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

GEO Technical Guidance Note No. 51 (TGN 51)
Design of Nail Head for Use of Soil Nails in Mitigation of Open Hillslope Landslides

1. SCOPE

1.1 This Technical Guidance Note (TGN) supplements the relevant guidance given in Geoguide 7 on the design of nail head for use of soil nails in mitigation of open hillslope landslides.

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

2. TECHNICAL POLICY

2.1 The technical recommendations promulgated in this TGN were agreed by GEO Geotechnical Control Conference on 22 December 2020.

3. RELATED DOCUMENTS

3.1 Campbell, S.D.G., Shaw, R., Sewell, R.J. & Wong, J.C.F. (2008*). Guidelines for Soil Bioengineering Applications on Natural Terrain Landslide Scars (GEO Report No. 227).* Geotechnical Engineering Office, Hong Kong. 162 p.

3.2 DOT (1994). *Design Methods for the Reinforcement of Highway Slopes by Reinforced Soil and Soil Nailing Techniques (HA 68/94)*. Department of Transport, UK. 108 p.

3.3 GEO (2017). *Guide to Soil Nail Design and Construction (Geoguide 7)*. (Continuously Updated E-Version released on 18 September 2017). Geotechnical Engineering Office, Civil Engineering and Development Department, HKSAR Government, 90 p.

3.4 GEO (2011). *Technical Guidelines on Landscape Treatment for Slopes (GEO Publication No. 1/2011).* Geotechnical Engineering Office, Hong Kong. 217 p.

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

3.6 Kong, V.S.F, Koo, R.C.H. & Chang, D.S. (2020). *Design of Nail Head for Use of Soil Nails in Mitigation of Open Hillslope Landslides (Technical Note No. 1/2020).* Geotechnical Engineering Office, Hong Kong, 23 p.

3.7 Shiu, Y.K. & Chang, G.W.K. (2004). *Soil Nail Head Review (GEO Report No. 175)*. Geotechnical Engineering Office, Hong Kong. 106 p.

4. BACKGROUND

4.1 Geoguide 7 (GEO, 2017) presents recommendation on sizing of soil-nail head for design of soil nails on slopes steeper than 45º based on the findings of numerical modelling using

the computer program *FLAC*, as reported in GEO Report No. 175 (Shiu & Chang, 2004).

4.2 The gradient of natural hillside, in particular hillsides susceptible to open hillslope landslides (OHL) is relatively gentler than man-made cut slopes. The design guidelines given in GEO Report No. 138 (Ho & Roberts, 2016) for mitigation of OHL hazards include the use of soil nails to increase the margin of safety against slope instability for the top 2 m of the hillslope. In these cases, the required soil nail forces as well as the required bearing capacity of the soil-nail head are usually much smaller than that for the typical design of soil nails in upgrading of steep man-made slopes. The direct application of soil-nail head sizes presented in Table 5.7 of Geoguide 7 often leads to very sizeable soil-nail heads on gentle hillslopes. As a result, it may cause unnecessary impact to the environment and hamper buildability and efficiency in the use of soil nails for mitigating OHL hazards with gentle slope angles (i.e. less than 45º).

4.3 GEO has conducted a series of numerical analyses using the computer program *FLAC* to assess bearing capacity of the soil-nail head on gentle slopes.

4.4 This TGN stipulates the technical recommendations pertaining to the sizing of soil-nail head for the use of soil nails to enhance the general stability of relatively gentle slopes, in particular mitigation of open hillslope landslides for rational and cost-effective design solutions, together with enhanced sustainable measures against shallow landslides and surface erosion.

5. ULTIMATE BEARING CAPACITY OF SOIL-NAIL HEAD ON GENTLE SLOPES

5.1 For general instability of slopes, the potential unstable soil mass (i.e. the ‘active zone’) tends to move downwards along a sliding surface under concentrated shearing at the base of the unstable mass. Given the low flexural stiffness of soil nails, the unstable soil mass is primarily supported by tension developed in the soil-nail steel bars. Under the tensile force in the soil nail due to development of deformation of the ‘active zone’, the bearing capacity of the soil underneath the soil-nail head is mobilised. Soil-nail heads should be designed to provide an adequate safety margin on bearing capacity against shear failure of the ground underneath the soil-nail head, assuming the structural capacity of the soil-nail head is satisfied.

