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

GEO Technical Guidance Note No. 52 (TGN 52)
Enhanced Technical Guidance on Design of Rigid Debris-resisting Barriers

Issue No.: 1	Revision: B	Date: 23.12.2023	Page: 1 of 10

1. SCOPE

1.1 This Technical Guidance Note (TGN) supplements and updates relevant guidance given in GEO Report No. 270 (Kwan, 2012) and GEO TGN No. 47 (GEO, 2023d) on geotechnical stability, structural integrity and detailing of deflector design of rigid debris-resisting barriers.

1.2 Any feedback on this TGN should be directed to the Chief Geotechnical Engineer/ Landslip Preventive Measures 2 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 24 December 2020.

3. RELATED DOCUMENTS

3.1 GEO (2023a). *Supplementary Technical Guidance on Design of Rigid Debris-resisting Barriers (GEO TGN 33)*. Geotechnical Engineering Office, Hong Kong, 1 p.

3.2 GEO (2023b). *Detailing of Rigid Debris-resisting Barriers (GEO TGN 35)*. Geotechnical Engineering Office, Hong Kong, 8 p.

3.3 GEO (2023c). *Assessment of Landslide Debris Impact Velocity for Design of Debris-resisting Barriers (GEO TGN 44)*. Geotechnical Engineering Office, Hong Kong, 4 p.

3.4 GEO (2023d). *Updates of Design Guidance of Rigid Debris-resisting Barriers (GEO TGN 47)*. Geotechnical Engineering Office, Hong Kong, 4 p.

3.5 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.

3.6 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.

3.7 Wong, L.A., Lam, H.W.K., Lam, C. & Kwan, J.S.H. (2022). *Technical Development Work on Design of Rigid Debris-resisting Barriers (GEO Report No. 358).* Geotechnical Engineering Office, Hong Kong, 397 p.

4. BACKGROUND

4.1 GEO Report No. 104 (Lo, 2000) sets out the geotechnical parameters and considerations for the design of rigid debris-resisting barriers based on a review of the literature and state of the knowledge as of the late 1990s. In 2012, GEO Report No. 270 (Kwan, 2012) was published, which supplements and updates the relevant design guidance provided by Lo (2000), based on a review of state-of-the-art literature in the early 2010s. The recommendations given in GEO Report No. 270 (Kwan, 2012) were promulgated in GEO TGN No. 33 (GEO, 2023a).

4.2 Based on a desk study review and site inspection of selected barriers, technical recommendations on proper detailing of rigid debris-resisting barriers were promulgated in GEO TGN No. 35 (GEO, 2023b). Subsequently, Professor O. Hungr conducted a ‘walk through’ exercise and provided technical advice to improve design practice from the perspective of value engineering. The prevailing design guidelines were updated based on his advice as promulgated in GEO TGN No. 47 (GEO, 2023d).

4.3 Since then, GEO has conducted a series of technical development work, with a view to further optimising the design of rigid debris-resisting barriers. The work included large-scale experimental studies, numerical analyses as well as analytical studies, covering geotechnical stability, structural integrity and detailing of deflector design for rigid debris-resisting barriers.

4.4 This TGN stipulates the technical recommendations pertaining to the enhancement of rigid debris-resisting barrier design. It supplements and updates the relevant guidance given in GEO Report No. 270 (Kwan, 2012) and GEO TGN No. 47 (GEO, 2023d).

5. TECHNICAL RECOMMENDATIONS

5.1 DESIGN APPROACH

5.1.1 Impacts of debris-resisting barriers by landslide debris are rare events in Hong Kong. It is more cost-effective to adopt a performance-based approach in the design of rigid debris-resisting barriers. In line with this, localised or minor damages that can be repaired after a landslide event are generally tolerable as long as the rigid barrier would not collapse or fail to satisfy the performance criteria in retaining the design volume of landslide debris.

5.2 DYNAMIC SOIL DEBRIS IMPACT FORCE

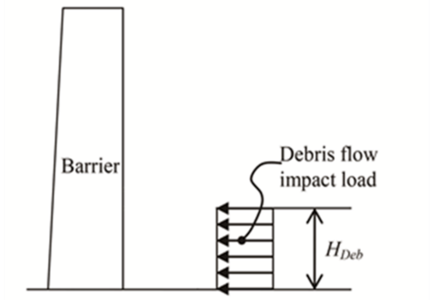
5.2.1 Based on the results of large-scale flume tests and numerical analyses (Section 1 in Wong et al (2022)), prediction of dynamic soil debris impact force (*F*) should follow Equation (1) and the dynamic soil debris pressure coefficient (α) of 1.5 should be adopted:-

$$F = \alpha \, \rho \, v^2 \, h \, w \sin\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

