Geotechnical Engineering Office, Civil Engineering and Development Department
The Government of the Hong Kong Special Administrative Region

GEO Technical Guidance Note No. 38 (TGN 38)
Guidelines on the Assessment of Debris Mobility for Failures within Topographic Depression Catchments

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1. SCOPE

1.1 This Technical Guidance Note (TGN) provides guidance on the assessment of debris mobility for failures within topographic depression (TD) catchments (TDF) as defined in TGN 36 (GEO, 2013).

1.2 Any feedback on this TGN should be directed to Chief Geotechnical Engineer/Standards & Testing of the GEO.

2. TECHNICAL POLICY

2.1 The technical recommendations promulgated in this TGN were agreed by GEO Geotechnical Control Conference (GCC) on 3 July 2013.

3. RELATED DOCUMENTS

3.1 GEO (2006). *The 5 May 2003 Debris Flow at Kau Lung Hang Shan, Tai Po (GEO Report No. 196)*. Geotechnical Engineering Office, Hong Kong, 84 p.

3.2 GEO (2011). *Guidelines on the Assessment of Debris Mobility for Channelized Debris Flows (TGN No. 29)*. Geotechnical Engineering Office, Hong Kong, 6 p.

3.3 GEO (2012). *Guidelines on the Assessment of Debris Mobility for Open Hillslope Failures (TGN No. 34)*. Geotechnical Engineering Office, Hong Kong, 16 p.

3.4 GEO (2013) *Guidelines on Enhanced Approach for Natural Terrain Hazard Studies under LPMitP (TGN No. 36)*. Geotechnical Engineering Office, Hong Kong, 18 p.

3.5 Hungr, O. (1995). A model for the runout analysis of rapid flow slides, debris flows and avalanches. *Canadian Geotechnical Journal*, vol. 32, pp 610-623.

3.6 Kwan, J.S.H. & Sun, H.W. (2006). An improved landslide mobility model. *Canadian Geotechnical Journal*, vol. 43, pp 531-539.

3.7 Lo, D.O.K. (2000). *Review of Natural Terrain Landslide Debris-resisting Barrier Design (GEO Report No. 104)*. Geotechnical Engineering Office, Hong Kong, 91 p.

3.8 Ng, K.C., Parry, S., King, J.P., Franks, C.A.M. & Shaw, R. (2003). *Guidelines on Natural Terrain Hazard Studies (GEO Report No. 138)*. Geotechnical Engineering Office, Hong Kong, 138 p.

3.9 GEO (2012). *User Manual for Computer Program "2d-DMM" - Two-dimensional Debris Mobility Model (spreadsheet version 1.2)*. Geotechnical Engineering Office, Hong Kong, 58 p.

3.10 Tattersall, J.W., Devonald, D.M., Hung, R.K.C & Kwong, R.T.S. (2009). Estimation of 'design event' landslide sources for the North Lantau Expressway and Yu Tung Road Natural Terrain Hazard Mitigation Works Study. *Proceedings of the 2009 Hong Kong Institution of Engineers Geotechnical Division Annual Seminar*, pp 141-147.

3.11 Wong, H.N., Ko, F.W.Y. & Hui, T.H.H. (2006). *Assessment of Landslide Risk of Natural Hillsides in Hong Kong (GEO Report No. 191).* Geotechnical Engineering Office, Hong Kong, 117 p.

4. BACKGROUND

4.1 Ng et al (2003) described two main types of natural terrain landslide hazards in Hong Kong, viz. channelized debris flow (CDF) and open hillslope landslide (OHL).

4.2 Wong et at (2006) introduced an additional hazard type, viz. TDF, to deal with the intermediate situation between CDF and OHL. Back analyses have been carried out to study the runout characteristics of TDF. This TGN promulgates the findings of the back analyses.

5. DEBRIS MOBILITY ANALYSES

Selection of TDF for Back Analyses

5.1 TDF for the back analyses were selected from the historical landslides contained in the Enhanced Natural Terrain Landslide Inventory (ENTLI), including the natural terrain landslides that occurred in June 2008 on Lantau. The more mobile landslides, including about 120 out of 12,500 recent OHL with runout distance exceeding 100 m and about 500 out of 6,700 recent CDF with runout distance exceeding 175 m, were identified initially. The site settings of these cases were reviewed using the LIC 1:1000-scale topographic maps and aerial photographs to ensure that they are genuine TDF. Where necessary, the debris runout distances were also updated based on aerial photograph interpretation (API) for the purposes of the back analyses.