5.2 To determine the ultimate bearing capacity of the soil underneath the soil-nail head, a parametric numerical study (Kong et al. 2020) has been conducted by varying the effective stress shear strength parameters, slope angles and soil nail inclinations. A range of effective stress shear strength parameters (i.e. c' = 2 kPa, 4 kPa, 6 kPa, 8 kPa and 10 kPa; and ϕ' = 34°, 36°, 38° and 40°) based on the recommendations in Geoguide 7 and typical soil nail inclinations at 10° and 20° were used. The numerical results for ultimate bearing capacity of soil-nail head sizes of 600 mm, 500 mm and 400 mm on gentle slopes with combinations of c' and ϕ' are shown in Tables 1, 2 and 3 respectively.

Table 1 - Calculated Ultimate Bearing Capacity of 600 mm Soil-nail Head on Gentle Slopes

Ultimate Bearing Capacity of 600 mm Soil-nail Head (kN)

30°≤ Slope Angle < 35°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	75 (56)	90 (68)	105 (79)	120 (90)
4	93 (70)	108 (81)	126 (95)	141 (106)
6	108 (81)	123 (92)	144 (108)	168 (126)
8	120 (90)	141 (106)	159 (119)	186 (140)
10	138 (104)	156 (117)	180 (135)	198 (149)

30°≤ Slope Angle < 35°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	81 (61)	99 (74)	120 (90)	138 (104)
4	102 (77)	120 (90)	141 (106)	165 (124)
6	120 (90)	138 (104)	162 (122)	186 (140)
8	135 (101)	153 (115)	180 (135)	204 (153)
10	150 (113)	174 (131)	198 (149)	225 (169)

35°≤ Slope Angle < 40°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	78 (59)	96 (72)	114 (86)	138 (104)
4	102 (77)	120 (90)	141 (106)	165 (124)
6	120 (90)	141 (106)	156 (117)	180 (135)
8	138 (104)	153 (115)	186 (140)	210 (158)
10	150 (113)	171 (128)	201 (151)	225 (169)

35°≤ Slope Angle < 40°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	84 (63)	105 (79)	126 (95)	156 (117)
4	111 (83)	132 (99)	153 (115)	180 (135)
6	135 (101)	156 (117)	180 (135)	207 (155)
8	150 (113)	174 (131)	204 (153)	234 (176)
10	168 (126)	192 (144)	219 (164)	252 (189)

40°≤ Slope Angle < 45°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	78 (59)	96 (72)	117 (88)	144 (108)
4	105 (79)	126 (95)	150 (113)	180 (135)
6	129 (97)	153 (115)	180 (135)	207 (155)
8	147 (110)	174 (131)	201 (151)	237 (178)
10	165 (124)	195 (146)	219 (164)	252 (189)

40°≤ Slope Angle < 45°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	84 (63)	105 (79)	129 (97)	159 (119)
4	114 (86)	138 (104)	162 (122)	195 (146)
6	138 (104)	165 (124)	195 (146)	231 (173)
8	162 (122)	192 (144)	225 (169)	252 (189)
10	186 (140)	213 (160)	246 (185)	288 (216)

Notes:
1. Effective stress shear strength parameter c' is in kPa, and ϕ' is in degree (°).
2. Ultimate bearing capacity of soil-nail head with its back parallel to slope surface are given in brackets (Section 5.3 and CEDD Standard Drawing No. C2106/7 refer).

