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)
Supplementary Guidelines on Soil-nail Head Designs

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1. SCOPE

1.1 This Technical Guidance Note (TGN) supplements the relevant guidance given in Geoguide 7 on the design of soil-nail heads. This also serves as an update to GEO Publication No. 1/2009 on the recommended sizes of soil-nail heads for prescriptive soil nails used in Hong Kong.

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 7 March 2025.

3. RELATED DOCUMENTS

3.1 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.

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

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

3.4 GEO (2023). *Guide to Soil Nail Design and Construction (Geoguide 7)*. (Continuously Updated E-Version released on 21 November 2023). Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 90 p.

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

3.6 Kong, V.S.F, Koo, R.C.H. & Chang, D.S. (2022). *Design of Nail Head for Use of Soil Nails in Mitigation of Open Hillslope Landslides (GEO Report No. 360)*. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong, 26 p.

3.7 Shiu, Y.K. & Chang, G.W.K. (2005). *Soil Nail Head Review (GEO Report No. 175)*. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong. 106 p.

4. BACKGROUND

4.1 Under the limit equilibrium condition, the potential unstable soil mass (i.e. the 'active zone') of a soil-nailed slope 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 nails, a bearing pressure of the soil underneath the soil-nail heads may be mobilised. Conventionally, soil-nail heads are designed to provide an adequate safety margin on bearing capacity against shear failure of the ground underneath the soil-nail heads, assuming that the structural capacity of the soil-nail heads is adequate.

4.2 Geoguide 7 (GEO, 2023) presents recommendations on the sizing of soil-nail heads for the design of soil nails on slopes steeper than 45° based on the findings of numerical analyses conducted using the computer program FLAC as reported in GEO Report No. 175 (Shiu & Chang, 2005).

4.3 Natural hillsides, especially those susceptible to open hillslope landslides (OHL), are typically gentler than man-made cut slopes. The design guidelines given in GEO Report No. 138 (Ho & Roberts, 2016) for mitigating OHL hazards include the option of using soil nails to increase the margin of safety against slope instability for the top 2 m of the hillslopes. In these situations, the soil-nail forces and the required bearing capacity of the soil-nail heads are usually much smaller than those required for upgrading steep man-made slopes. The same is true for man-made cut slopes with gradients lower than 45°. The use of soil-nail head sizes presented in Table 5.7 of Geoguide 7 can thus lead to very sizeable soil-nail heads on gentle slopes, and this may cause unnecessary environmental impact and hamper the buildability and efficiency of using soil nails in these situations. To this end, numerical analyses were carried out using the computer program FLAC to assess the required bearing capacity of soil-nail heads on gentle slopes with gradients of 30°, 35° and 40° and for a range of shear strength parameters of soils. The findings are documented in GEO Report No. 360 (Kong et al., 2022).

4.4 To supplement the design guidelines developed based on the numerical analyses mentioned in paragraphs 4.2 and 4.3, the actual performance of soil-nailed slopes with 400 mm wide soil-nail heads constructed in the 1990s and early 2000s has been systematically reviewed. These slopes were upgraded before the promulgation of the current design guidelines given in Table 5.7 of Geoguide 7.

4.5 This TGN stipulates technical recommendations on the sizing of soil-nail heads on gentle slopes with gradients lower than 45°, and promulgates an alternative prescriptive approach for specifying 400 mm wide soil-nail heads on typical slopes subject to certain conditions. Recommendations on enhanced surface protection measures against shallow landslides and surface erosion are also given.

5. TECHNICAL RECOMMENDATIONS ON SIZING OF SOIL-NAIL HEADS

Prescriptive Approach based on Assessment of Actual Performance

5.1 A prescriptive approach has been developed based on an assessment of the actual performance of constructed 400 mm wide soil-nail heads. Based on the results of the assessment, 400 mm wide soil-nail heads are considered adequate and can be prescribed for typical slopes in Hong Kong. This approach can be used for both upgrading and emergency repair works provided that the following unusual or unfavourable conditions are not encountered:

(i) Slope-abutting structures (e.g. building foundations) that may exert a dead load greater than or equal to 20 kPa on the soil mass in the active zone;

(ii) Soil nails carrying sustained loads; and

(iii) Slopes or sites with special concern or serviceability requirements such that a deformation analysis is required according to Geoguide 7.