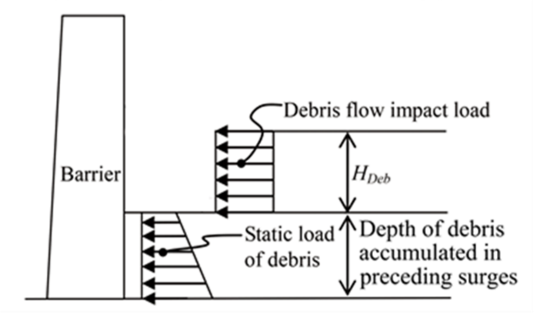
where F = dynamic soil debris impact force (in N)
α = dynamic soil debris pressure coefficient
ρ = debris density (in kg/m^3)
v = debris velocity (in m/s)
h = debris flow thickness (in m)
w = debris flow width (in m)
β = angle between impact face of barrier and debris motion direction.

5.2.2 The dynamic soil debris impact force should be used in the pseudo-static force equilibrium analyses for both geotechnical stability and structural integrity based on the multiple-surge load model shown in Figure 1. For design events involving both soil debris and boulders, the geotechnical stability of the barriers under boulder impacts should be assessed separately based on the displacement approach (see Section 5.3) while for structural integrity check, the multiple-surge load model in Figure 2.1 of GEO Report No. 270 (Kwan, 2012) should still be followed as appropriate.

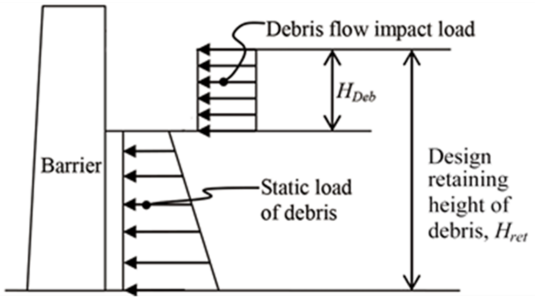
5.2.3 The adoption of dynamic soil debris pressure coefficient (α) of 1.5 supersedes the relevant guidance given in Section 4.2 of GEO Report No. 270 (Kwan, 2012) and Section 5.2 of GEO TGN No. 47 (GEO, 2023d).



(a) First Impact when the Barrier is Empty



(b) Subsequent Surges Hitting the Barrier



(c) Last Surge which Fills Up the Barrier to the Design Debris Retaining Height, H_{ret}

Notes:

(1) Design calculations for scenario (b) should be carried out for debris impacts at different levels coresponding to the depth of the debris accumulated in preceding surges.

(2) Debris retaining height, H_{ret}, shall be estimated using the retention capacity of the barrier. H_{ret} is not necessary the height of barrier wall. Normally, the height of the barrier wall could be greater than H_{ret} to provide freeboard and safety margin of debris retention volume.

(3) Reference should be made to GEO TGN No. 44 (GEO, 2023c) for the assessment of debris impact velocity and impact load thickness (H_{Deb}).

Figure 1 Multiple Surge Load Model for Geotechnical Stability and Structural Integrity Assessment under Soil Debris Impact

5.3 DISPLACEMENT APPROACH FOR GEOTECHNICAL STABILITY ASSESSMENT OF BOULDER IMPACT

5.3.1 Boulder impact loads are highly transient and of high magnitude. Adopting boulder impact loads to assess geotechnical stability of rigid debris-resisting barriers based on pseudo-static force equilibrium analyses may yield an overly-conservative solution. Instead, the geotechnical stability of a rigid debris-resisting barrier under boulder impacts could be assessed based on the displacement approach, in terms of translational and rotational movements.

5.3.2 In general, displacement check of translational and rotational movements of a rigid debris-resisting barrier is not required for normal design scenarios. Based on a series of sensitivity analyses, if a rigid barrier has a mass that satisfies the requirement set out in Table 1 for different ranges of boulder impact velocity considered, the resulting translational and rotational movements of the barrier are deemed to be insignificant and further checking of geotechnical stability (i.e. estimation of translational and rotational movements) due to boulder impact is not required. If a cushion layer is installed to a rigid debris-resisting barrier, the mass of such cushion layer can be taken as part of the mass of the barrier for the displacement check.