Table 2 - Calculated Ultimate Bearing Capacity of 500 mm Soil-nail Head on Gentle Slopes

Ultimate Bearing Capacity of 500 mm Soil-nail Head (kN)

30°≤ Slope Angle < 35°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	45 (34)	55 (41)	65 (49)	78 (58)
4	58 (43)	68 (51)	80 (60)	93 (69)
6	70 (53)	78 (58)	90 (68)	108 (81)
8	80 (60)	90 (68)	105 (79)	120 (90)
10	88 (66)	100 (75)	118 (88)	133 (99)

30°≤ Slope Angle < 35°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	58 (43)	70 (53)	85 (64)	103 (77)
4	75 (56)	93 (69)	108 (81)	128 (96)
6	90 (68)	108 (81)	128 (96)	148 (111)
8	105 (79)	123 (92)	140 (105)	165 (124)
10	118 (88)	135 (101)	160 (120)	183 (137)

35°≤ Slope Angle < 40°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	50 (38)	63 (47)	73 (54)	85 (64)
4	65 (49)	78 (58)	90 (68)	103 (77)
6	78 (58)	90 (68)	105 (79)	118 (88)
8	88 (66)	103 (77)	120 (90)	135 (101)
10	100 (75)	115 (86)	130 (98)	153 (114)

35°≤ Slope Angle < 40°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	60 (45)	75 (56)	88 (66)	108 (81)
4	78 (58)	95 (71)	110 (83)	135 (101)
6	95 (71)	113 (84)	133 (99)	158 (118)
8	115 (86)	133 (99)	155 (116)	185 (139)
10	130 (98)	150 (113)	175 (131)	205 (154)

40°≤ Slope Angle < 45°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	50 (38)	63 (47)	75 (56)	95 (71)
4	70 (53)	83 (62)	95 (71)	118 (88)
6	83 (62)	98 (73)	115 (86)	135 (101)
8	98 (73)	113 (84)	133 (99)	153 (114)
10	113 (84)	128 (96)	150 (113)	173 (129)

40°≤ Slope Angle < 45°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	60 (45)	75 (56)	90 (68)	108 (81)
4	80 (60)	95 (71)	115 (86)	138 (103)
6	100 (75)	120 (90)	138 (103)	163 (122)
8	118 (88)	135 (101)	160 (120)	193 (144)
10	133 (99)	160 (120)	183 (137)	218 (163)

Notes:
1. Effective stress shear strength parameter c' is in kPa, and ϕ' is in degree (°).
2. Ultimate bearing capacity of soil-nail head with its back parallel to slope surface are given in brackets (Section 5.3 and CEDD Standard Drawing No. C2106/7 refer).

Table 3 - Calculated Ultimate Bearing Capacity of 400 mm Soil-nail Head on Gentle Slopes

Ultimate Bearing Capacity of 400 mm Soil-nail Head (kN)

30°≤ Slope Angle < 35°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	26 (20)	32 (24)	36 (27)	44 (33)
4	34 (26)	40 (30)	46 (35)	54 (41)
6	40 (30)	48 (36)	56 (42)	64 (48)
8	48 (36)	54 (41)	64 (48)	72 (54)
10	54 (41)	62 (47)	72 (54)	82 (62)

30°≤ Slope Angle < 35°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	30 (23)	36 (27)	42 (32)	52 (39)
4	38 (29)	46 (35)	54 (41)	62 (47)
6	46 (35)	54 (41)	62 (47)	74 (56)
8	54 (41)	62 (47)	72 (54)	84 (63)
10	62 (47)	70 (53)	80 (60)	92 (69)

35°≤ Slope Angle < 40°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	30 (23)	36 (27)	42 (32)	50 (38)
4	38 (29)	46 (35)	52 (39)	62 (47)
6	46 (35)	54 (41)	62 (47)	72 (54)
8	54 (41)	62 (47)	72 (54)	80 (60)
10	60 (45)	70 (53)	80 (60)	92 (69)

35°≤ Slope Angle < 40°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	32 (24)	40 (30)	46 (35)	56 (42)
4	42 (32)	50 (38)	60 (45)	72 (54)
6	52 (39)	60 (45)	70 (53)	82 (62)
8	60 (45)	70 (53)	80 (60)	92 (69)
10	68 (51)	78 (59)	90 (68)	104 (78)

