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

GEO Technical Guidance Note No. 29 (TGN 29)
Guidelines on the Assessment of Debris Mobility for Channelised Debris Flows

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1. SCOPE

1.1 This Technical Guidance Note (TGN) supplements the guidance on the assessment of debris runout for channelised debris flows as given in Section 5.1 of GEO Report No. 104 "Review of Natural Terrain Landslide Debris-resisting Barrier Design".

1.2 Any feedback on this TGN should be directed to Chief Geotechnical Engineer/Planning and Development of the Geotechnical Engineering Office (GEO).

2. TECHNICAL POLICY

2.1 The technical recommendations promulgated in this TGN were agreed by GEO Geotechnical Control Conference on 29 December 2010.

3. RELATED DOCUMENTS

3.1 Ayotte, D. & Hungr, O. (1998). *Runout Analysis of Debris Flows and Debris Avalanches in Hong Kong*. A Report for the Geotechnical Engineering Office, Hong Kong. University of British Columbia, Canada, 90 p.

3.2 Ho, H. Y. & Roberts, K. J. (2016). *Guidelines for Natural Terrain Hazard Studies (GEO Report No. 138, Second Edition)*. Geotechnical Engineering Office, Hong Kong, 173 p.

3.3 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.

3.4 Hungr, O. (1998). *Mobility of Landslides in Hong Kong: Pilot Analysis Using a Numerical Model*. A Report for the Geotechnical Engineering Office, Hong Kong. O. Hungr Geotechnical Research Inc., Canada, 52 p.

3.5 Hungr, O. (2003). *User's Manual of DAN-W*. O. Hungr Geotechnical Research Inc., Canada, 49 p.

3.6 Hungr, O., Morgenstern, N.R. & Wong, H.N. (2007). Review of benchmarking exercise on landslide debris runout and mobility modelling. *Proceedings of the International Forum on Landslide Disaster Management, Hong Kong*, vol. II, pp 755-812.

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

3.8 Kwan, J.S.H. & Sun, H.W. (2007). Benchmarking exercise on landslide mobility modelling – runout analyses using 3dDMM. *Proceedings of the International Forum on Landslide Disaster Management, Hong Kong*, vol. II, pp 945-966.

3.9 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.

3.10 Sun, H.W. (2010). *User Manual for Computer Program "2d-DMM" – Two-dimensional Debris Mobility Model (spreadsheet version 1.1)*. Geotechnical Engineering Office, Hong Kong, 58 p.

3.11 Wong, H.N. (2009). Rising to the Challenges of Natural Terrain Landslides. *Proceedings of the HKIE Geotechnical Division Annual Seminar on Natural Hillsides: Study and Risk Management Measures, Hong Kong Institution of Engineers*, pp 15-53.

4. BACKGROUND

4.1 It is stipulated in GEO Report No. 138 (Ho & Roberts, 2016) that the Design Event Approach may be used, either individually or in combination with other approaches, to evaluate natural terrain hazards and the required mitigation measures. The framework of the Design Event Approach and guidance on the determination of the Design Event in a Natural Terrain Hazard Study are given in GEO Report No. 138 (Ho & Roberts, 2016).

4.2 Section 5.1 of GEO Report No. 104 states that with the friction model, "the apparent angle of friction could conservatively be taken as 20° for channelised debris flows". It further states that "the Voellmy model, together with an apparent friction angle, $\phi_a = 11°$ and a turbulence coefficient, $\xi = 500 m/s^2$ (which have been found to be appropriate by Hungr (1998) and Ayotte & Hungr (1998)), is suggested to be used to assess the mobility of debris flows."

4.3 Since the publication of GEO Report No. 104, additional data on channelised debris flows in Hong Kong have become available and more cases have been back analysed by the GEO. Advances have also been made in debris mobility modelling.

4.4 The June 2008 rainstorm, being one of the most intense rainstorms since the setting up of the GEO, resulted in about 2,400 natural terrain landslides, some 900 of which were channelised debris flows. As noted by Wong (2009), some of the channelised debris flows were of a sizeable volume (active debris volume in excess of 10,000 m^3), with long runout distances (> 1,700 m).

