

1. GENERAL

1.1 Scope of works

This works specification for soil nailing works shall cover all the necessary resources and materials for the supply, installation, testing and completion of soil nails in accordance to this Specification and the details shown in the design/contract Drawings. The Contractor shall also comply with all the requirements of local authorities and Regulations and all amendments thereto.

All materials used shall be of the best quality of the types specified and subject to the approval of the SO/Engineer in writing.

Any unsatisfactory works or material shall be removed and replaced at the expense of the Contractor.

1.2 Contractual obligations

The Contractor performing the soil nailing works described in this Specification shall have comparable experience of soil nailing for a minimum of one year. The Contractor's on-site supervisors shall have a minimum of one-year comparable experience in installing soil nails with any other Contractor's organization.

Notwithstanding the information given in the drawings, the Contractor shall carry out the works with due care, diligence and skill to avoid damages and disturbance/nuisance to any services and nearby buildings/structures. The Contractor shall provide adequate temporary protection of both temporary and permanent slopes against heavy rainfall during soil nail installation. Safety and stability of all temporary works include staging, temporary slopes and access, etc., shall be checked and endorsed by qualified P Eng when requested by the SO/Engineer with necessary justifications and calculations.

The Contractor shall install the trial or preliminary soil nails and carry out the verification pull-out test (Clause 8) at locations selected by the SO/Engineer before commencement of installation of working soil nails.

Full-time supervision by qualified Engineer or technician shall be accorded by the Contractor to all soil nailing works especially all the inspection checks and quality control tests.

1.3 Method statement

The Contractor shall inspect the site, study the soil investigation results and design drawings together with this Specification before preparation and submission of the **method statement** to the SO/Engineer for prior written approval (at least 7 working days) before the commencement of works. The method statement shall include:

- A complete list of **specific Machine/equipment/tools** (type/model/make/capacity), **Materials** /products (catalogues/quality test certs) and **Manpower** (names of supervisor, operators with CV) required to carry out the scope of works specified within the approved work program.

- Works details & sequence of works (in diagrammatic illustrations with descriptions for each sub-activity of soil nailing work) including site slope surface preparation & setting up, layout of drilling rig, drilling method & temporary support of collapsible drill holes, preparation of working platform/staging, placement of rebars & joints/couplers (if relevant), grouting procedure, nail head preparation and pull-out tests layout, etc.
- Estimated work output rate for soil nailing and each of the sub-activity for the numbers of machine and manpower proposed so as to show the works can be completed well within the approved work program.
- Program/tabulation for QC tests & workmanship including methods/types & frequency of QC tests/measurements and the acceptance criteria for each sub-activity of soil nailing including slope surface preparation/cleansing, soil nail position & geometry (size, length, straightness & hole cleanliness), placement of rebars (protection & tensile strength of rebar & joint, strength & conditions of centralizers after inserting), grouting (quality of grout mix: strength, bleed & viscosity), nail head preparation & pull-out test. (Notes: Method statement for sub-activity grouting & pull-out testing may be prepared separately).
- Appendix shall include work program for soil nailing, product catalogues, photos and test certificates, catalogues & photos for drilling machine and accessories, drawings/sketches illustrating sequence of works, etc.

The proposals in the method statement shall meet the requirements shown on the SO/Engineer's drawings and this Specification hereafter.

The SO/Engineer may interview the site supervisor and key personnel to ensure they are really capable to prepare the method statement and prepare the soil nail installation records as required in Clause 2.5.

2. GENERAL REQUIREMENTS

2.1 Setting out

Setting out shall be as shown in the Drawing or as directed by the SO/Engineer. Immediately before drilling or installation of soil nail, the nail head position shall be marked with suitable identifiable pegs or markers on the slope/wall for necessary inspection and checking by the SO/Engineer. The positions of soil nails including preliminary/sacrificial and working soil nails shall be checked to ensure any buried utilities, surface boulders, trees and other structures, etc., are not affected. Engineer's approval is necessary if the positions of soil nails have to be shifted.

2.2 Position

The maximum allowable deviation for drill hole entry point shall not exceed 75mm in any direction.

2.3 Alignment of nail

The drilling machine shall be attached with suitable alignment control device set to attain the finished nail direction or inclination shown on the Drawing and the maximum permitted deviation of alignment shall not exceed 1 in 20. Deviation from straight shall not exceed 20 mm in any 3 m length of drill hole. The alignment of soil nails for the preliminary nails or the first 3 nails for every

working day shall be checked, recorded and submit to the SO/Engineer for approval (refer Clause 4.3).