40°≤ Slope Angle < 45°
Nail inclination = 10°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	45 (34)	58 (43)	69 (52)	81 (61)
4	63 (47)	75 (56)	87 (65)	102 (77)
6	75 (56)	90 (68)	105 (79)	120 (90)
8	90 (68)	102 (77)	123 (92)	138 (104)
10	102 (77)	117 (88)	135 (101)	156 (117)

40°≤ Slope Angle < 45°
Nail inclination = 20°

Cohesion (c') \ Friction Angle (ϕ')	34	36	38	40
2	48 (36)	60 (45)	75 (56)	90 (68)
4	69 (52)	81 (61)	99 (74)	114 (86)
6	84 (63)	99 (74)	117 (88)	141 (106)
8	99 (74)	117 (88)	132 (99)	156 (117)
10	114 (86)	129 (97)	150 (113)	177 (133)

Notes:
1. Effective stress shear strength parameter c' is in kPa, and ϕ' is in degree (°).
2. Ultimate bearing capacity of soil-nail head with its back parallel to slope surface are given in brackets (Section 5.3 and CEDD Standard Drawing No. C2106/7 refer).

5.3 Designers are recommended to give due consideration to ensure effective interaction between the soil-nail head and the ground for gentle slopes. It has been demonstrated by Kong et al. (2020) that the bearing capacity of the soil-nail head with its back being parallel to slope surface would be generally 25% less than that with the back of the nail head being perpendicular to the nail alignment. In this regard, designers should adopt typical details of soil-nail heads as shown in Figures 1, 2 and 3 of this TGN in order to maximise the efficiency of the soil-nail head. To ensure the integrity of the soil-nail head, the fixing details of the hessian bags for the recessed nail head as shown in the CEDD standard drawing (Drawing No. C2106/7) are shown. Designers may adopt alternative details to suit specific site conditions and applications. Alternatively, for ease of construction, the typical details of recessed soil-nail head presented in the CEDD standard drawing are also generally acceptable for gentle slopes and for mitigation of OHL hazards to promote soft landscaping in current design practice. In this case, the ultimate bearing capacity presented in brackets in Tables 1, 2 and 3 should be adopted.