5.2 From the above review, 46 TDF were identified for back analyses.

Rheological Model

5.3 The turbulent action involved in the debris motion of TDF is expected to be somewhere between that of OHL and CDF. Lo (2000), supplemented by the technical recommendations in TGN No. 29 (GEO, 2011) and TGN No. 34 (GEO, 2012), recommended the use of friction model and Voellmy model for mobility analyses of OHL and CDF respectively. When using the Voellmy model to assess debris mobility of CDF, a turbulence coefficient, $\xi = 500 \text{ m/s}^2$, is considered appropriate. Based on the numerical formulation of the Voellmy model (Hungr, 1995), mobility analyses using a high turbulence coefficient, e.g. $\xi = 5000$ m/s^2 or more, would produce results comparable to those derived from the friction model with the same apparent friction angle (ϕ_a). It is therefore considered appropriate to use the Voellmy model with a ξ value within the range of 500 m/s^2 to 5000 m/s^2 for assessing the debris mobility of TDF.

5.4 A range of probable Voellmy runout parameters was considered in order to identify the most appropriate set of rheological parameters for assessing the debris mobility of TDF. Details of the numerical modelling and rheological parameters considered, together with the results of the back analyses, are presented in Annex TGN 38 A1.

6. TECHNICAL RECOMMENDATIONS

6.1 It is recommended that the Voellmy model should be used for the assessment of debris mobility of TDF. Except for situations referred to in paragraph 6.2 below, the following generic rheological parameters should be used:

$$\phi_a = 18° \text{ and } \xi = 1000 \text{ m/s}^2$$

6.2 Where historical landslides in the TD catchments have resulted in more mobile debris runout than that assessed by the recommended rheological parameters, the appropriate rheological parameters to be adopted in analytical design of TDF mitigation measures should be assessed on a case-by-case basis, with account taken of the back-analyzed rheological parameters of the historical TDF within the TD catchments and any other relevant factors that may affect debris mobility.

6.3 The above recommendations are applicable to the study and mitigation of natural terrain hazards for existing and new developments/redevelopments in Hong Kong.

7. ANNEXES

7.1 TGN 38 A1 - Back Analyses of TDF

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Annex TGN 38 A1 - Back Analyses of TDF

1. Numerical Modelling

1.1 The back analyses were carried out using the computer program 2d-DMM (Kwan & Sun, 2006; GEO, 2012). The source volumes of the 46 TDF were estimated based on API with reference to the correlations suggested by Tattersall et al (2009). No entrainment along the runout paths was considered. The actual runout distances of the 46 TDF were reviewed using the site-specific aerial photographs and where necessary, updated for the purposes of the back analyses (e.g. debris runout due to secondary washout was not considered).

2. Rheological Model

2.1 Back analyses of the 46 TDF were carried out using the Voellmy model. Ten sets of rheological parameters (ϕ_a and ξ) were considered (Figure 1). The calculated debris runout distances were compared with the actual debris runout distances.

3. Rheological Parameters for Estimating Runout Distance of TDF

3.1 The calculated debris runout distances of the 46 TDF, as compared with the actual debris runout distances, are given in Figure 2.

3.2 It is noted that the predicted debris runout distances of TDF are very sensitive to the value of ϕ_a used. Among the ten sets of rheological parameters considered, the one with $\phi_a = 25°$, $\xi = 500\ m/s^2$ represents the least mobile while the one with $\phi_a = 15°$, $\xi = 5000\ m/s^2$ is the most mobile. The rheological parameters, $\phi_a = 18°$, $\xi = 1000\ m/s^2$, give runout distances larger than the actual distances for about 80% of the cases (37 cases) analysed (i.e. under-prediction for about 20% of the cases (9 cases)) (Figure 3). Most of the under-predicted cases have their predicted runout distances within 10% of the actual runout distances (Figure 4). It should be noted that the back analyses only covered a biased dataset of the more mobile historical TDF. If less mobile cases are also considered, the percentage of cases with under-prediction of the runout distance would be much lower.

3.3 Having regard to the nature of the dataset, results of the above sensitivity analyses, uncertainties involved and dependence of runout distance on the severity of rainfall, the rheological parameters, $\phi_a = 18°$, $\xi = 1000\ m/s^2$, are considered appropriate for the present purposes.

