Execution of special geotechnical works — Soil nailing

ICS 93.020

National foreword

This British Standard is the UK implementation of EN 14490:2010. It partially supersedes BS 8006:1995 which is currently being revised in order to remove conflicting material and to include technical updates. In the meantime, where conflict exists between the two standards, the provisions of BS EN 14490 take precedence.

The UK participation in its preparation was entrusted to Technical Committee B/526/4, Strengthened/reinforced soils and other fills.

A list of organizations represented on this committee can be obtained on request to its secretary.

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This European Standard was approved by CEN on 25 April 2010.

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Foreword

This document (EN 14490:2010) has been prepared by Technical Committee CEN/TC 288 "Execution of special geotechnical works", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2010, and conflicting national standards shall be withdrawn at the latest by December 2010.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

The remit of CEN/TC 288 is the standardisation of the execution procedures for geotechnical works (including testing and control methods) and of the required material properties. CEN/TC 288/WG 13 has been charged with the preparation of EN 14490 in the subject area of soil nailing.

The document has been prepared to stand alongside EN 1997-1, *Eurocode 7: Geotechnical design.* "Design considerations" of this European Standard deals only with those matters which should be taken into account during the execution stage of soil nailing so that the design of the soil nailing system may be fulfilled. This European Standard, however, provides full coverage of the construction and supervision requirements.

This European Standard has been drafted by a working group comprising delegates from ten countries and the comments of these countries have been taken into account.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

1.1 This European Standard establishes general principles for the execution, testing, supervision and monitoring of soil nailing.

1.2 Soil nailing is a construction technique, used to enhance/maintain the stability of a soil mass by installation of reinforcing elements (soil nails). Typical examples of soil nailing are given in Annex A.

1.3 The scope of soil nailing applications considered in this European Standard includes the installation and testing of soil nails and associated operations, required when stabilising existing and newly cut slopes and faces in soil, existing earth retaining structures, embankments, existing tunnels and the excavated facing of new tunnels in soil.

1.4 Soil nailing may be used to form part of a hybrid construction. This European Standard is relevant only to the soil nailing aspect of such constructions.

1.5 Techniques, such as reinforcement of ground by vertical inclusions (sheet piles, bored or driven piles, or other elements) and stabilisation with rock bolts, prestressed ground anchors or tensions piles are not covered by this European Standard.

1.6 Guidance on practical aspects of soil nailing and aspects on design, durability and testing is given in informative Annexes A, B and C, respectively.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 196-1, *Methods of testing cement — Part 1: determination of strength*

EN 197-1, *Cement — Part 1: Composition, specifications and conformity criteria for common cements*

EN 206-1, *Concrete — Part 1: Specification performance, production and conformity*

EN 1537, *Execution of special geotechnical work — Ground anchors*

EN 1992-1-1, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

EN 1997-1:2004, *Eurocode 7: Geotechnical design — Part 1: General rules*

EN 1997-2:2007, *Eurocode 7 — Geotechnical design — Part 2: Ground investigation and testing*

EN 10025-2, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 10079, *Definition of steel products*

EN 10080, *Steel for the reinforcement of concrete — Weldable reinforcing steel — General*

EN 10138 (all parts), *Prestressing steels*

EN 10210 (all parts), *Hot finished structural hollow sections of non-alloy and fine grain steels*

EN 10219 (all parts), *Cold formed welded structural hollow sections of non-alloy and fine grain steels*

EN 10244 (all parts), *Steel wire and wire products — Non-ferrous metallic coatings on steel wire*

EN 10245 (all parts), *Steel wire and wire products — Organic coatings on steel wire*

EN 13251:2000, *Geotextiles and geotextile-related products — Characteristics required for use in earthworks, foundations and retaining structures*

EN 13670, *Execution of concrete structures*

EN 14487-1, *Sprayed concrete — Part 1: Definitions, specifications and conformity*

EN 14488 (all parts), *Testing sprayed concrete*

EN ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods (ISO 1461:2009)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
bearing plate
fr: plaque d'appui
de: Kopfplatte
plate connected to the head of the soil nail to transfer a component of load from the facing or directly from the ground surface to the soil nail

3.1.2
design life
fr: durée de service
de: Entwurfslebensdauer
service life in years required by the design

3.1.3
drainage system
fr: système de drainage
de: Dränagesystem
series of drains, drainage layers or other means to control surface and ground water

3.1.4
facing
fr: parement
de: Frontausbildung
covering to the exposed face of the reinforced ground that may provide a stabilising function to retain the ground between soil nails, provide erosion protection and have an aesthetic function

3.1.5
facing drainage
fr: drainage de parement
de: Dränage der Frontausbildung
system of drains used to control water behind the facing

