sediment run-off volume through close type check dams. *Proceedings of the Fourth International Conference on Debris-flow Hazards Mitigation Mechanics, Prediction, and Assessment*, Chengdu, China, pp 659-667.

Annex B-A

Debris Mobility Analysis

Debris mobility analyses of the following four landslide case histories have been carried out (see Table B-A1). The landslides were field-mapped by Landslip Investigation Consultants (LIC) in detail. The active landslide volume and deposition profile along landslide trail of each case were recorded. Total volume listed in Table B-A1 pertains to the sum of the landslide source volume and the entrainment volume of the landslides.

Table B-A1 Landslide Cases Studied

Landslide	Type	Total Volume	Runout Distance	Reference
Ewan Court Landslide	OHF	180 m^3	80 m	SFWJV (2013)
Landslide LS08-0498 at Nam Chung	TDF	290 m^3	220 m	Clahal et al (2009)
Landslide LS08-0401 close to Po Lin Monastery	CDF	740 m^3	410 m	Hart (2008)
Kwun Yam Shan Debris Flow	CDF	2,350 m^3	335 m	MGS (2008)

Rheological parameters have been back calculated by the debris mobility analyses against the reported landslide runout distance (see Table B-A2). The analysis of Ewan Court Landslide and Landslide LS08-0498 at Nam Chung were carried out using DAN/W. The DAN/W files originally developed by Lam (2013) have been used for the back calculation. For the purpose of this study, the rheological parameters for the landslide at Nam Chung have been refined to take into account of the current guidelines for topographic depression catchment (GEO, 2013). The Landslide LS08-0401 close to Po Lin Monastery and Kwun Yam Shan Debris Flow were analysed using 2dDMM. In these analyses, the maximum active debris volume is assumed at the landslide source location.

Table B-A2 Back Calculated Rheological Parameters

Landslide	Rheological Model	Apparent Friction Angle	Turbulent Coefficient
Ewan Court Landslide	Friction	33^o	---
Landslide LS08-0498 at Nam Chung	Voellmy	31^o	1,000 m/s^2
Landslide LS08-0401 close to Po Lin Monastery	Voellmy	12^o	500 m/s^2
Kwun Yam Shan Debris Flow	Voellmy	15^o	500 m/s^2

Figures B-A1 to B-A4 show the comparisons between the debris deposition profiles observed on site and the results of the debris mobility analysis. In all the four cases, the landslide debris deposition profiles produced by the debris mobility analysis are located at the distal end. However, results of the field mapping indicated that the landslide debris was deposited at different locations along the landslide trails. In two of the cases, debris deposition started at a considerable distance behind the distal end.

For the landslide case histories reviewed, the cumulative debris volume hydrographs calculated by debris mobility analysis tends to be larger than those of the field observations. This may probably be the result of using a single set of rheological parameters along the entire runout path and the assumption of total debris volume assigned at the landslide source.