2.4 Nail out of position or alignment

The contractor shall demonstrate to the Engineer that the position and alignment of soil nails is within the tolerance limits specified. Any nail found out of the tolerable position or alignment shall be rejected and the Engineer shall order to add additional nails at the Contractor's own costs.

2.5 Submittals

The Contractor shall engage a qualified supervisor/manager and technicians who shall be capable to prepare and to submit the necessary documents and to keep/prepare the records for each soil nail installation detailed hereafter and to submit one signed copy to the SO/Engineer not later than noon of the next working day after the soil nails have been installed. The submittals and records for each soil nail including drilling, rebar inserting, grouting, pull-out testing and nail head preparation, etc., shall have details as listed as follows:

a) Submittals before commencement of works:

- **Method statement** including catalogues & photos/samples for machine, materials/products & Cv of key personnel (Clause 1.3)
- **Test certificates** and samples for the materials to be used (Clause 3).
- **Format of forms** for drilling, grouting & pull-out tests, etc.
- **Any other details and information requested by the SO/Engineer.**

b) Submittals during construction period:

Drilling records for each nail shall include:

- Soil nail reference number & design capacity. Layout plan showing the positions reference numbers of soil nails with date of completion, etc., shall be prepared by the Contractor.
- Date & duration time of drilling (Time of start & completion of drilling; time of interruptions, if any time starts & ends).
- Type & model of drilling machine.
- Soil nail details: size, length, rebar size, rebar protection method, design capacity.
- Type & size of drill rods & drilling shoe.
- Description of drilling penetration rate.
- **Description of strata of materials penetrated** such as colour, type, size, wetness/dryness, any special observations/irregularities such as underground voids encountered, collapse of hole, groundwater encountered, approximate depth to groundwater, depth of zone of no air/debris returns, obstructions, change of wetness of cuttings, etc. Photos showing the drilling rig, tools & drilling debris, etc., shall be included.
- **Inform the SO/Engineer immediately** for the observed the exceptions & peculiarities/irregularities such as drill hole collapse, wet soil/WT, seepage, no air/debris returns, etc. Photos and videos for such problems shall be captured.
- Results of checking on straightness, cleaning & alignment as specified.
- Record for each completed soil nail & QC test results (alignment checks and position checks for drilling) **shall be submitted not later than noon of the next working day after the soil nails have been installed.**

- Summary in tabulation for each soil nail including Nail Reference/No, Nail size & drilled length, Date completed, Duration of drilling, Duration for grouting, Volume of grout used, Remarks (any irregularities observed in drilling, inserting rebar & grouting, Accepted/rejected, etc.) **shall be submitted weekly.**

Inserting of Rebar Records

- Conditions of centralizers & coupler in pull-out checks for the initial first 5 and any subsequent 3 locations/day selected by the SO/Engineer (photos and description as per Clause 5 requirements). Records for the QC checks (soil nail reference/No, description of centralizer conditions with photos, accepted/rejected decision of SO/Engineer, Clause 5) for pull-out checks on centralizers **shall be submitted daily.**

Grouting records for each nail shall include:

- Type & model/capacity of colloidal mixer & paddle mixer.
- Type & model/capacity of pump
- Grout mix design details (W/C ratio, type & dosage of admixture, etc.)
- QC test results of bleeding, flow cone efflux time and strength tests.
- Time of start & completion of grouting.
- Type of nail protection.
- Volume of grout consumed & volume of top-up after grout settlement.
- Observed exceptions (loss of grout details, machine breakdown, etc.)
- Record grouting for each completed soil nail as detailed above & QC test results (cube tests, bleeding test & flow test, Clause 3.2) **shall be submitted daily.**

Pull-out Tests

- Report for each pull-out test as detailed in Clause 8 shall be submitted within 1 week after completion of each test.

c) Post- construction submittals

Project completion report shall be submitted within 2 weeks after all the soil nails are completed. The project completion report shall include the following details:

- **Table of contents** (Introduction, Site & subsoil conditions, Soil nail installation records for Drilling, Placement of rebar, Grouting & Nail head preparation, Pull-out Tests, Conclusions & Appendix).
- **Introduction** (Brief description of the project and access condition, scope works involved & project costs, design consultant, RE/supervisors, name of Contractor & key personnel & CV/brief experience, etc.)
- **Site & subsoil Conditions** (Brief site conditions, any nearby buildings/structures/utilities, access conditions, site plan, brief summary of subsoil conditions & critical information affecting soil nail installation such as collapsible strata, groundwater conditions/artesian pressure/seepage, etc.)
- **Soil nail installation** (General problems encountered during drilling, placement of rebar, grouting & nail head preparation. Summary of soil nail installation records in tabulation of soil nail details such as Soil nail reference No/size & length & rebar & capacity), date of installation & time, strata description & drill rate, dry/moist/wet hole, exceptions/irregularities, date & time of grouting, volume of grout consumed. Summary of