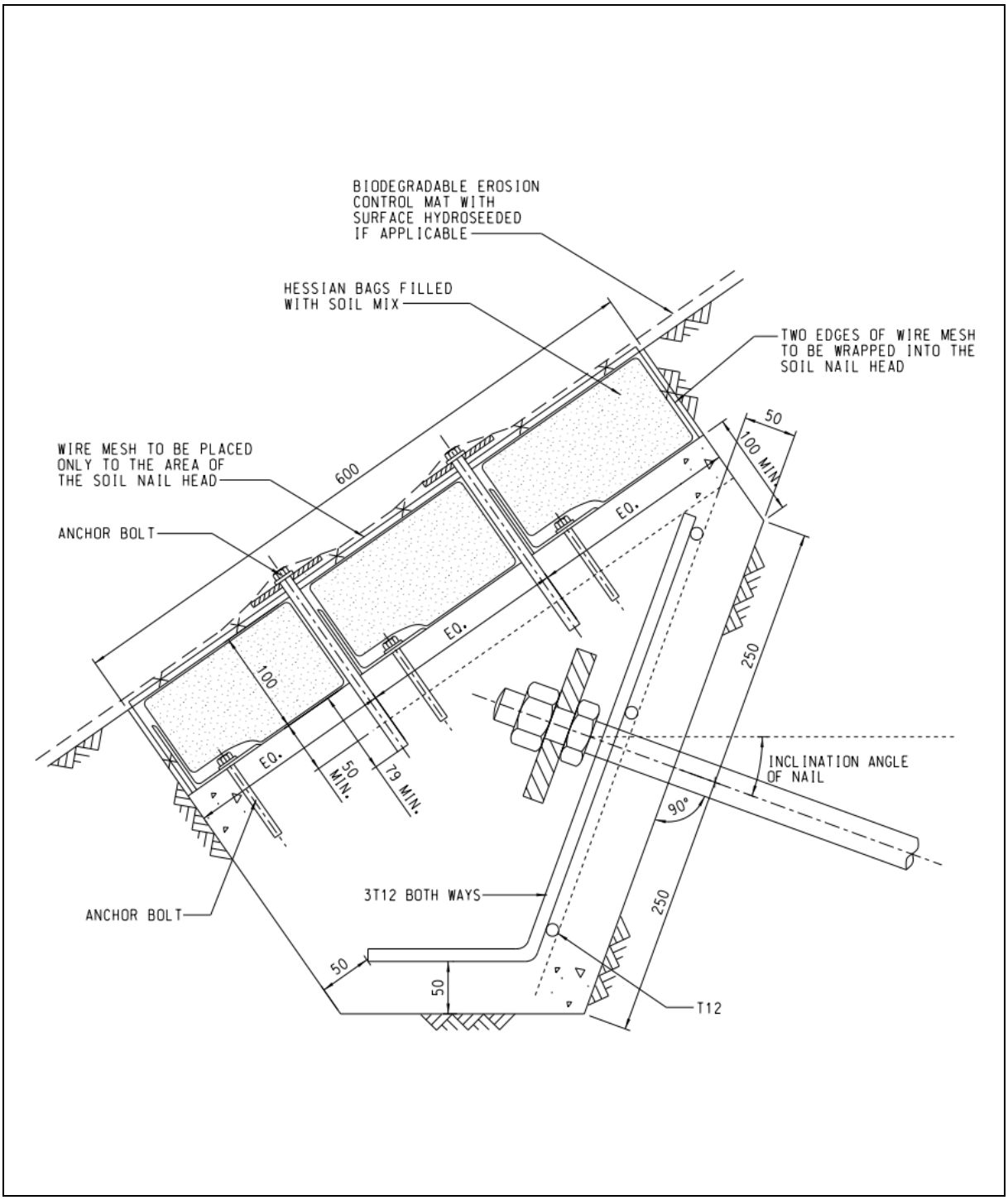

Figure 1 - Enhanced Soil-nail Head Details for a 600 mm Soil Nail on Gentle Slopes
(Back of Nail Head Perpendicular to the Nail Alignment)

