GEO Technical Guidance Note No. 10 (TGN 10)
Enhancement of Rock Slope Engineering Practice Based on Findings of Landslide Studies

1. SCOPE

1.1 This Technical Guidance Note (TGN) serves as a reminder of good practice on selected aspects in respect of investigation, design, construction and maintenance of rock cut slopes, with particular reference to observations and lessons learnt from studies of engineered rock cut slope failures and other related studies. It is intended to supplement the information given in Section 5 of the Geotechnical Manual for Slopes (GCO, 1984), Geoguide 2 (GEO, 2017a), Sections 2 and 4 of Geoguide 3 (GEO, 2017b), Section 5 of Geoguide 1 (GEO, 2020) and Sections 4 and 7 of the Highway Slope Manual (GEO, 2017c). This TGN should also be read in conjunction with Sections 4.5 and 4.6 of Geoguide 5 (GEO, 2018), Section 3 of the Engineering Geological Practice in Hong Kong (GEO, 2007) and Section 5 of the Prescriptive Measures for Man-made Slopes and Retaining Walls (GEO, 2009).

1.2 Any feedback on this TGN should be directed to Chief Geotechnical Engineer/Landslip Preventive Measures 2 of the GEO.

2. TECHNICAL POLICY

2.1 The technical guidelines promulgated in this TGN were agreed by GEO Geotechnical Control Conference (GCC) in November 2002. Subsequent updates were made in October 2009, May 2014 and October 2020.

3. RELATED DOCUMENTS

3.1 Evans, N.C. & Irfan, T.Y. (1991). *Landslide Studies 1991 : Blast-induced Rock Slide at Shau Kei Wan, November 1991 (Special Project Report No. SPR 6/91)*. Geotechnical Engineering Office, Hong Kong, 115 p.

3.2 Fugro Scott Wilson Joint Venture (2006). *Review of Landslide Incident at Slope No. 11SE-D/C57, Sai Wan Service Reservoir, Tai Tam Road (Landslide Study Report No. LSR 2/2006).* Geotechnical Engineering Office, Hong Kong, 49 p.

3.3 Geotechnical Control Office (1984). *Geotechnical Manual for Slopes (2nd edition)*. Geotechnical Control Office, Hong Kong, 302 p.

3.4 Geotechnical Engineering Office (2004). *Guidelines on Recognition of Geological Features Hosting, and Associated with, Silt- and Clay-rich Layers Affecting the Stability of Cut Slopes in Volcanic and Granitic Rocks (GEO Technical Guidance Note No. 4)*. Geotechnical Engineering Office, Hong Kong, 8 p.

3.5 Geotechnical Engineering Office (2007). *Engineering Geological Practice in Hong Kong (GEO Publication No. 1/2006).* Geotechnical Engineering Office, Hong Kong, 278 p.

3.6 Geotechnical Engineering Office (2009). *Prescriptive Measures for Man-made Slopes and Retaining Walls (GEO Publication No. 1/2009).* Geotechnical Engineering Office, Hong Kong, 76 p.

3.7 Geotechnical Engineering Office (2017a). *Guide to Site Investigation (Geoguide 2) (Continuously Updated E-Version released on 18 December 2017).* Geotechnical Engineering Office, Hong Kong, 324 p.

3.8 Geotechnical Engineering Office (2017b). *Guide to Rock and Soil Descriptions (Geoguide 3) (Continuously Updated E-Version released on 29 August 2017).* Geotechnical Engineering Office, Hong Kong, 171 p.

3.9 Geotechnical Engineering Office (2017c). *Highway Slope Manual (Continuously Updated E-Version released on 7 September 2017).* Geotechnical Engineering Office, Hong Kong, 116 p.

3.10 Geotechnical Engineering Office (2018). *Guide to Slope Maintenance (Geoguide 5, 3rd Edition) (Continuously Updated E-Version released on 20 November 2018).* Geotechnical Engineering Office, Hong Kong, 116 p.

3.11 Geotechnical Engineering Office (2020). *Guide to Retaining Wall Design (Geoguide 1, 2nd Edition) (Continuously Updated E-Version released on 1 June 2020).* Geotechnical Engineering Office, Hong Kong, 245 p.