If any one of conditions (i) to (iii) above are identified, designers should assess whether the prescriptive approach can be safely adopted on a case-by-case basis. Otherwise, the analytical approach with consideration of bearing capacity should be used.

5.2 In connection to the recommendation given in paragraph 5.1, when prescriptive soil nails are proposed to upgrade soil cut slopes according to GEO Publication No. 1/2009 (GEO, 2009), 400 mm wide soil-nail heads, in lieu of the head sizes given in Table 5.5 in GEO (2009), can be prescribed provided that the conditions in paragraph 5.1 are not encountered. For soil cut slopes steeper than 65°, embedded reinforced concrete tie beams, instead of isolated soil-nail heads, should be specified according to GEO (2009) but the width of the prescriptive tie beams can be reduced from 600 mm to 400 mm if the conditions are not encountered. Details of the tie beams are shown in the CEDD Standard Drawing No. C2525.

Analytical Approach based on Consideration of Bearing Capacity

5.3 The analytical approach based on consideration of bearing capacity should be adopted if the prescriptive approach is not applicable. In general, 400 mm to 600 mm soil-nail heads should be adequate to provide the stabilisation forces required for the soil nails to enhance the stability of relatively gentle slopes. Designers should specify soil-nail heads with sufficient bearing capacity to counteract the required stabilisation force of the soil nails according to the bearing capacity values shown in Tables A1 to A3 in Annex TGN 51 A. Designers should apply a minimum factor of safety of 1.2 to the selected values. A larger soil-nail head might be warranted in particular situations in respect of adverse hydrogeological and geological conditions.

5.4 The bearing capacity values of soil-nail heads as shown in Tables A1 to A3 in Annex TGN 51 A are based on typical conditions of slopes with gradients lower than 45°. The recommendations of Geoguide 7 should be followed for slopes steeper than 45°. These recommendations are conservative as the pull-out resistance in the active zone was not

considered in the numerical analyses conducted by Shiu & Chang (2005) and Kong et al. (2022).

5.5 Designers should give due consideration to ensure effective interaction between the soil-nail heads and the supporting ground mass in gentle slopes. It was demonstrated by Kong et al. (2022) that the bearing capacity of a 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 B1, B2 and B3 in Annex TGN 51 B to maximise their efficiency. To ensure the integrity of the soil-nail heads, the fixing details of hessian bags for recessed nail heads as shown in CEDD Standard Drawing No. C2106/7 should be adopted. Designers may adopt alternative details to suit specific site conditions and applications. Alternatively, for the ease of construction, the typical details of recessed soil-nail heads presented in the CEDD standard drawing are also generally acceptable for gentle slopes to promote soft landscaping. In this case, the ultimate bearing capacity presented in brackets in Tables A1, A2 and A3 in Annex TGN 51 A should be adopted.

Verification of Design Assumptions

5.6 Regardless of the method adopted for the soil-nail head design, it is particularly important for designers and site supervision personnel to verify the design assumptions, evaluate the suitability and adequacy of the adopted design approach and examine the actual site condition during the construction stage. If there exist any loose or soft materials near the slope surface that would significantly affect the functioning of soil-nail heads, the size of the soil-nail heads should be reviewed and, when considered appropriate, enlarged to cater for the presence of any weak materials.

Enhanced Measures for Slope Surface Protection

5.7 As a good practice, designers should avoid specifying a small group of soil nails to resist disproportionately large landslide slips as far as practicable, since it would result in exceptionally high soil-nail forces. The unsupported soil portion will still be susceptible to local failure. Suitable arrangement of the soil-nail layout, proper detailing of surface drainage provision and appropriate surface protection or erosion control measures are crucial to the overall performance of slopes.

5.8 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.

6. ANNEXES

6.1 TGN 51 A – Ultimate Bearing Capacity Values of Soil-nail Heads

6.2 TGN 51 B – Enhanced Details for Soil-nail Heads on Gentle Slopes

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Annex TGN 51 A – Ultimate Bearing Capacity Values of Soil-nail Heads

Table A1 – Ultimate Bearing Capacity of a 600 mm Soil-nail Head on Gentle Slopes (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 parameters: c' is in kPa and ϕ' is in degrees.
2. The ultimate bearing capacity of a soil-nail head with its back parallel to slope surface is given in brackets (See Section 5.5 of this TGN and CEDD Standard Drawing No. C2106/7).