3.1.6
facing system
fr: système de parement
de: Frontausbildungssystem
assemblage of facing units used to produce a finished facing of reinforced ground

3.1.7
facing unit
fr: élément de parement
de: Frontausbildungselement
discrete element used to construct the facing

3.1.8
flexible facing
fr: parement flexible
de: bedingt nachgiebige Frontausbildung
flexible covering which assists in containing soil between the nails

3.1.9
ground
fr: terrain
de: Baugrund
soil, rock and fill existing in place prior to the execution of the construction works

3.1.10
hard facing
fr: parement rigide
de: starre Frontausbildung
stiff covering, for example sprayed concrete, precast concrete section or cast *in-situ* concrete

3.1.11
production nail
fr: clou de l'ouvrage
de: Bauwerksnagel
soil nail which forms part of the completed soil nail structure

3.1.12
reinforcing element
fr: élément de renforcement
de: Bewehrungselement
generic term for reinforcing inclusions inserted into ground

3.1.13
reinforced ground
fr: massif renforcé, sol cloué
de: bewehrter Boden
ground that is reinforced by the insertion of reinforcing elements

3.1.14
sacrificial nail
fr: clou sacrificiel
de: Sondernagel
soil nail installed in the same way as the production nails, solely to establish the pullout capacity but not forming part of the soil nail structure

3.1.15
soft facing
fr: parement souple
de: vollkommen nachgiebige Frontausbildung
soft facing has only a short-term function to provide topsoil stability while vegetation becomes established

3.1.16
soil nail
fr: clou
de: Bodennagel
reinforcing element installed into the ground, usually at a sub-horizontal angle, that mobilises resistance with the soil along its entire length

3.1.17
soil nail construction
fr: ouvrage en sol cloué
de: Vernagelungsbauwerk
work that incorporates soil nails, and can have a facing and/or a drainage system

3.1.18
soil nail system
fr: système de clouage de sol
de: Bodennagelsystem
reinforcing element which may include joints and couplings, centralisers, spacers, grouts and corrosion protection

3.1.19
test nail
fr: clou d’essai
de: Prüfnagel
nail installed by the same method as the production nails for the purpose of verifying the pullout capacity and durability, and could be forming a part of the structure

3.1.20
proof load
fr: chargement d’essai
de: Prüflast
load applied in the testing

3.2 Symbols

3.2.1 A_{gt} elongation of a metallic reinforcement.

3.2.2 f_y yield strength of steel.

3.2.3 L_{db} debonded nail length.

3.2.4 p_p proof load (maximum load to which the nail is subjected during the test).

3.2.5 P_o datum load.

3.2.6 R_t load at which pullout failure occurs.

3.2.7 $R_{t,k}$ characteristic value of the structural tensile resistance of the test soil nail or any of the extension pieces.

3.2.8 $R_{t0.1,k}$ characteristic value of the 0,1 % yield resistance of the test soil nail or any of the extension pieces.

3.2.9 s_1, s_2 measured nail displacement at time t_1 and t_2 respectively.

3.2.10 s_r residual nail displacement.

3.2.11 s_o initial nail displacement.

3.2.12 t_1, t_2 measurements taken at time t_1 and t_2.

4 Information needed for the execution of the works

4.1 General

4.1.1 Prior to the execution of the work, all necessary information shall be provided, requirements (in accordance with EN 1997-1) in particular, but not limited to the following:

a) details of the soil nailing project and the construction sequence and programme;

b) site investigation report, incorporating geotechnical classification and engineering properties of the ground in which the soil nails are to be located;

c) information regarding all other boundary conditions, including underground services, existing foundations (and their sensitivity) and requirements relevant to the location and performance of the soil nails;

d) details of ownership of the ground into which the soil nails are to be installed;

e) details of any agreement required to gain access to ground into which the soil nails are to be installed.

4.1.2 The information regarding the site conditions shall cover:

a) site investigation data about the ground conditions for execution of the soil nailing works according to EN 1997-1 and EN 1997-2;

b) the geometry of the site (boundary conditions, topography, access, slopes, headroom restrictions);

c) the existing surface of underground structures, services, known contamination and archaeological constraints;

d) the environmental restrictions, including noise, vibration, pollution;

e) the future ongoing activities, such as de-watering, tunnelling, deep excavations;

f) where the site may be subject to tidal working or flooding, cold climatic conditions or allied restrictions, details of such restrictions;

g) details of expected groundwater levels, perched water levels and fluctuations;

h) the conditions of buildings, roads and services adjacent to the work, including any necessary surveys.