- QC tests including records of grout test results (bleeding, viscosity & cube strength), results of pull-out checks on centralizers, etc.)
- **Pull-out tests** (Details/description of pull-out tests including loading sequence, layout of test, figures/graphs showing load-displacement for each pull-out test, summary of all pull-out test results in tabulation; photos & installation records for each pullout test shall be included in Appendix G).
 - **Appendix A:** Site plan & Design/construction drawings & finalized BQ
 - **Appendix B:** Approved Method Statement
 - **Appendix C:** Works programme (planned & actual)
 - **Appendix D:** As-built Drawings, Drilling & Grouting records for each nail (may be prepared as separate volume).
 - **Appendix E:** QC tests results for drilling, pull-out checks, grouting, nail head preparation, etc.
 - **Appendix F:** Catalogues & factory test certificates with photos for rebar, centralizers, coupler HDPE sheath samples, etc.
 - **Appendix G:** Pull-out test reports, including drilling & grouting records, photos & Drg/diagram showing test layout, calibration records & certificates, etc.
 - **Appendix H:** Photos showing drilling layout, close views of drill rod, drill bits/head, drilling equipment, compressor, etc.
 - **Appendix I:** Photos showing grouting layout, colloidal mixer, paddle mixer, pump, etc.
 - **Appendix J:** Photos showing how the rebar is fixed with centralizers before and after pull-out checks, etc.
 - **Appendix K:** Important corresponding letters or documents related to design changes/approvals, non-compliance order, etc.

The Contractor shall prepare and submit a draft copy of the specified Project Completion Report to the SO/Engineer for approval and acceptance before sending 5 copies of the final report with soft copy in pendrive to the SO/Engineer for record purpose. All important documents such as as-built drawings, approved method statement, approved works programme, all QC test results, etc., shall be checked and endorsed by the supervising Resident Engineer.

3. MATERIALS

3.1 Reinforcement

Unless otherwise shown on Drawings, reinforcement bars (rebars) for soil nails shall be high yield deformed steel reinforcing bars (yield stress $f_y=460$ MPa) complying with M.S. 146, threaded and fully hot-dip galvanized to BS EN ISO1461:1999 with minimum coat thickness of 85 microns or 610 gm per meter square surface. For aggressive slopes/soils or as shown on Drawings, the reinforcement bars shall be also pregrouted and additionally protected by HDPE corrugated sheath with necessary centralizers. The nail bars or rebars shall be threaded at the ends for a sufficient length (minimum 150 mm long) to facilitate fixing of galvanized washer, overlap locking washers, MS bearing plates (Grade 43A to BS4360:1986) and nuts shall be Grade 4 steel complying with BS 4190: 2001 at the exposed end and fixing of galvanized coupler at the other end, if required. All steel components for soil nails including rebar, MS bearing plate, wedge/and taper washers, hexagonal nuts, couplers, etc., shall be also hot-dip galvanized to BS EN ISO 1461:1999 with minimum coat thickness of 85um or 610gm per square metre. The holes in MS bearing plate shall be drilled perpendicular to the face of MS plate and the centre of the hole shall be at a position of

within 2mm from the centroid of the MS plate. The clearance between the galvanized rebar and the hole of MS plate shall not exceed 2mm. The tightened nut shall be tested to ensure it can take a tension load of at least 1.5 times the design working load of the soil nail or minimum 150 kN without failure.

Only soil nails of more than 12m long shall have rebars spliced or coupled. The tensile strength of the bar coupler shall be capable to develop at least 95% of the tensile strength of the rebar as tested and certified by the manufacturer. **Test certificates from reputable laboratory such as SIRIM, IKRAM or Universities or accredited laboratory approved by the SO/Engineer to show compliance with the specification shall be submitted to the SO/Engineer for verification and approval before commencement of works.**

In case of doubt, the installed steel nail length shall be checked and determined by coring with casing slightly bigger than the design nail size or by non-destructive tests (magnetometry, etc.) as recommended by GEO Hong Kong (GEO Report No.133, May 2003).

3.2 Cement Grout (non-shrink cement grout)

Cement for grouting shall be Ordinary Portland cement complying with MS 522 or BS 12.