3.4 Figure 5 shows the prediction of runout distances using the rheological parameters, $\phi_a = 18°$, $\xi = 1000\ m/s^2$, according to landslide volumes. It is noted that there is no strong evidence to support the use of different sets of rheological parameters for different landslide volumes.

3.5 In the study of the TDF in Kau Lung Hang Shan, Tai Po, under the systematic landslide investigation programme, the landslide was mapped in detail and super-elevation data were available. Debris velocity at different points along the runout path could be deduced from the super-elevation data. These are compared with the predicted debris velocity profile using a Voellmy model with $\phi_a = 18°$, $\xi = 1000$ m/s^2 (Figure 6). It can be seen from the figure that the suggested rheological parameters provide a reasonably good fit to both the velocity data and runout distance (within about 10%).

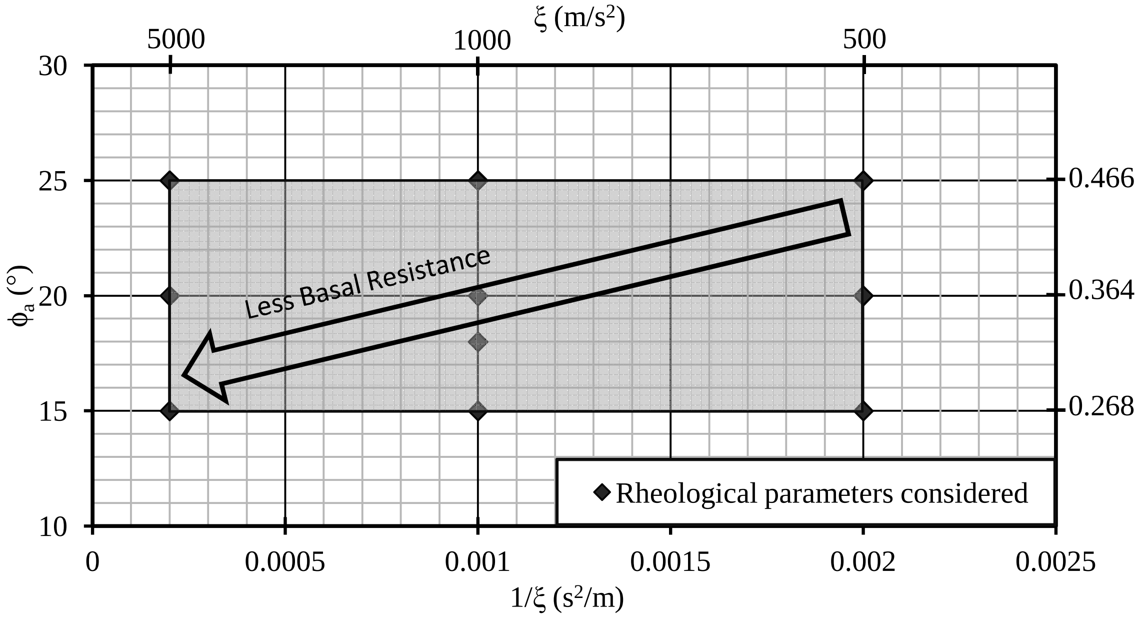

Figure 1 - Range of rheological parameters considered

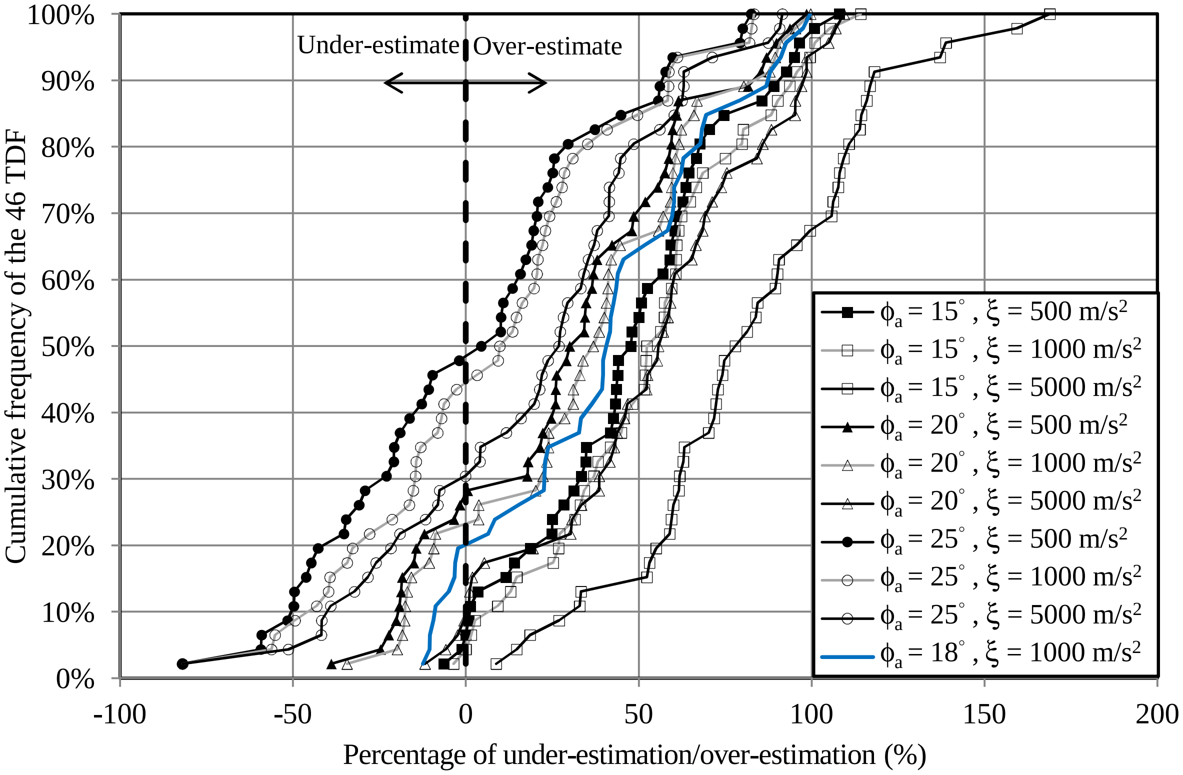

Figure 2 - Comparison of calculated and actual debris runout distances

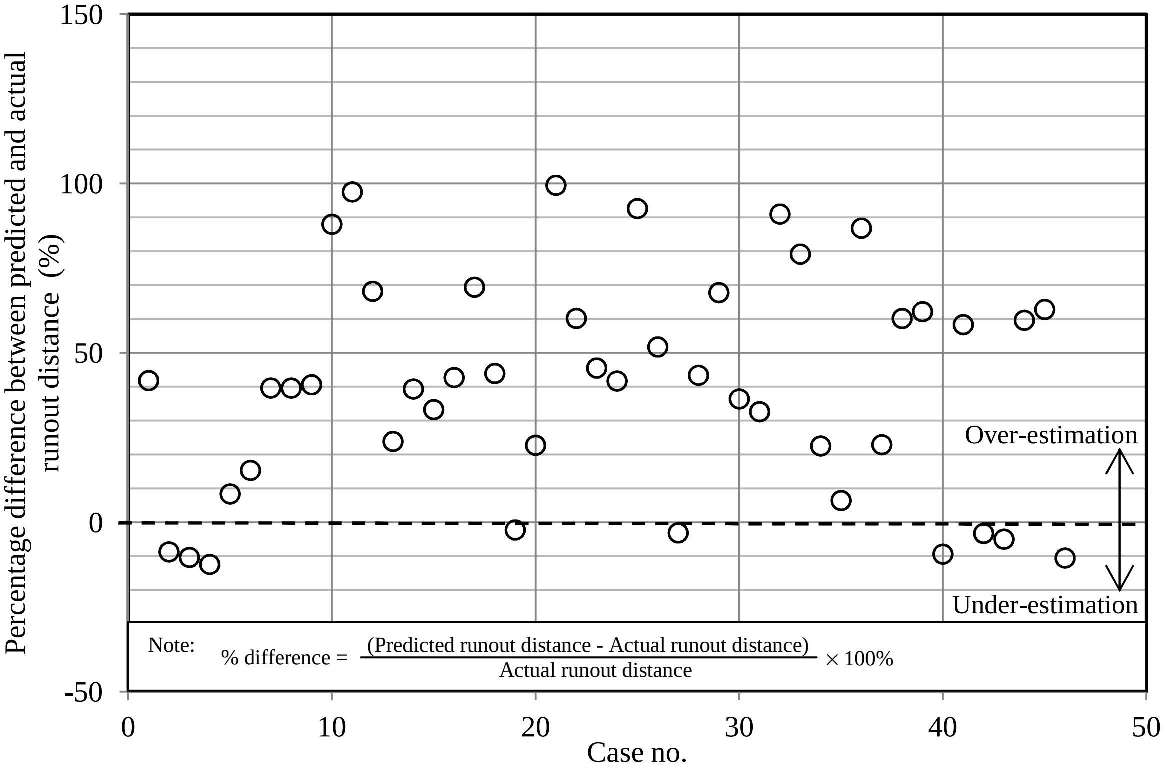

Figure 3 - Prediction of runout distances using $\phi_a = 18°$, $\xi = 1000$ m/s^2