4.5 Systematic back analyses have been carried out on some selected long runout channelised debris flows that occurred in June 2008, based on detailed field mapping and other supplementary information such as video records where available. This TGN promulgates the findings of the back analyses.

5. DEFINITIONS

5.1 Landslide Hazard refers to the threat posed by a landslide to a given facility. The assessment of landslide hazard typically involves the consideration of the frequency of landslide occurrence, the landslide debris volume and the debris runout characteristics, and aims to obtain an estimated frequency of a given volume of landslide debris reaching the facility causing a certain magnitude of impact.

5.2 Design Event refers to the magnitude of the Landslide Hazard that is required to be mitigated against, based on the use of the Design Event Approach as described in GEO Report No. 138. ‘Magnitude’ is a generic, all encompassing term covering the relevant attributes that characterize the severity of the impact of the Landslide Hazard, including the source volume, and debris volume, height and velocity at the location where the mitigation measures are to be provided.

6. TECHNICAL RECOMMENDATIONS

Computer Program for Debris Mobility Assessment

6.1 The computer programs 2d-DMM (Kwan & Sun, 2006; Sun, 2010), DAN (Hungr, 1995 & 2003) and 3d-DMM (Kwan & Sun, 2007) adopt a similar analytical approach (i.e. continuum model using integrated approach with a depth-averaged shallow-flow solution) and have been found to produce generally similar results in terms of runout distance, velocity and thickness profiles of debris in the back analyses of some notable landslides in Hong Kong. These programs may be used for back analysis as well as forward prediction of debris mobility. Other computer programs for debris mobility modelling may be considered if they have been approved by the GEO.

Debris Mobility Modelling

6.2 Based on the results of the systematic back analyses of the known long-runout (i.e. >200 m) historical channelised debris flows in Hong Kong using the 2d-DMM program, the Voellmy model would provide a better prediction of the spatial distribution of debris deposition along the runout path, as well as velocity profile where the velocity could be cross checked against that deduced from the available information, as compared with the friction model. Also, the friction model tends to give a higher predicted velocity profile along the runout path of a channelised debris flow. Similar observations were made by Ayotte & Hungr (1998). As such, the Voellmy model should be used for channelised debris flows and that the recommendations given in Figure 21 of the GEO Report No. 104 on the use of friction model for channelised debris flows (see paragraph 4.2 above), for both the analytical approach and empirical approach, are no longer applicable.

6.3 Back analyses of selected June 2008 channelised debris flows of high mobility were carried out using the 2d-DMM program, as well as 3d-DMM program in some cases. The Voellmy parameters back calculated by both programs were found to be similar for the cases analysed. Based on the results of back analyses, it is projected that approximately 1% of the June 2008 channelised debris flows were more mobile than that predicted using the recommended Voellmy parameters given in GEO Report No. 104. Most of these landslides involved adverse site settings and watery debris (i.e. debris mass with a very high water content) of high mobility. The characteristics of these selected mobile landslides in June 2008 are given in Table 1 below.

Landslide case	Catchment size	Source volume	Total maximum active volume	Runout distance	Travel angle	Back analysed Voellmy parameters (based on 2d-DMM)	
						ϕ_a	ξ
Yu Tung C30	102,000 m^2	~2,350 m^3	~3,300 m^3	> 590 m	16.6 ^{o}	7.7^o	500 m/s^2
Shek Pik 2	165,000 m^2	~ 1,000 m^3	> 8,500 m^3	> 910 m	17.7 ^{o}	7.6^o	500 m/s^2
Shek Pik 4	672,000 m^2	~ 150 m^3	> 5,000 m^3	> 1,700 m	15.8 ^{o}	7.3^o	500 m/s^2
Shek Mun Kap	121,000 m^2	~ 220 m^3	> 1,700 m^3	> 980 m	23.6 ^{o}	8.7^o	500 m/s^2

Table 1 – Characteristics of selected mobile landslides with watery debris in June 2008

6.4 Adverse site settings that are prone to the development of sizeable channelised debris flows with watery debris of high mobility have been diagnosed by Wong (2009). These include the following:

- Sizeable debris flow at a major drainage line (e.g. site with a large catchment and a long flow path where a large amount of storm water and entrainable materials may be available for mixing with the landslide debris).
- Sizeable debris flow along a major drainage line into which many tributaries are feeding (i.e. possible sudden increase in the water content of the moving debris whenever the debris passes through a confluence point).
- Discharge of debris onto a pool of water on the drainage line or debris from a small drainage line onto a major drainage line, where there is a potential for a large amount of running storm water.