Non-shrink cement grout shall consist of cement and water plus approved grout admixtures and fluidifier specified by ASTM C937. Water cement ratio shall be **0.40 to 0.45** and unless otherwise stated in the design drawing, minimum cube strength of 7-day strength and 28-day strength shall be 20 MPa and 30 MPa respectively (BS 1881). Water shall be from approved public water supply and shall comply with the quality specified in MS28. Suitable admixtures shall be used to improve flowability and to control bleeding or shrinkage problems. Admixtures shall comply with the requirements of BS 5075: Part 1 and Part 3 and shall only be used with the prior approval of the Engineer. Grout shall be thoroughly mixed by suitable high-speed colloidal mixer (with rotor speed of at least 1000 rpm) until a homogeneous grout free from undispersed cement, free from lumps and free from bleeding is obtained. The grout after mixing for a few minutes shall be transferred through a 5mm sieve to remove lumps into a storage holding tank attached with paddle agitator to provide continuous agitation of the grout at 100 rpm to prevent sedimentation. **Grout shall be rejected if not used within 30 minutes after mixing.**

Unless otherwise specified on design Drawings, the following important quality control tests shall be carried out **at least once daily per grouting mixer** or once for every **40 cubic meters** of grout used, whichever is more:

- **Crushing strength** of 100 mm cubes at 7-days and 28-days (BS1881) shall be minimum 20 and 30 MPa respectively for 3 cubes each.
- **Bleeding test** (<0.5 % by volume 3 hours after mixing or 1 % (maximum) when measured at $23\pm 1.7^{\circ}$ C in a covered glass cylinder of 100 mm internal diameter and with a grout depth of 100mm. In addition, the water shall be re-absorbed by the grout within 24 hours. Free expansion shall not exceed 10 %, ASTM C940).
- **The flow cone efflux time of grout** shall be less than 15 seconds (ASTM C939) or approved equivalent.

If any of the above results falls below the acceptable limits, the Contractor shall re-propose detail of mix design and also propose necessary remedial measures for the SO/Engineer approval to those soil nails that have used the defective grout, if any, at the Contractor own cost.

The Contractor shall carry out flow cone and bleeding tests before grouting to ensure the grout mix and admixture can comply with the specified requirements.

3.3 Centralizers

Soil nails shall have non-corrodible centralizers capable of ensuring an even annulus of grout around the steel bar. The nominal diameter of the centralizers shall not differ from the specified diameter of the drill-hole by more than 10 mm. Wires and ties for fixing and anchoring packers, centralizers and grout pipes, etc., shall be made of non-corrodible materials. The spacing of the centralizers and the suitability of the method of fixing the centralizers, grout pipes and corrugated sheathing where required shall be determined by carrying out trials on site for at least the first 3 soil nail locations by inserting at least 95% of the length and then pull-out checks to examine any visible damage/deformation/displacement of the centralizers. Once approval is given, no change to the type, method and arrangement of fixing of the centralizers, grout pipe and corrugated sheathing (if relevant) shall be made without the prior approval of the SO/Engineer.

Centralizers from approved factory manufactured shall be tightly fixed to the rebar at the spacing as shown on the Drawing. The centralizers shall be firm and as small as possible (not more than 50 % of the nail section) so that the blockage of grout flow is minimum.

Centralizers shall be fixed inside and outside of the protective sheath, if applicable, and shall be spaced at not more than 2m. Centralizers shall be sized to position the rebar within 25mm of the centre of the drill holes; sized to allow tremie pipe (about 30mm diameter) insertion to the bottom of the drill hole. The centralizers shall be produced by reputable manufacturer or specialist using welded on galvanized steel strips or PP (polypropylene) or PVC (polyvinyl chloride) and comply with following properties:

- Tensile strength (BS 2782: Part 3, method 320C) > 30 MPa
- Hardness (BS 2782: Part 3, method 365B) >65
- Brittleness temperature (ASTM D746-79) < 5 degree C
- Environmental Stress Cracking Resistance (ASTM D1693-70): 200 hrs (no cracking).

Test certificates of centralizers from reputable laboratory such as SIRIM, IKRAM, Universities or accredited laboratory approved by the SO/Engineer to show compliance with the above requirements shall be submitted to the SO/Engineer for verification and approval.

Suitability of the method of assembly and fixing of the centralizers, grout pipes, etc., shall be determined by carrying out trials at site until no damages and no distortion of centralizers and grout pipes are observed during inserting and withdrawing the soil nails. In addition, pull-out checks as specified in Clause 5 shall also be carried out during the installation of working soil nails.