Table A2 – Ultimate Bearing Capacity of a 500 mm Soil-nail Head on Gentle Slopes (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 parameters: c' is in kPa and ϕ' is in degrees.
2. The ultimate bearing capacity of a soil-nail head with its back parallel to slope surface is given in brackets (See Section 5.5 of this TGN and CEDD Standard Drawing No. C2106/7).

Table A3 – Ultimate Bearing Capacity of a 400 mm Soil-nail Head on Gentle Slopes (kN)

$30° \leq$ 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)

$30° \leq$ 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)

$35° \leq$ 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)

$35° \leq$ 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)

$40° \leq$ 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)

$40° \leq$ 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 parameters: c' is in kPa and ϕ' is in degrees.
2. The ultimate bearing capacity of a soil-nail head with its back parallel to slope surface is given in brackets (See Section 5.5 of this TGN and CEDD Standard Drawing No. C2106/7).

Annex TGN 51 B – Enhanced Details for Soil-nail Heads on Gentle Slopes

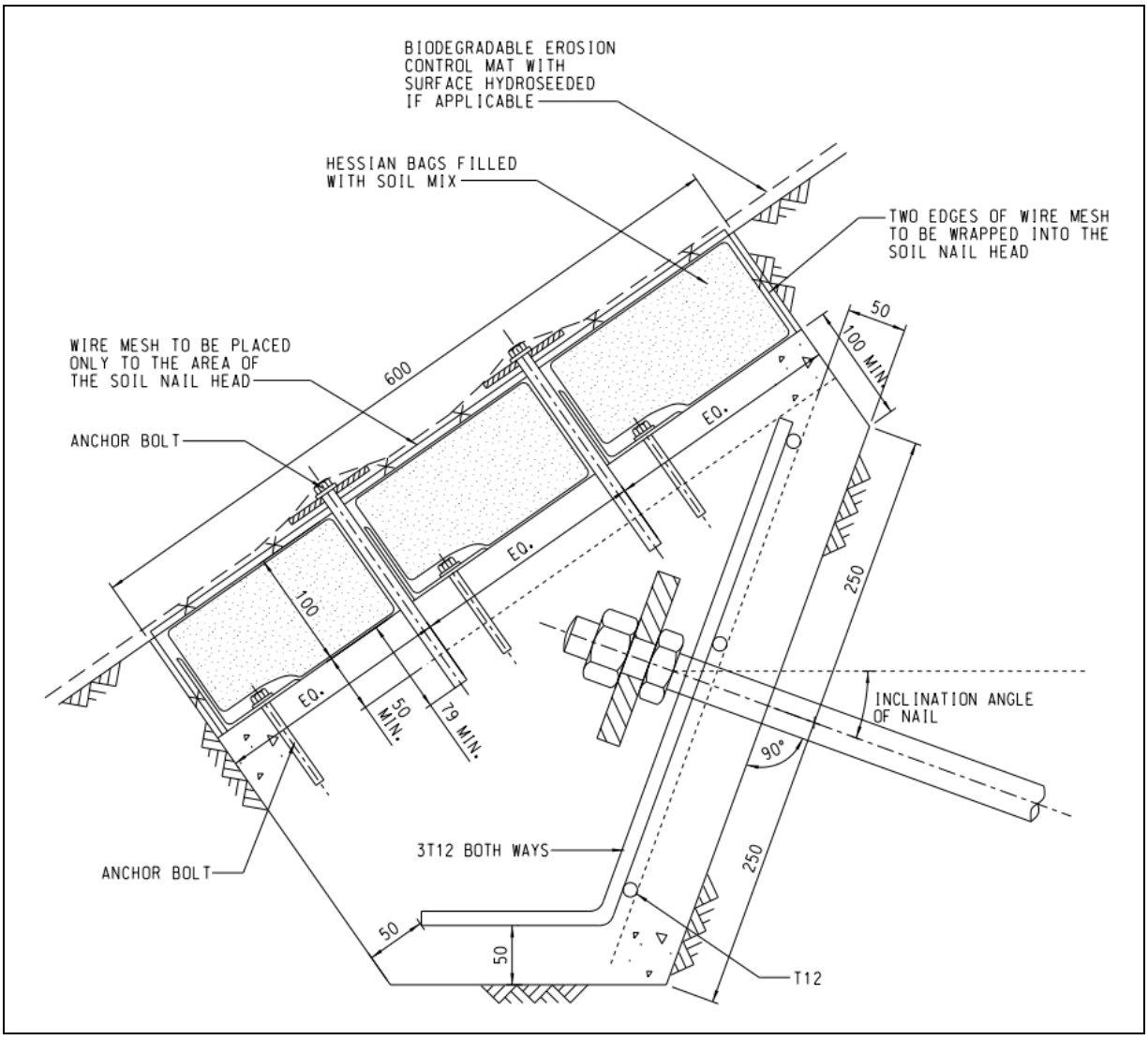

Figure B1 – Enhanced Details for a 600 mm Soil-nail Head on Gentle Slopes (Back of Nail Head Perpendicular to the Nail Alignment)