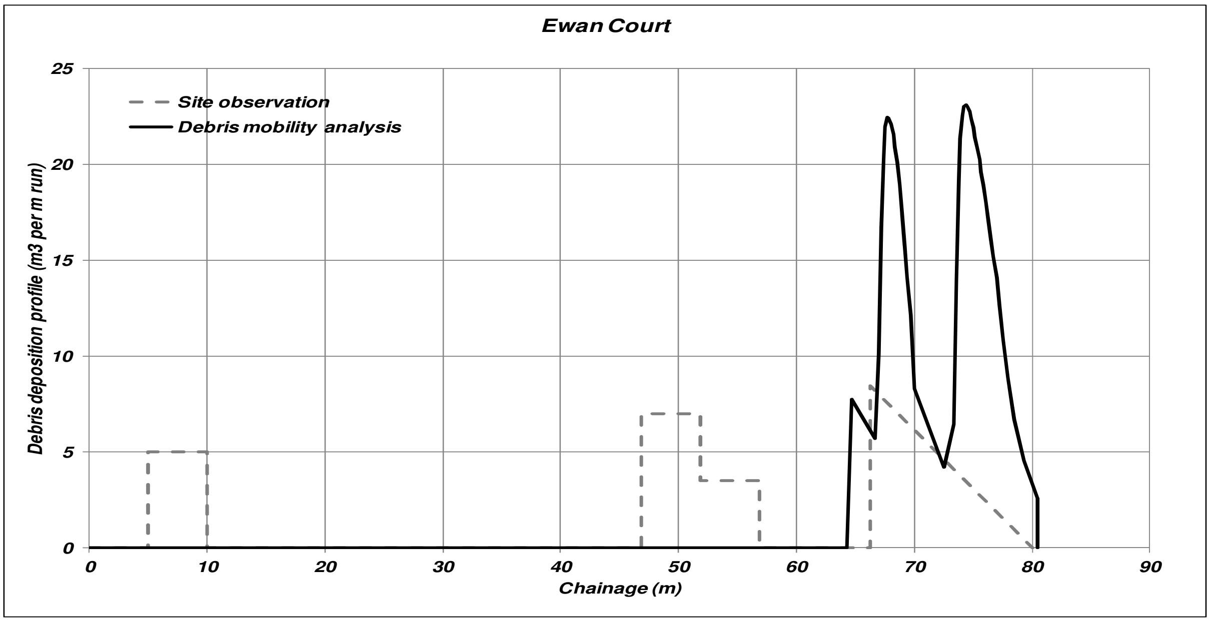


Figure B-A1 Debris Deposition Profile of Ewan Court Landslide

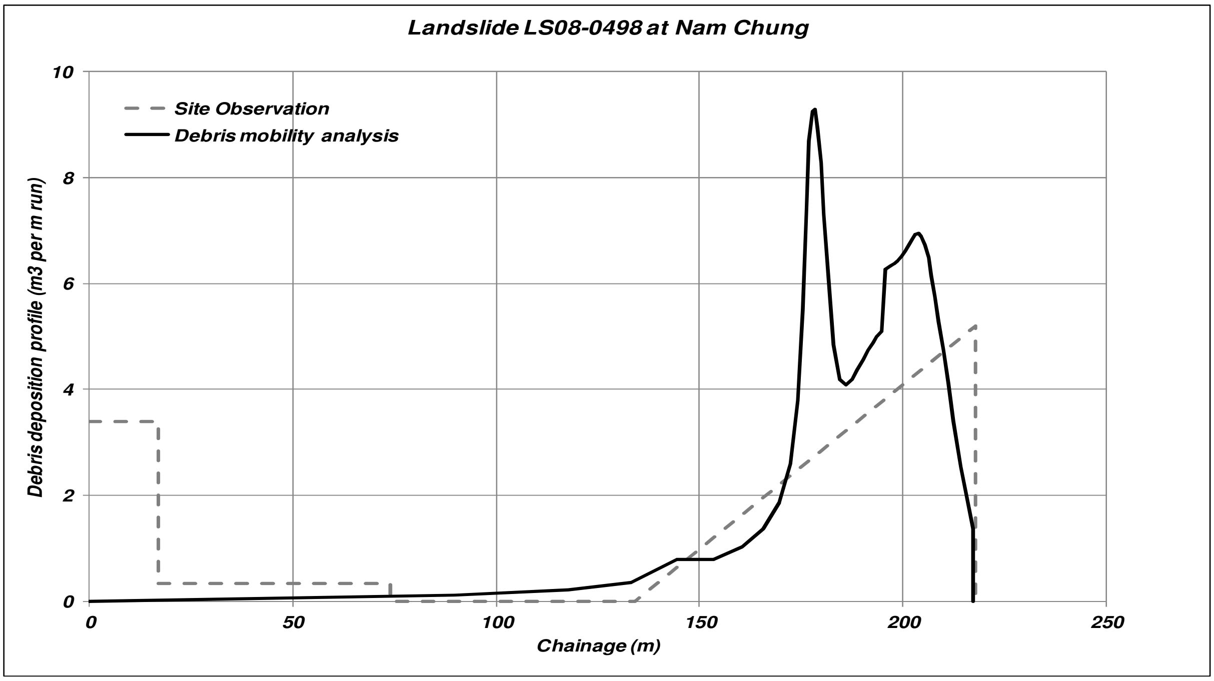


Figure B-A2 Debris Deposition