3.4 Corrugated HDPE Sheath

The size, shape and length of the sheath for double protection of the rebar, if required and specified, shall be as shown on the Drawing or as directed by the Engineer. The sheath shall consist of HDPE (high density polyethylene) tube with wall thickness not less than 1.0 mm and shall be at least 10 mm of grout cover over the nail rebar within the sheath. The thickness of grout between the HDPE sheath and the sides of drill hole shall be not less than 20 mm. Corrugated sheathing shall be embedded at least 50 mm into the nail head. Other important properties that shall be complied are as follows:

- Tensile strength (BS 2782: part 3, method 320C) > 29 MPa
- Softening point (BS 2781: Part 3, method 120A) >110 degree C
- Environmental Stress Cracking Resistance (ASTM D1693-70): 200 hrs (no cracking).
- Hydrostatic pressure Resistance (BS 6437): no localized swelling, leaking or weeping.

The Contractor shall submit test certificates from reputable laboratory such as SIRIM, IKRAM, Universities or accredited laboratory approved by the SO/Engineer to show compliance with the specification to the SO/Engineer for verification and approval.

3.5 Materials Handling and Storage

Cement shall be stored properly to prevent moisture degradation and partial hydration. Cement that has been caked and lumpy shall be rejected and discard. Rebars shall be stored on firm supports to prevent the steel from contacting the ground. Damage to the rebar as a result of abrasion, cuts, nicks, welds and weld splatter shall be cause for rejection. Rebars shall be protected from dirt, rust and other deleterious substances prior to installation. Heavy corrosion or pitting of rebars shall be cause for rejection. Anchorage end of rebars to which bearing plate and nuts will be attached shall be protected by some protective wrap during handling, installation, grouting and guniting.

Pregouted rebars in HDPE sheaths shall not be moved or transported until the grout has reached sufficient strength to resist damage during handling. The pregouted rebars shall be handled with care and with sufficient supports to prevent large deflections, distortions or damage. Conditions of the pregouted rebars shall be checked first before inserting into the drill holes. Damaged pregouted rebars shall be rejected.

4. DRILLING

- 4.1 Drilling shall be carried out in accordance to Section 10.2, BS8081 (1989) with suitable drill bits. Unless otherwise approved in writing by the SO/Engineer, the Contractor shall deploy suitable duplex or Odex dry pneumatic rotary percussion drilling machine and tools plus skilled operator and qualified supervisor that have adequate capacity and experience to produce the drill hole through all soils/rocks/hard obstructions according to the size, length and accuracy as shown in the Drawings and within 2 hours as specified in this specification.
- 4.2 Suitable drill bit of not less than 100 mm diameter or as shown in the drawings or as directed by SO/Engineer shall be used. In ground likely to collapse, suitable drilling methods using duplex or Odex system or temporary casing or approved equivalent shall be used. Drill holes shall be flushed clean on completion of drilling and the opening protected or sealed to prevent the entry of water or

- any foreign matter. A drilling record for each soil nail shall be carried out by approved qualified technician as specified in Clause 2.5.
- 4.3 Unless otherwise approved by the SO/Engineer, drilling for the whole design nail length shall be carried out uninterrupted and completed with necessary hole cleansing within two hours. To ensure reliable and effective cleansing of the drill holes, an additional drilled length of about 0.6 m to the design length shall be provided so that cleansing of cuttings and debris towards the bottom of the drill holes by the compressed air through the drill rods can be effectively and eventually carried out. A high intensity light shall be used to inspect the drill hole for cleanliness just before the insertion of rebar and grouting. All drill rods shall be at least N size and can be properly jointed without leakage. Inclination of drill rod shall be checked by geological compasses. Alignment of drill hole shall not deviate more than 20 mm in 3 m in any direction or the permitted deviation of drill holes shall be $\pm 2^0$ to the specified vertical and horizontal alignments. The diameter of drill holes shall be the minimum diameter as specified. The grout cover to the lower end of steel bar shall be at least 50 mm.
- 4.4 At least 1 % of the drilled holes or minimum 3 holes per day **shall be selected for straightness test by inserting 100mm diameter tube (OD) or designed diameter** to the designed length. Drilled holes that cannot pass the test shall be redrilled and the suitability of the drilling machine be reassessed.
- 4.5 Temporary support shall be provided to drill holes to prevent the collapse of drill holes until after the completion of grouting, including but not limited to the use of temporary casing. Drill holes shall be cleared of all debris and standing water immediately before installation of soil nails. All necessary equipment and assistance shall be provided to the SO/Engineer to check the inclination, diameter, bearing, cleanliness and length of all drill holes.
- 4.6 Where required in the Contract or ordered by the SO/Engineer, permanent steel casing of appropriate internal diameter and of 6.3 mm minimum thick shall be installed and left in place with soil nails. Unless otherwise specified by the SO/Engineer, the bottom 2 m length of drill hole shall be left unsupported by permanent casing.
- 4.7 No drilling shall be carried out within 10 m radius of any freshly grouted soil nails, including soil nails for pull-out tests, grouted less than 12 hours previously.
- 4.8 Adequate temporary or permanent site drainage or temporary tarpaulin shall be provided to prevent infiltration from surface run-off into the slope where soil nailing is carried out and permanent slope protection has not been completed.
- 4.9 The set-up of drilling plant and ancillary equipment shall be in such a manner that water, dust, fumes and noise generated during of drilling operation shall be sufficiently diverted, controlled, suppressed and muffled. In order to ensure no nuisances to the environment and nearby buildings, the Contractor shall provide appropriate and effective measures approved by the SO/Engineer to minimize the spread of dust, fumes, debris, etc., during drilling. The SO/Engineer shall order to stop works immediately if effective mitigations are not taken by the Contractor.
- 4.10 Drilling for each soil nail shall be recorded as specified in Clause 2.5. Any soil nail installed without proper records as specified in Clause 2.5 shall be rejected.