Boulder Impact Velocity (v)	$v \leq 8$ m/s	8 m/s $< v \leq 10$ m/s	10 m/s $< v \leq 12$ m/s
Mass of Rigid Barrier	> 20 times of mass of boulder	> 25 times of mass of boulder	> 30 times of mass of boulder

Table 1 – Mass of rigid barrier where displacement check is not required

5.3.3 Under special circumstances when displacement check of translational and rotational movements is considered necessary (e.g. the mass of the rigid barrier does not satisfy the requirement in Table 1), supplementary guidelines given in Annex TGN 52 A can be followed to assess the movements.

5.3.4 As a good practice, rigid debris-resisting barriers should be founded on a levelled and competent ground, and the ground in front of the barrier should be well protected against erosion as necessary.

5.3.5 As an alternative to the displacement check, designers may consider adopting measures such as baffles, boulder straining structures, cushioning materials, etc. to deal with the boulder impact, taking into account cost-effectiveness, constructability and maintenance requirement, etc.

5.4 STRUCTURAL INTEGRITY ASSESSMENT OF BARRIERS UNDER BOULDER IMPACT

5.4.1 For design events involving both soil debris and boulders, assessment of impact load arising from boulders of 1 m diameter or below is generally not required in the structural design of a rigid barrier. This approach is based on consideration of the transient and localised nature of boulder impact, the probable benefits of 3-dimensional effects of typical barriers with wing walls, built-in conservatism in the dynamic soil debris impact model, as well as the low probability of simultaneous occurrence of the peak dynamic soil debris and boulder impact loads.

5.4.2 Under special circumstances if boulder impact loads are required to be considered in the structural design, the flexural response of barriers due to boulder impact can be assessed based on Enhanced Flexural Stiffness Method given in Annex TGN 52 B.

5.4.3 Alternatively, designers may consider adopting measures such as baffles, boulder straining structures, cushioning materials, etc. to deal with the boulder impact, taking into account cost-effectiveness, constructability and maintenance requirement, etc.

5.5 ASSESSMENT OF RUN-UP HEIGHT OF LANDSLIDE DEBRIS

5.5.1 Based on experimental results (Section 8 in Wong et al (2022)), the prediction of run-up height of landslide debris should be assessed following the Energy Model (Kwan, 2012). This supersedes the relevant guidance given in Section 6.2 of GEO Report No. 270 (Kwan, 2012).

5.6 DEFLECTOR TO PREVENT SPILLAGE OF LANDSLIDE DEBRIS

5.6.1 If the predicted run-up height does not exceed the height of the wall stem, spillage of landslide debris is generally not a concern.

5.6.2 The provision of a crest deflector to prevent spillage of landslide debris is generally not necessary and should be considered as a last resort if the barrier is situated in close proximity to downstream facilities where there is a safety concern when spillage of landslide debris occurs. As an alternative, other precautionary measures such as provision of freeboard may also be considered to prevent spillage of debris.

5.6.3 Deflectors can be horizontal or inclined up to 45° to the horizontal. In general, the required horizontal projected length of the deflector should be, at least, half of maximum debris flow depth at the barrier location calculated by debris mobility analysis (Section 9 in Wong et al (2022)). This supersedes the relevant guidance given in Section 6.3 of GEO Report No. 270 (Kwan, 2012). Guidance on detailing and selection of the shape and form of a deflector is given in Section 9 in Wong et al (2022).

6 ANNEXES

6.1 TGN 52 A - Supplementary Guidelines on Displacement Approach for Geotechnical Stability Assessment of Boulder Impact

6.2 TGN 52 B - Supplementary Guidelines on Enhanced Flexural Stiffness Method for Structural Integrity Assessment of Boulder Impact

(Raymond W M Cheung)
Head, Geotechnical Engineering Office

Annex TGN 52 A - Supplementary Guidelines on Displacement Approach for Geotechnical Stability Assessment of Boulder Impact

1. Under the displacement approach for geotechnical stability assessment of boulder impact set out in Section 5.3 of this TGN, Equations (A1) and (A2) below may be used to assess the translational and rotational movements. The derivation (with assumptions) and verification of the equations are given in Section 3 in Wong et al (2022). Worked examples are also given in Section 2 in Wong et al (2022).