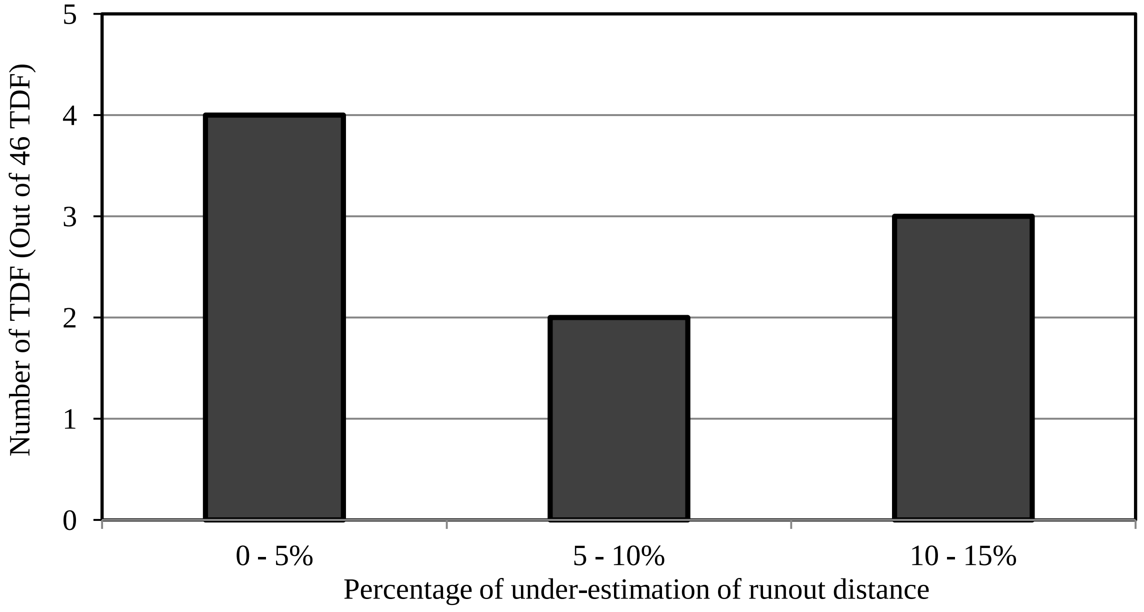

Figure 4 - Under-estimation of runout distances using $\phi_a = 18°$, $\xi = 1000$ m/s^2