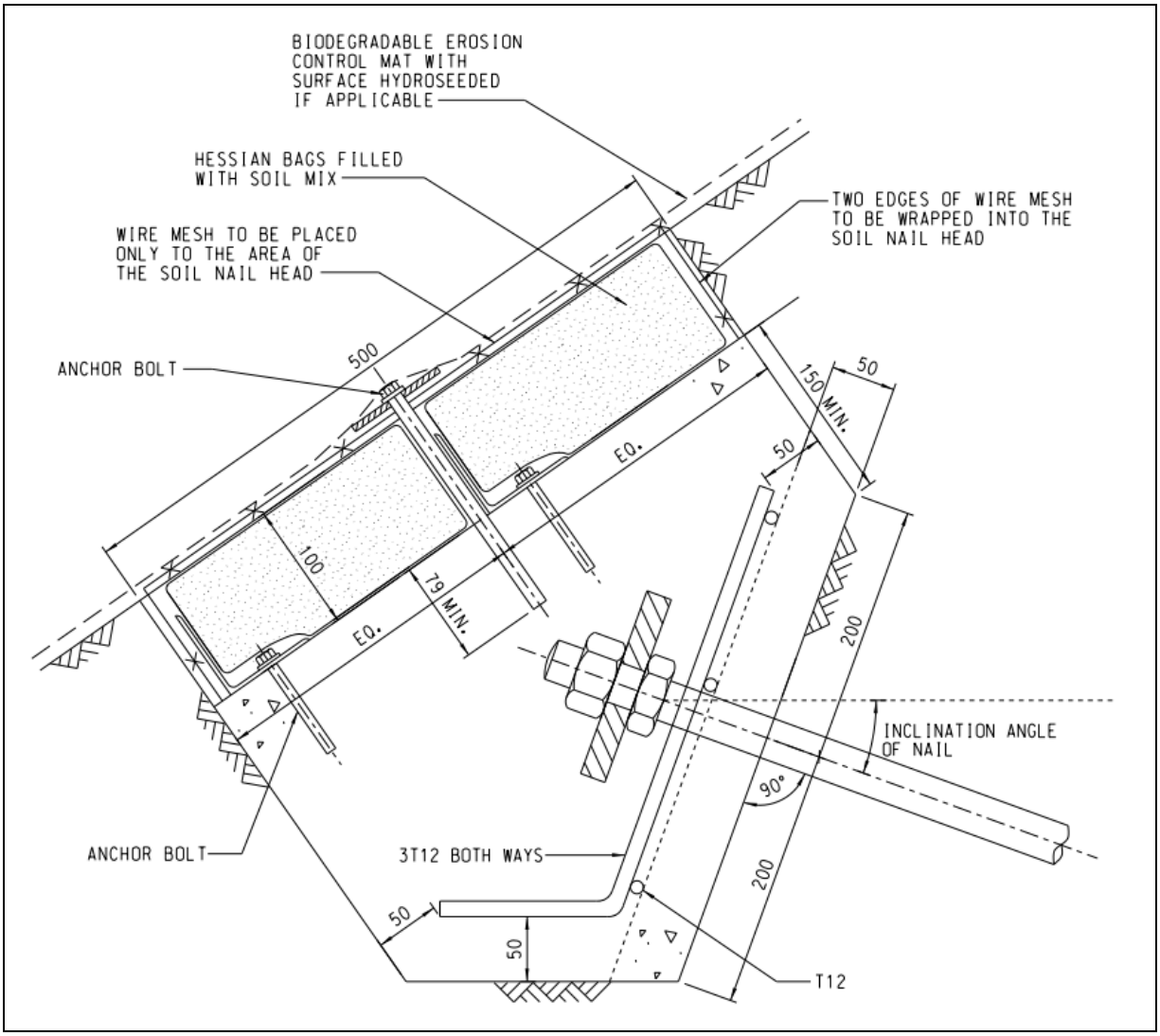

Figure B2 – Enhanced Details for a 500 mm Soil-nail Head on Gentle Slopes (Back of Nail Head Perpendicular to the Nail Alignment)