3.12 Halcrow China Limited (2002). *Detailed Study of Selected Landslides on Slope No. 11NE-D/C45, Hiu Ming Street, Kwun Tong (GEO Report No. 130).* Geotechnical Engineering Office, Hong Kong, 96 p.

3.13 Hencher, S.R. (1981). *Report on Slope Failure at Yip Kan Street (11SW-D/C86) Aberdeen on 12th July 1981 (GCO Report No. GCO 16/81).* Geotechnical Control Office, Hong Kong, 26 p.

3.14 Hui, T.H.H. (2006). *Detailed Study of the 6 June 2003 Rockfall Incident on Slope No. 11NE-C/C71 at Kung Lok Road, Kwun Tong (GEO Report No. 192).* Geotechnical Engineering Office, Hong Kong, 68 p.

3.15 Lee, R.W.H, Leung, J.C.W & Lo, D.O.K. (2015). *Review of Landslides in 2012 (GEO Report No. 312).* Geotechnical Engineering Office, Hong Kong, 45 p.

3.16 Maunsell Geotechnical Services Ltd. (2004). *Detailed Study of the 9 June 2001 Rockfall Incident at Slope No. 11NW-A/C58 at Castle Peak Road below Wah Yuen Tsuen (GEO Report No. 151).* Geotechnical Engineering Office, Hong Kong, 74 p.

4. TECHNICAL RECOMMENDATIONS

4.1 GROUND INVESTIGATION

4.1.1 General principles and key considerations relating to the development of engineering geological models are given in Section 3 of the Engineering Geological Practice in Hong Kong (GEO, 2007). Some salient points relevant to rock slope engineering based on findings of landslide studies are summarised in paragraphs 4.1.2 to 4.1.4.

4.1.2 In the mapping of discontinuities, special emphasis should be given to identifying adverse geological features and dilated rock joints or open joints with infill or sediment, which could indicate progressive slope deterioration and/or adverse groundwater conditions. The key characteristics of these adverse geological features should be adequately mapped. In addition, care must be taken to ensure that apparently minor, but kinematically significant joint sets or individual joints are not overlooked (Evans & Irfan, 1991). However, sample of joint measurements should be representative of the overall picture, in order to avoid collection of large quantities of measurements that may have little relevance to stability assessment.

4.1.3 Large-scale rock slope failures have occurred involving laterally persistent discontinuities such as sheeting joints. The waviness of a sheeting joint could involve local steepening of the joint dip angle behind the slope face, which can be difficult to detect in practice (HCL, 2001).

4.1.4 Site-specific laboratory tests may be carried out to characterise the operational joint shear strength where considered necessary, with consideration given to the roughness and persistence of the joint, influence of any weak infill, etc. (Hencher, 1981).

4.2 DESIGN CONSIDERATIONS

4.2.1 The practice of relying on conventional stereographic projections and generalised assumptions about joint strength, groundwater, block size, etc. may not be adequate to cater for local weaknesses in the rock mass. Local variations in the slope surface profile that could make minor instabilities kinematically feasible may not be identified if generalised assumptions about the slope profile are made in stereographic analysis. In addition, where a slope has a plan curvature and the presence of an undulating joint set is evident, some localised, potentially unstable, rock blocks may not be reflected in the stereoplots (Hui, 2006). Where appropriate, sensitivity analysis should be carried out to allow for local variations in the slope surface profile.

4.2.2 Caution should be exercised to avoid over-reliance on simple statistical computer programs because kinematic analysis using joint sets derived from a contoured stereoplot may obscure the variability of discontinuity orientations. With the use of statistical computer programs, the significance of some of the infrequent but critical joints may be missed. Designers should be involved in the site mapping and examine the original uncontoured joint data to critically appraise the results of stereographic analysis. For an existing rock slope, designers should rely less on the stereoplots and more on field mapping to directly identify the problematic rock blocks, in particular the potential root wedging effect of vegetation on the blocks (Hui, 2006).

4.2.3 Large-scale engineering geological drawings and marked-up transparent overlays to photographs showing all salient features of the rock mass, including locations and extent of potentially unstable blocks and areas of seepage as well as dimensioned locations, extent and details of the proposed support and drainage measures should be prepared.