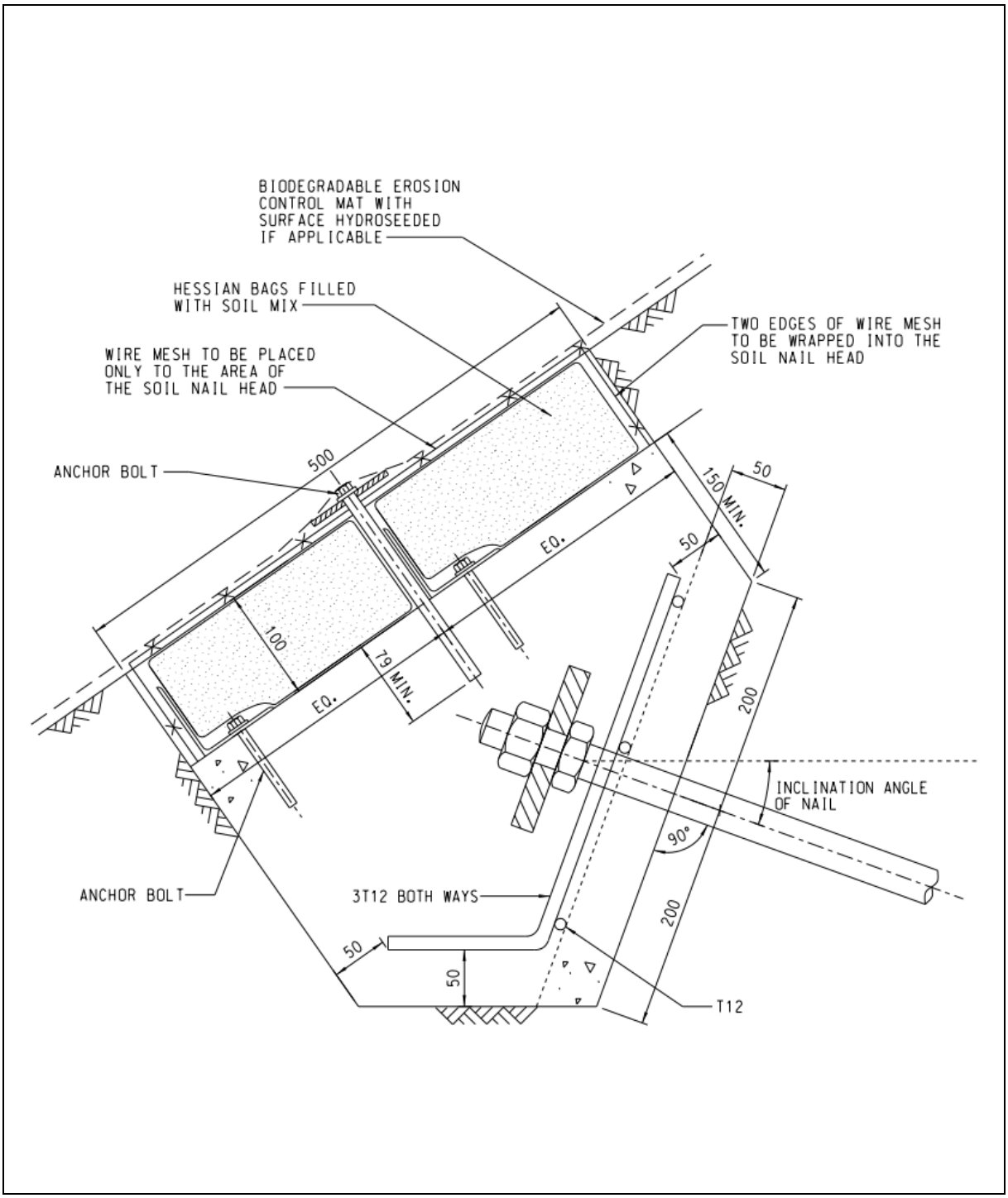

Figure 2 - Enhanced Soil-nail Head Details for a 500 mm Soil Nail on Gentle Slopes
(Back of Nail Head Perpendicular to the Nail Alignment)