Profile of Landslide LS08-0498 at Nam Chung

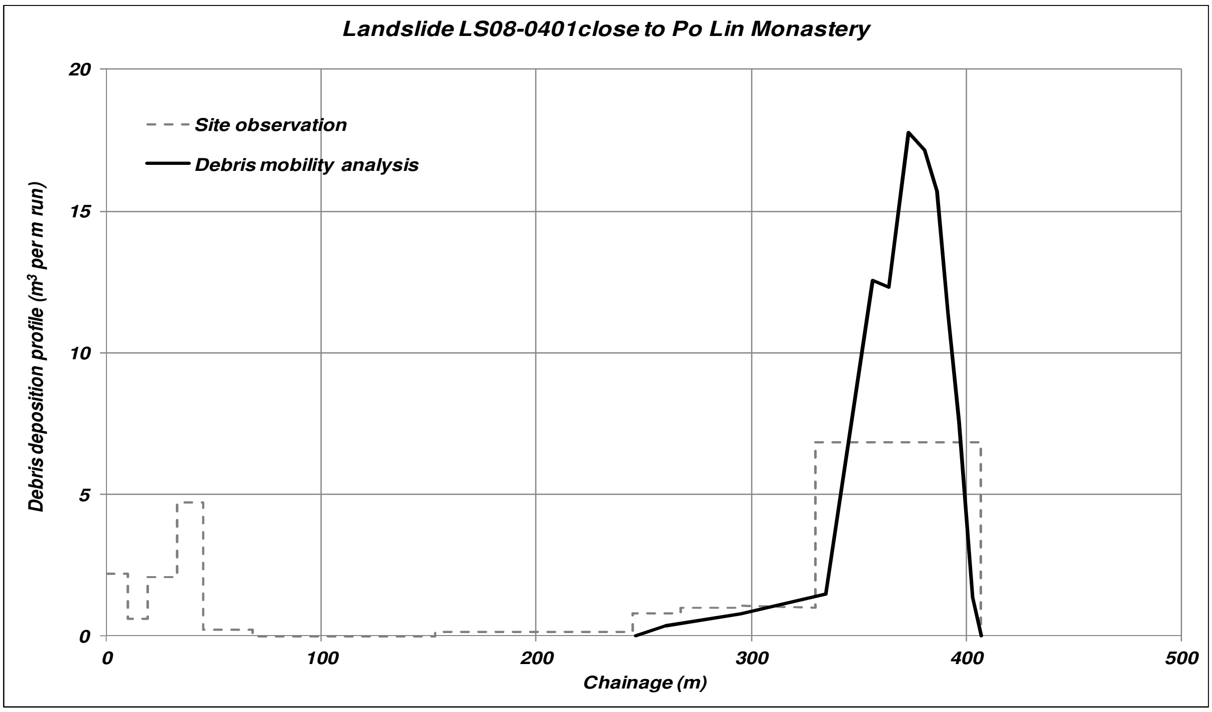


Figure B-A3 Debris Deposition Profile of Landslide LS08-0401 close to Po Lin Monastery