Translational Movement

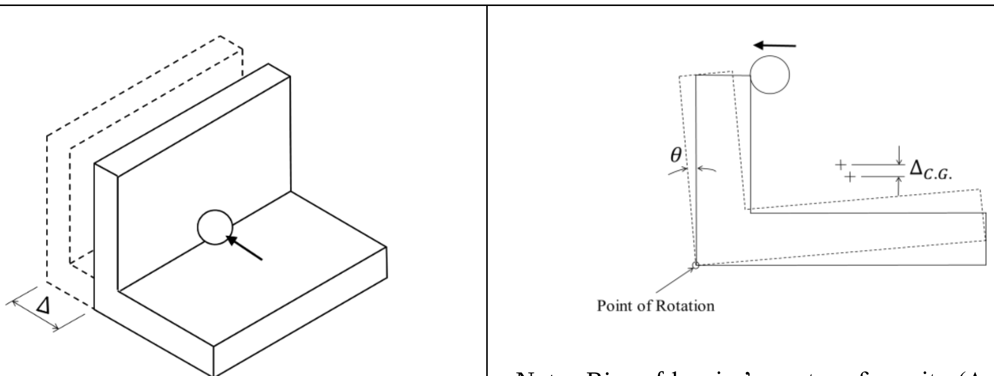
$$\Delta = \frac{KE_2}{(Mg - uA)\tan\delta'} \qquad \text{(A1)}$$

where Δ = translational movement of barrier (in m)
KE_2 = kinetic energy gained by barrier (in J) (see Appendix B of Section 2 in Wong et al (2022))
M = mass of barrier (in kg)
g = gravity (9.81 m/s^2)
u = water uplift pressure acting on barrier's base (in N/m^2)
A = contact area between barrier's base and ground surface (in m^2)
δ' = effective interface friction angle between concrete and ground surface (in degrees)

Rotational Movement

$$\Delta_{C.G.} = \frac{KE_2}{Mg} \qquad \text{(A2)}$$

where $\Delta_{C.G.}$ = rise of barrier's centre of gravity (in m)
KE_2 = kinetic energy gained by barrier (in J) (see Appendix C of Section 2 in Wong et al (2022))
M = mass of barrier (in kg)
g = gravity (9.81 m/s^2)



Note: Rise of barrier's centre of gravity ($\Delta_{C.G.}$) can be converted to rotational angle (θ) (Section 2 in Wong et al (2022)).

Figure A1 Translational (Left) and Rotational (Right) Movements of a Rigid Debris-resisting Barrier subject to Boulder Impact

Annex TGN 52 B - Supplementary Guidelines on Enhanced Flexural Stiffness Method for Structural Integrity Assessment of Boulder Impact

1. For assessing the flexural response of a rigid barrier under boulder impact, the boulder impact load at the crest of the barrier can be assessed based on the Enhanced Flexural Stiffness Method (EFSM) (see Section 3.1 of Section 4 in Wong et al (2022)) below:-

$$F_b = \sqrt{\lambda\left(\frac{1+COR}{1+\lambda}\right)^2}\, v_0\sqrt{mk} \ldots\ldots\ldots\ldots\ldots\ldots \text{(B1)}$$

where F_b = boulder impact force at the barrier's crest (in N)
COR = coefficient of restitution
λ = ratio between the participating mass of barrier and mass of boulder (Note: Participating mass of barrier can be based on (a) the width of a barrier or width of a single bay of the barrier where appropriate, e.g. distance between movement joints, if any (Kwan, 2012) and (b) the top 0.24 portion of wall stem.)
v_0 = impact velocity of boulder (in m/s)
m = mass of boulder (in kg)
k = flexural stiffness of barrier (in N/m) (See Appendix A of Section 5 in Wong et al (2022))

2. The EFSM has been validated by a series of large-scale impact tests (Sections 5 & 6 in Wong et al (2022)). Based on the experimental results, COR of 0.3 is recommended.

3. For scenarios of boulder impact at the mid-height of a barrier or below, the induced bending moment at the base of a wall stem can be reduced by 30% as compared to that for boulder impact at the barrier's crest (Section 6 in Wong et al (2022)).

4. Based on parametric studies using the validated Two Degree-of-Freedom Lumped Mass Model (Section 7 in Wong et al (2022)), if a minimum 500 mm thick rockfill gabion cushion is adopted, the flexural response (i.e. bending moment at the bottom of wall stem) of a rigid debris-resisting barrier calculated based on the EFSM can be reduced by 35%. No reduction of flexural response should be allowed if the thickness of the rockfill gabion cushion is less than 500 mm.

5. The boulder impact force derived from the EFSM is applicable to the structural integrity check of the wall stem of a barrier only, but not for the design of its foundations or tie-backs, if any. If a barrier is provided with foundations or tie-backs, designers should adopt other appropriate design approaches or conduct appropriate dynamic analyses for the design of these foundations or tie-backs.