5. INSERTING REINFORCEMENT

- 5.1 The galvanized rebar or sheath protected rebar fixed with centralizers as specified (Clause 3.3) or as shown on the Drawing shall be checked for rigidity before inserting into the drill hole. The rebar shall be carried by experienced workers or cranes with supports at spacing not greater than 3 m without jerking.
- 5.2 After inserting about 80 % of the total design length into the drill hole, the rebar shall be withdrawn to check the conditions of the centralizers and contamination of rebar. **Such pull-out checks shall be carried out on at least at 5 locations per day if the drilled holes are grouted within five (5) hours after drilling and cleaning. For drilled holes that are to be grouted after 5 hours of drilling and cleaning, pull-out checks shall be carried out for all drilled holes.** If collapse of drill hole is suspected, re-drilling and flushing have to be carried out as directed by the SO/Engineer. Damaged centralizers or spacers shall be assessed for the causes and necessary remedial proposal shall be proposed by the Contractor and approved by the SO/Engineer.

6. GROUTING

- 6.1 Soil nails shall be installed and grouted as soon as possible after drilling and cleansing. In any case, each drill hole shall not be left unsupported by temporary casing for more than 24 hours.
- 6.2 Grouting shall be carried out in accordance with Section 10.4, BS8081 (1989). Grout mix shall be prepared and tested according to Clause 3.2. Layout of machine plus the capacity, etc, shall be as shown in method statement and approved by the SO/Engineer in writing before mobilization. Grout shall be pumped or injected from the lowest point of the drill hole into its final position in drill hole through a grouting tube of about 25mm diameter by tremie method under gravity or low pressure (< 5 bars) as soon as possible/immediately after the completion of hole drilling and is not more than 30 minutes after mixing. Unless otherwise approved by the SO/Engineer in writing, grouting shall be carried out **within five (5) hours after drilling and cleansing** of drill hole are completed unless the drilled hole is fully supported by temporary casing or re-drilling and re-flushing are carried out.
- 6.3 Grouting shall be carried out promptly and continuously in one operation without interruption to avoid any disturbance caused by sedimentation within the grout and to reduce air bubble entrapment. Full operation shall continue until injected grout of the same composition and consistency as that mixed emerges from the drill hole outlet for at least one minute, i.e. continuous pumping grout until fresh uncontaminated grout is observed flowing out from the drill hole for at least one minute.

Any excessive grout loss shall be recorded and reported to the SO/Engineer immediately. If a drill-hole cannot be fully filled with grout after injecting a volume of grout equal to 10 times the calculated gross volume of the drill-hole, discounting the volume of all cast-in components, the grouting operation shall immediately cease for that drill-hole unless otherwise agreed by the SO/Engineer. The grouted length of the drill-hole shall be reported to the Engineer and proposals for completing the grouting for that drill-hole shall be submitted to the SO/Engineer for approval as soon as possible.

All grouting works shall be recorded by approved qualified technician as required and specified in Clause 2.5.