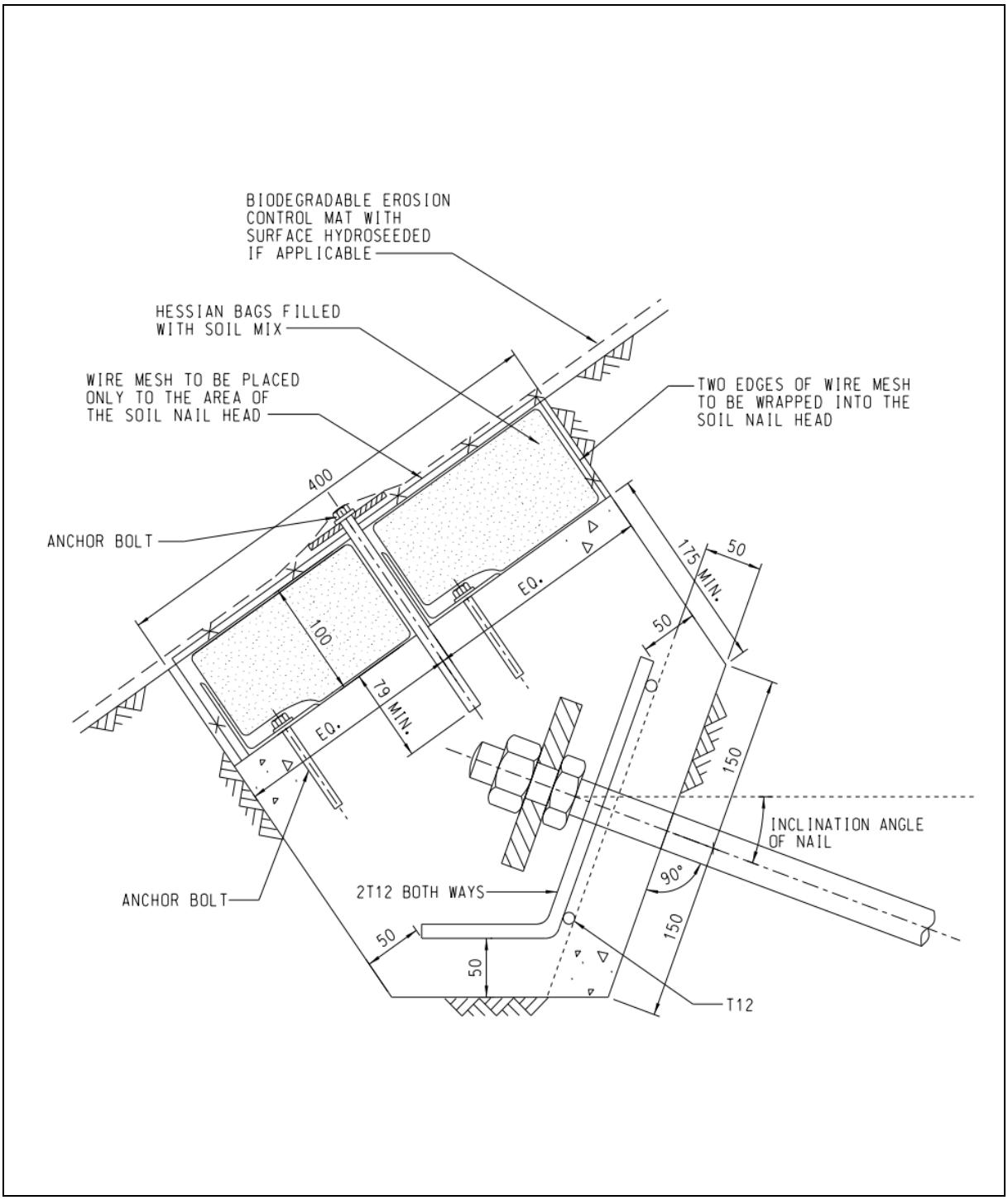

Figure 3 - Enhanced Soil-nail Head Details for a 400 mm Soil Nail on Gentle Slopes
(Back of Nail Head Perpendicular to the Nail Alignment)

6. TECHNICAL RECOMMENDATIONS

Bearing Capacity of Soil-nail Head

6.1 In general, a range from 400 mm to 600 mm soil-nail heads should be adequate to cater for the stabilisation forces required for the soil nails to enhance general stability of relatively gentle slopes, in particular for mitigation of OHL hazards. This will greatly enhance buildability of the soil nail solution and promote sustainability to the environment as part of the natural terrain hazard mitigation works. Designers should specify soil-nail head with sufficient bearing capacity to counteract the required stabilisation force of the soil nail, based on site-specific conditions according to bearing capacity values as shown in Tables 1 to 3, and with a minimum factor of safety of 1.2.

6.2 The calculated bearing capacity of soil-nail head in this TGN is based on typical conditions of gentle slopes. Designers should review the application if any adverse hydrogeological, geological and topographic features are present.

6.3 The sizes of soil-nail heads on gentle slopes may alternatively be designed using the lower bound plastic mechanism method recommended by the UK Department of Transport (DOT, 1994) as shown in Figure 5.4 of Geoguide 7. This method gives more conservative results than the numerical study by Kong et al. (2020).

Slope Surface Protection

6.4 Attention should be given to prevent concentrated surface runoff and promote vegetation cover to prevent surface erosion of the ground between soil-nail heads. It is also important to prevent erosion by maintaining the existing vegetation as recommended in GEO Publication No. 1/2011 (GEO, 2011). Planting of additional vegetation, such as pit planting of shrubs and provision of bioengineering measures such as planting of live stakes, should be considered as appropriate to enhance the robustness against potential shallow failure and soil erosion between soil-nail heads and to promote sustainability to the environment. For areas that are susceptible to concentrated surface runoff and erosion, designers may consider adopting the combined use of erosion control mats fixed with stainless steel pins in addition to planting and bioengineering measures.

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