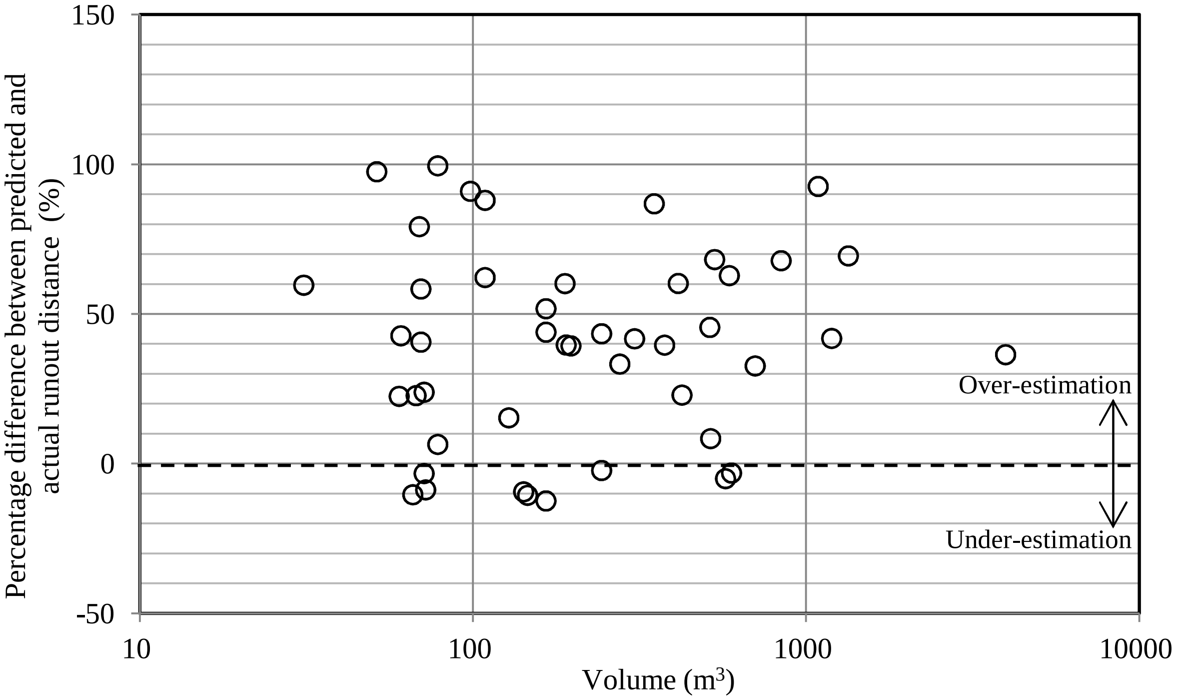

Figure 5 - Prediction of runout distances using $\phi_a = 18°$, $\xi = 1000\ m/s^2$ according to landslide volumes

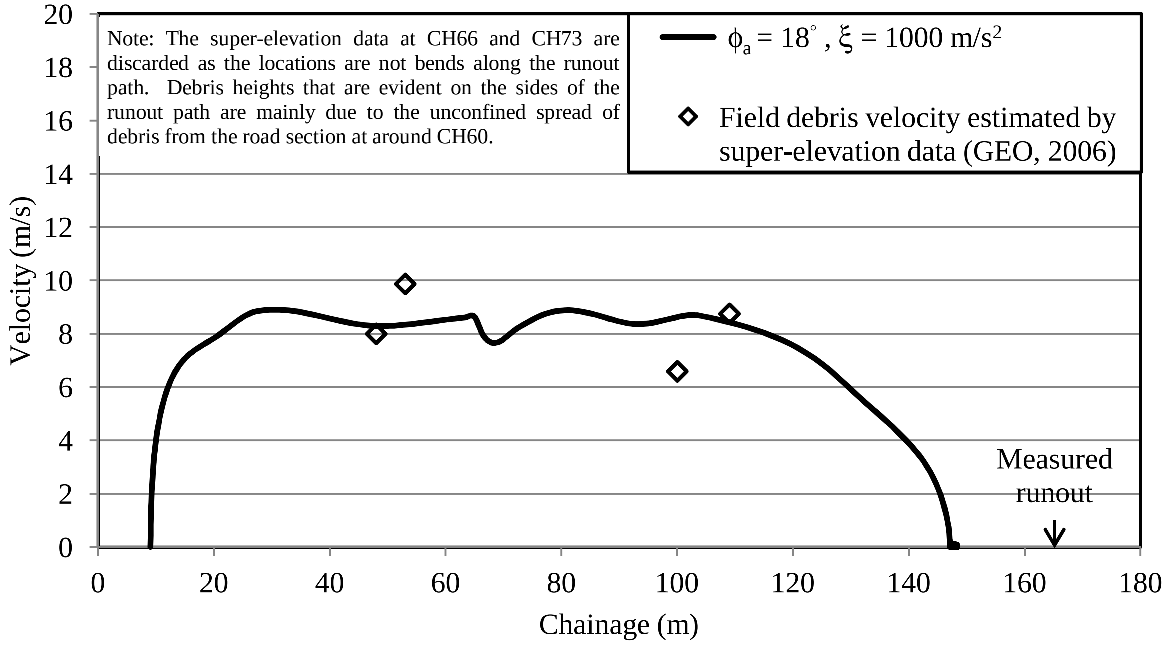
Note: The super-elevation data at CH66 and CH73 are discarded as the locations are not bends along the runout path. Debris heights that are evident on the sides of the runout path are mainly due to the unconfined spread of debris from the road section at around CH60.

Figure 6 - Comparison of predicted debris velocity profile using $\phi_a = 18°$, $\xi = 1000\ m/s^2$ and field debris velocity