4.2.4 The majority of engineered rock cut slope failures in Hong Kong involve minor rockfalls due to local adverse groundwater regimes, root wedging and/or loose or unstable blocks. The latter may be associated with the presence of weaker, more weathered and/or closely jointed rock within a generally strong rock mass, which can be especially vulnerable to deterioration. Such minor rockfalls can be difficult to guard against in design. Although the chance of direct impact by a small rockfall is not high, the consequence in the event of direct impact could be serious given the nature of the material. A pragmatic approach is to provide suitable protective and mitigation measures such as rock mesh netting, rockfall fence, rock trap or rock ditch, rockfall barrier or buffer zone (where space permits) in order to mitigate the consequence and hence reduce the risk of minor rockfalls. In this regard, minor rockfalls successfully retained by these mitigation measures as intended should not be regarded as a failure.

4.2.5 Specific unstable blocks and seepage locations should be dealt with by means of appropriate local support and drainage measures. However, in the case of a heavily jointed or intensely fractured rock mass, patterned rock dowelling in conjunction with prescriptive subsurface drainage measures and rock mesh netting could be an appropriate solution (MGSL, 2002). Adequate number of fixing pins should be provided to ensure that rock mesh netting closely follows the rock slope profile as far as practical, particularly along the edge of the rock mesh netting on rugged rock surface to prevent any potential loose blocks from falling out from the opening between the netting and the rock surface (Lee et al, 2014). The fixing details of any existing rock mesh netting especially for those installed in early years without the provision of a bottom wire rope with adequate fixing at the toe should be enhanced where opportunities arise to the latest standard, e.g. provision of a bottom wire rope and fixing pins to secure the rock mesh to the slope toe (see Figure 1), for improved robustness. Where potentially unstable blocks exceed the maximum size that rock mesh netting could retain, other appropriate methods (e.g. stabilisation, removal, etc.) should be considered (Hui, 2006).