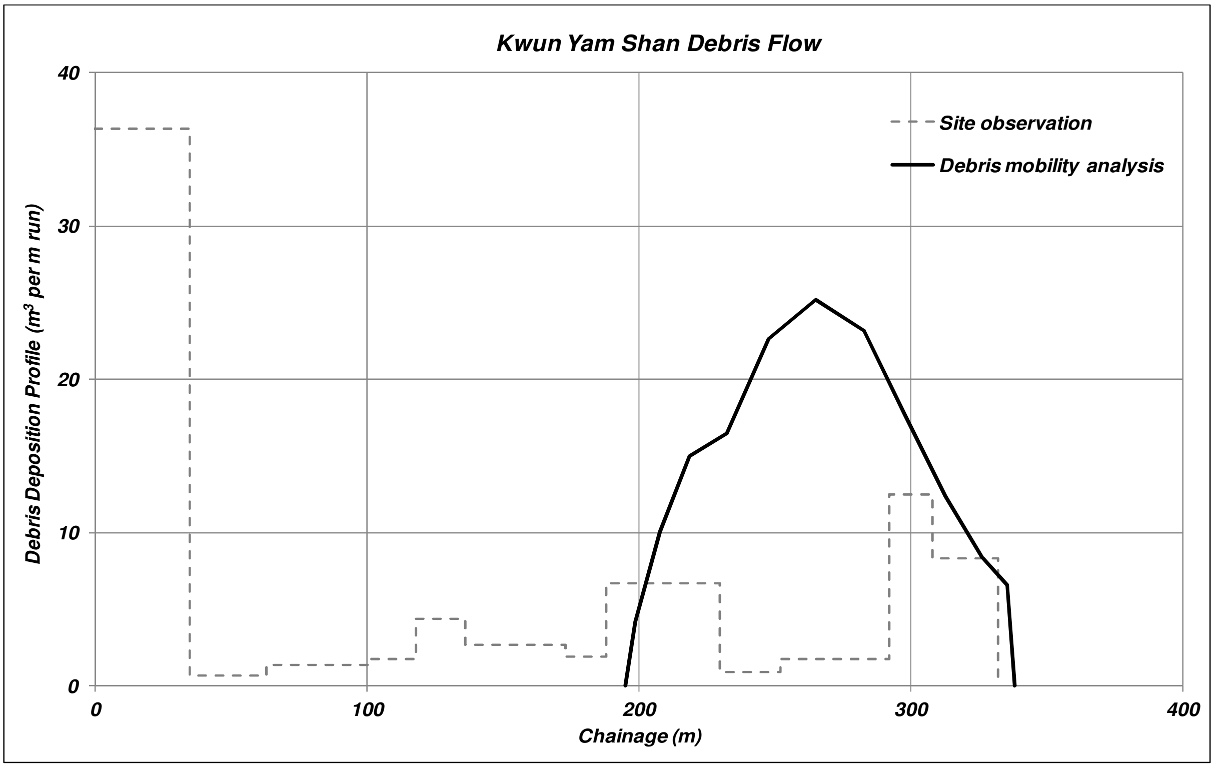


Figure B-A4 Debris Deposition Profile of Kwun Yam Shan Debris Flow

References

Clahal, K., McMackin, M. & Dee, S. (2009). *Landslide Mapping Report of Landslide No. LS08-0498*. Landslide mapping report prepared for Geotechnical Engineering Office, Hong Kong, 19 p.

GEO (2013). *Guidelines on the Assessment of Debris Mobility for Failures within Topographic Depression Catchments.* GEO Technical Guidance Note No. 38. Geotechnical Engineering Office, Hong Kong, 5 p.

Hart, J. (2008). *Landslide Mapping Report of Landslide No. LS08-0401.* Landslide mapping report prepared for Geotechnical Engineering Office, Hong Kong, 18 p.

Lam, C. (2013). *Mobility Modeling of Open Hillslope Failures in Hong Kong*. MSc Thesis, The University of British Columbia, Canada, 262 p.

MGS (2008). *Detailed Study of the 22 August 2005 Landslide and Distress on the Natural Hillside at Kwun Yam Shan, below Tate's Ridge*. GEO Report No. 239. Geotechnical Engineering Office, Hong Kong, 49 p.

SFWJV (2013). *Detailed Study of the 7 June 2008 Landslide behind Ewan Court, Kennedy Road, Wan Chai*. GEO Report No. 278. Geotechnical Engineering Office, Hong Kong, 56 p.

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