For channelised debris flow catchments that are deemed to be prone to watery debris (e.g. with any of the above adverse site settings), the following Voellmy parameters are recommended: $\phi_a = 8^o$ and $\xi = 500\ m/s^2$. Judicious judgement should be exercised in assessing the site setting and selecting of appropriate input parameters for forward predictions.

6.5 Where a channelised debris flow catchment is not associated with the above adverse site settings, the recommendations on debris mobility modelling using the Voellmy model as given in Section 5.1 of GEO Report No. 104 (i.e. Voellmy parameters of $\phi_a = 11^o$ and $\xi = 500$ m/s^2) are suitably conservative and still applicable.

Assessment of Possible Entrainment and Dam Break

6.6 Entrainment could be a major component of the total active volume in channelised debris flows, particularly for drainage lines with a large amount of entrainable materials (e.g. perched materials on stream bed). Detailed field mapping should be carried out to allow an assessment of the potential for entrainment and the likely entrainment rates.

6.7 Given the uncertainties involved, a pragmatic approach for forward predictions of debris mobility would be to model the potential entrainment as part of the source volume. The alternative approach of separately modelling the source volume and entrainment along the drainage line may be used if there is sufficient confidence in the estimated entrainment rates based on detailed field mapping.

6.8 The possibility of a dam break scenario should be assessed. Careful field mapping and judicious judgement are needed in examining the potential for formation of debris dams and subsequent dam break along a drainage line, which could greatly affect the debris runout.

Use of 3-Dimensional Debris Mobility Models

6.9 Where the actual debris runout path is sensitive to the Digital Terrain Model (DTM) (e.g. possibility of debris overshooting bends along a drainage line, splitting of debris at bifurcation of drainage lines, etc.), the potential for deposition of debris filling up local ground depressions and hence changing the debris runout path should be considered. This would normally call for 3-dimensional debris mobility models (e.g. 3d-DMM), with suitable adjustments of the DTM in order to cater for such possible debris deposition. The provision of engineering measures (e.g. deflector wall, guide wall, etc.) at suitable locations along the runout path, where practicable, may help to reduce the sensitivity of the actual debris runout path to the DTM.

6.10 The 3d-DMM computer program can simulate debris flows over irregular and complex terrain profiles (e.g. without a well-defined channel alignment, drainage lines with abrupt bends, etc.), and estimate the lateral spread of debris at the outlets of drainage lines. The results of back analyses of selected notable landslides (Hungr et al, 2007) have shown that the lateral spread simulated by 3d-DMM generally agrees with the site observations. In special cases (e.g. the benchmarking exercise against the USGS flume tests as reported by Hungr et al (op cit)), the 3d-DMM could under-estimate the thickness of debris deposition and over-estimate the extent of lateral spread. However, the relevance and representativeness of such small-scale physical tests are open to question.

Need for Reliable Digital Terrain Model and Sensitivity Analysis

6.11 The DTM to be adopted for debris mobility modelling should adequately reflect the site characteristics that affect the debris runout path and travel distance. The DTM derived from published topographic maps may not give reliable topographic data, particularly at locations masked by thick vegetation. Multi-return air-borne Light Detection and Ranging (LiDAR) surveys have the capability of deriving the DTM of the ground surface through the 'virtual deforestation' process in a vegetated hillside. Such LiDAR data, if available, should be used to compile the DTM after validation against known coordinates of surveyed locations within or in the vicinity of the site.

6.12 Sensitivity analyses should be carried out, given the uncertainties in the input data. These should include an assessment of the effect of landslide volume (i.e. source volume as well as entrained volume and entrainment rate where appropriate) and the assumed rheological parameters on debris runout, debris thickness and debris velocity profiles along the runout path. Where the 3d-DMM program is used, the sensitivity of the lateral spread and thickness of debris at the outlet of a drainage line to the input parameters should also be examined.

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