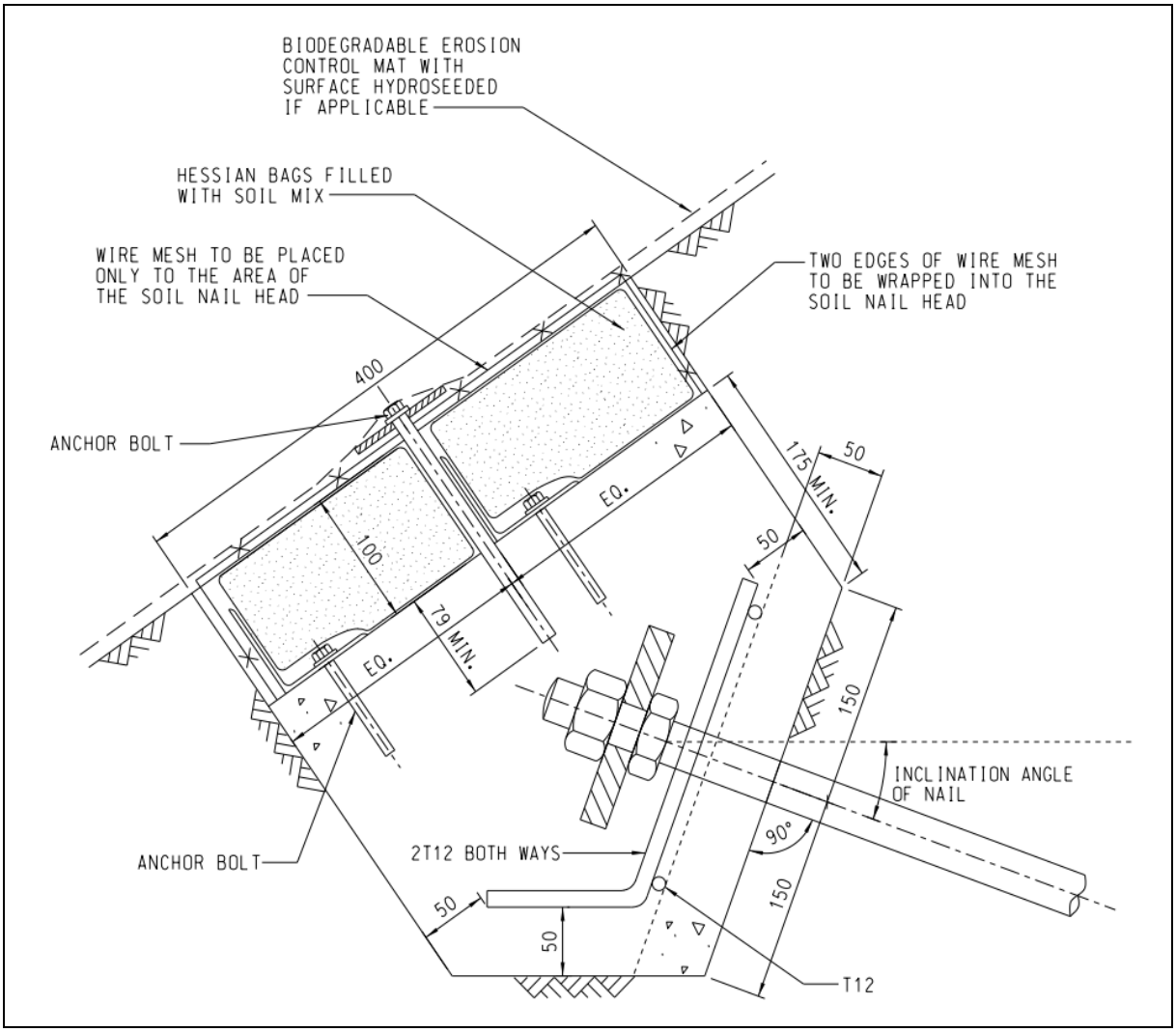

Figure B3 – Enhanced Details for a 400 mm Soil-nail Head on Gentle Slopes (Back of Nail Head Perpendicular to the Nail Alignment)