7. NAIL HEAD CONSTRUCTION

- 7.1 After inspection by the SO/Engineer, all the disturbed, loose and soft soil around the nail head shall be removed and replaced by non-shrink mortar of grade 30 strength or approved equivalent by the SO/Engineer, before construction of nail head as shown in the design Drawings.
- 7.2 Unless approved otherwise in writing by the SO/Engineer, guniting or concreting of soil heads shall be carried out in 2 stages, allowing the galvanized MS bearing plate with wedge washer to be positioned firmly against the first stage guniting or fresh concreting as specified hereafter.
- 7.3 Nail head with steel plate shall be in a plane normal to the nail axis clamped down with galvanized nut and washers to the clamping down forces of 5kN (min) or as shown in the design Drawings, using a calibrated torque wrench. Clamping shall be carried out with a thin layer (< 25mm) of fresh non shrink mortar (grade 30) behind the steel plate to ensure proper seating. Nail head construction shall only be carried out after the grout and the mortar have reached at least 7-days strength (> 20 MPa).
- 7.4 Soil nailing works shall be stopped if encountered by bad weather conditions e.g. rain, high winds, high waves, etc. The freshly drill holes shall be protected by cloth or news-paper or equivalent to prevent water from entering the drill holes. The work shall only be resumed when conditions are satisfactory and acceptable for the work. Any excessive erosion near the drill holes shall be replaced by the Contractor on the account of the Contractor and no extra claims will be considered. The drill holes shall be re-drilled and re-flushed/re-cleansed before grouting.
- 7.5 Measures to protect the newly constructed nail head against erosion such as cover the nail head with tarpaulin, etc., shall be carried out until the slope is properly protected (by guniting, etc)

The Contractor shall uncover a maximum of 3 selected (by the SO/Engineer) soil nail heads from the batch of soil nail head cast on any one day for examination to ensure compliance of specification. If defective workmanship is found in any one of the 3 selected and examined nail heads, all the nail heads cast in that day shall be excavated and recast to the SO/Engineer's satisfaction.

8. PULL-OUT TESTS

- 8.1 The Contractor shall provide all necessary resources including all torque wrenches, jacks, gauges, reaction frame, pump, load cell, bearing plates, and other equipment required to carry out the pull-out test of the soil nails specified hereafter. **Measurement of nail head movement shall be by at least by 3 dial gauges capable of measuring displacement up to 50mm and up to 0.05 mm accuracy.** Apparatus for measuring loads shall be **capable of measuring a load of about 3 times of the maximum test load (MTL) and shall have an accuracy of 5 kN.**
- 8.2 Extreme care shall be taken to ensure the pull-out load on the nail is at the interface between the grout sleeve and the soil/ rock and not at the interface of rebar and grout. The reaction of the pull-out load from the loading apparatus shall act on a sufficiently sized rigid MS bearing plate placed against a temporary cut surface at normal to the alignment of the rebar to ensure adequate load spreading and to avoid eccentric loading. Monitoring instruments shall be carefully positioned and independently supported to measure the movement of the rebar and any movement of the MS bearing plate.

- 8.3 The Contractor shall also present up-to-date test (not more than half year ago) and calibration certificates to the SO/Engineer for the equipment that are proposed for testing. The Contractor shall submit a proposed test procedure including testing arrangement on drawing and format of pull-out test report to the SO/Engineer for approval before the test commences. Method statement and layout of pull-out test as specified in Clause 1 shall also be submitted at least 7 day before commencement of test at site.
- 8.4 The location of soil nail to be tested shall be selected by the SO/Engineer. Soil nails subjected to pull-out tests shall not form part of the permanent works unless otherwise approved by SO/Engineer in writing.
- 8.5 **Pull-out test procedure shall be as follows:**