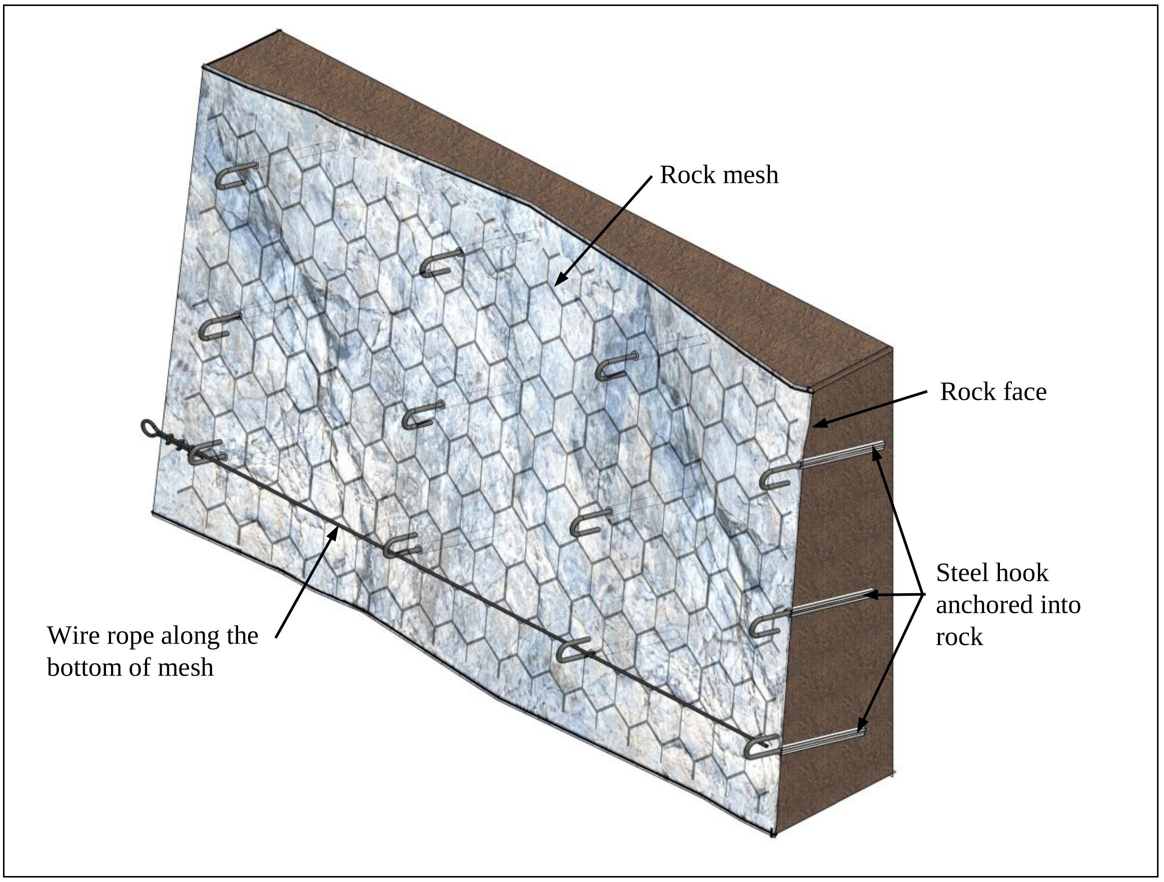

Figure 1 An example of fixing of rock mesh to the bottom of rock face

4.2.6 The identification of the weaker parts of the rock mass and seepage locations requiring works can only be specified in detail once the rock face is exposed during construction. A hard cover, such as shotcrete, to the entire rock face is generally not necessary and should be avoided on aesthetic grounds. However, the provision of a hard cover (e.g. stone pitching) together with subsurface drainage measures to local patches of weaker rock mass to limit infiltration and deterioration may be justified from slope stability point of view, subject to appropriate landscape treatment.

4.2.7 General guidance on the use of prescriptive concrete buttresses for rock cut slopes is given in Section 5.6 of the Prescriptive Measures for Man-made Slopes and Retaining Walls (GEO, 2009). However, the use of prescriptive concrete buttresses should only be confined to the treatment of small local overhangs or rock wedges. Detailed stability assessment and structural design of reinforced concrete buttresses should be carried out when they are used to stabilize sizeable unstable rock blocks.

4.2.8 As only a small amount of water is needed to fill up rock joints and lead to high cleft water pressure, extreme caution should be exercised in assessing the design groundwater condition. Sufficient subsurface drainage provisions should be prescribed in order to minimise the uncertainty and sensitivity associated with groundwater response in rock slopes.

4.3 CONSTRUCTION CONSIDERATIONS

4.3.1 Very often, the design of necessary works for both new and existing rock slopes can only be finalised during the construction stage. Design reviews during construction are critical to refine the preliminary design where the rock face is well exposed and more extensive access scaffolding is available for mapping. Extra care should also be exercised in assessing the weathering grades and verifying the boundaries of different weathering grades of rocks, particularly when detailed mapping of the rock face has not been carried out at the design stage (FSWJV, 2006). Design reviews during construction call for input by geotechnical professionals with adequate engineering geological knowledge and local experience.

4.3.2 Site inspections by geotechnical professionals responsible for independent checking of the slope design should be carried out at critical stages of the works including site inspections to vet the design assumptions (and proposed design amendments as appropriate) based on the actual ground conditions encountered.

4.3.3 In the formation of new rock cuts involving substantial rock breaking using expanding agents, adequate measures need to be taken to prevent the uncontrolled flow of the expanding agents, which may adversely affect the stability of rock faces. Moreover, as expanding agents can continue to expand for at least several days, time-dependent deterioration in stability can occur where there is uncontrolled or unintended flow of the expanding agents into joints.

4.3.4 Detailed as-built records should include large-scale engineering geological drawings (e.g. marked-up transparent overlays to photographs) depicting all the major geological features and dimensioned locations, extent and details of all support, drainage and mitigation measures. Photographic record of the exposed rock face should be made as part of the as-built record, especially where a surface cover (e.g. shotcrete to local weak zones or fibre-reinforced soil) is provided.

4.4 MAINTENANCE

4.4.1 The maintenance of rock slopes and related issues are covered in Sections 4.5 and 4.6 of Geoguide 5 (GEO, 2018).

5. **ANNEXES**

5.1 Nil.

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