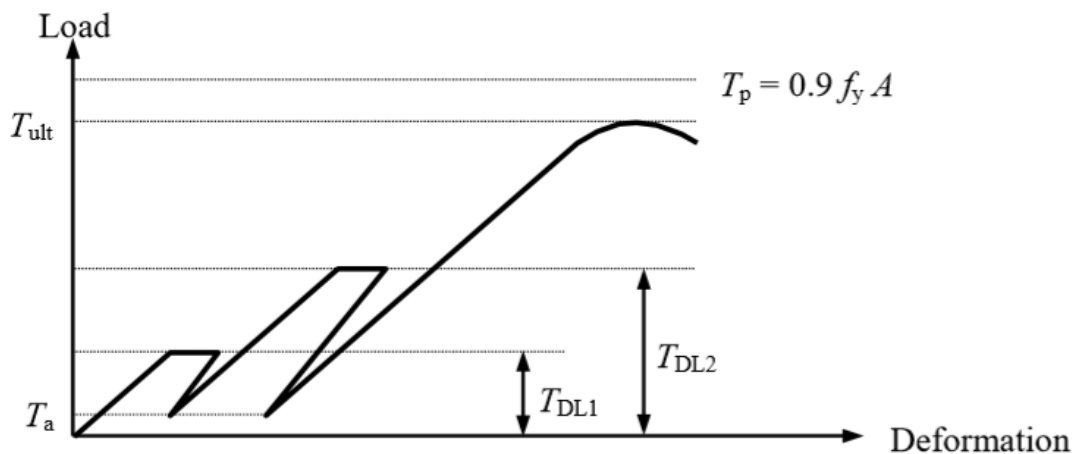


Diagram of load-deformation cycle of a pull-out test (Ultimate pullout resistance, $T_{ult} = \pi D L_b f_{su}$, where D =diameter of drill-hole, L_b =grouted bond length & f_{su} =ultimate friction of ground & cement grout. All loadings including T_a , T_{DL1} , T_{DL2} and T_p shall be specified in the Drawings or as given/directed by the designer or SO/Engineer.)

- The selected test soil nail shall be loaded in stages: from the initial load (T_a) via two intermediate test loads (T_{DL1} and T_{DL2}) to the maximum test load as shown in the diagram above.
- T_{DL1} shall be the allowable pullout resistance provided by the bond length of the cement grout sleeve of the test soil nail. $T_{DL1} = T_{ult}/2$.
- T_{DL2} shall be T_{DL1} times the factor of safety against pullout failure at soil-grout interface.
- The maximum test load shall be 90% of the yield load of the test soil-nail reinforcement ($T_p = 0.9 f_y A_s$, where f_y =yield stress & A_s =steel bar sectional area) unless the ultimate ground-grout bond load (T_{ult}) is reached during the test. **Reinforcement size larger than that of the working soil nail should be used in the pullout test, where necessary,** to allow the development of T_{ult} prior to reaching T_p .
- T_a shall be T_{DL1} or 5% of T_p , whichever is smaller.
- During the first two loading cycles, T_{DL1} and T_{DL2} shall be each maintained for 60 minutes for deformation measurement. The measurement at each of the cycles shall be taken at time intervals of 1, 3, 6, 10, 20, 30, 40, 50 and 60 minutes. If the test soil nail can sustain the test load subject to the acceptance criteria given below, the load shall be reduced to T_a and the residual deformation shall be recorded, after which the test shall proceed to the next loading cycle.

- g) In the last loading cycle, the test load shall be increased gradually from T_a straight to the maximum test load and then maintained for deformation measurement. The measurement shall be taken at time intervals of 1, 3, 6, 10, 20, 30, 40, 50 and 60 minutes. If the test soil nail can sustain the test load subject to the acceptance criteria given below, the load shall be reduced to T_a and the residual deformation shall be recorded, after which the test is completed.
- h) If the test soil nail fails to sustain T_{DL1} , T_{DL2} , or the maximum test load in any cycle, the test shall be terminated and the soil nail movement against residual load with time shall be recorded. The measurements shall be taken at time intervals of 1, 3, 6, 10 and, every 10 minutes thereafter over a period for at least two hours. The measurements shall be taken for a longer period where considered necessary.

8.6 Acceptance Criteria

The test soil nail is considered to be able to sustain the test load (T_{DL2}) if the difference of soil nail movements/deformation at 6 minutes and 60 minutes does not exceed 2 mm or 0.1% of the bond length of the test soil nail.

In this case, the test shall proceed to the next loading cycle or be terminated if the test nail is subject to T_p .

8.7 Report for pull-out test

Throughout the test, the soil nail movement versus the applied load shall be measured, plotted on a graph and recorded along with all other relevant information and details for the tested soil nail. All the results shall be submitted to the SO/Engineer within 3 days of completion of the test.

Where required, the whole soil nail shall be pulled out from the drill-hole for the SO/Engineer's inspection. Where the steel bar remains in-situ after the pull-out test, the bar shall be cut-off flush with the finished ground and the remaining part of the drill-hole grouted.

9. RIGHTS TO REJECT DEFECTIVE WORKS

The SO/Engineer reserves the right to reject any of the defective construction not in compliance with the Specification and Drawings placed under any of the following conditions and for any other conditions deemed unsatisfactory:-

- Soil nailing works without the prior inspection/approval of the SO/Engineer and/or without written approval of method statement (Clause 1.3).
- Incomplete submittals before commencement of works or during construction period (Clause 2.5).
- Defective materials (Clause 3).
- Defective drilling (Clause 4).
- Failure in pull-out checks (Clause 5.2).
- Defective grouting (Clause 6).
- Defective nail head construction (Clause 7).
- Defective pull-out test (Clause 8)
- Failure to meet any QC tests.

All necessary rectification or reworking shall be carried out by the Contractor at his own expense all to the satisfaction of the SO/Engineer.