4.2 Special features

4.2.1 Design aspects shall cover, where relevant:

a) definition of the Geotechnical Category and the design life of the works;

b) assessment of the site investigation data with respect to the design assumptions;

c) overall design of the soil nailing works;

d) the relevant temporary phases of execution;

e) specification of the soil nailing system;

f) any other items in the design to which special requirements exist during execution.

4.2.2 Execution information shall include the following:

a) specification regarding the working procedures and sequence;

b) definition of the reporting procedure to deal with unforeseen circumstances, or with any conditions revealed or considered during construction, which appear to be worse than those assumed in the design;

c) definition of the reporting procedure, if an observational method of design is adopted or monitoring is required;

d) specified levels, co-ordinates and tolerances shall be shown on plans, or in the specification, together with the positions, levels and co-ordinates of fixed reference points at or near the work construction site;

e) definition of tolerable limits of the effects of soil nailing (deformations, settlements, noise, vibrations, grouting loss) on existing and proposed structures;

f) the location of main grid lines for setting out.

4.2.3 Testing, supervision and monitoring information shall cover, where relevant:

a) a schedule of any trials and testing and acceptance procedures, for materials incorporated in the soil nail structure;

b) a schedule of preliminary trials (if required) and of relevant tests and control;

c) the results from the evaluation of trials and tests;

d) if necessary, specification regarding sacrificial nails;

e) a specification for monitoring the effects of soil nailing on adjacent structures and services and for interpreting the results.

5 Geotechnical investigation

5.1 General

5.1.1 The geotechnical investigation shall fulfil the requirements of EN 1997-1 and EN 1997-2.

NOTE Indications are given in EN 1997-2:2007, Annex B on the depth and the contents of geotechnical investigations.

5.1.2 The geotechnical investigation report shall be available in time, to allow for reliable design and execution of the special geotechnical works.

5.1.3 The geotechnical investigation shall be checked to see whether it is sufficient for the design and execution of the special geotechnical works.

5.1.4 If the geotechnical investigations are not sufficient, a supplementary investigation shall be conducted.

5.2 Special aspects of soil nailing

5.2.1 The interaction between the nail and the ground shall be considered. The site investigation shall establish (or confirm) the nature and the mechanical characteristics of the ground in order to assess the soil nail interface properties directly or by comparable experience.

5.2.2 Stability of the face during construction shall be considered, with special respect to geotechnical, hydro-geological and hydrological conditions (see 9.3.4).

5.2.3 Excavation tests should be performed to evaluate the stability during construction, if bulk excavation is to take place.

5.2.4 If necessary on account of site conditions, specific instrumentation (inclinometers, piezometers, etc.) should be installed.

5.2.5 An assessment of the aggressiveness of ground and groundwater shall be established in order to define the durability requirements of the soil nail material with respect to design life, see Annex B.

6 Materials and products

6.1 General

6.1.1 A soil nail construction can involve the following material components for:

a) soil nail system;

b) facing system;

c) drainage system.

6.1.2 All requirements on materials and products shall be specified in advance for the works, based on a European or a National standard. Where no appropriate European or National standard exists, its application shall comply with the manufacturer's recommendations and with the relevant acceptance certification. The compliance with the specified requirements shall be documented during execution.

6.1.3 All requirements on materials shall be specified in advance. The compliance with the specified requirements shall be documented during execution.

6.1.4 Materials and products used in the soil nail, the facing and the drainage systems shall be mutually compatible.

6.1.5 Material and products shall exhibit the properties necessary to ensure that they satisfy the design life of the structure and that the serviceability limits are not exceeded.

6.1.6 Newly developed materials may be used, provided that the performance of the system and durability of the materials have been proven.

6.2 Soil nails systems

6.2.1 General

Soil nail systems are produced using a wide range of materials and configurations. The following subclauses describe the main components that may be required to produce a soil nail system. Examples of soil nail systems are given in Annex A.

6.2.2 Reinforcing element

6.2.2.1 General

6.2.2.1.1 The reinforcing element of the nail is usually produced from metals (typically steel) and to a lesser extent from other materials, such as fibre reinforced plastics, geo-synthetics or carbon fibre.

NOTE The reinforcing element may be a solid bar, a hollow bar, an angle bar or some other form of cross-section.

6.2.2.1.2 When nails are to be grouted, they may be ribbed or profiled to improve the effective bond with the grout.

6.2.2.1.3 All reinforcing elements shall exhibit the stress/strain properties, durability and soil-reinforcement interaction properties required by the design.

6.2.2.2 Metallic reinforcing element

6.2.2.2.1 All metallic reinforcement used shall conform to 6.1.2 in particular (no entire enumeration):

a) a metallic reinforcement needs an elongation (A_{gt}) of at least 5 % at failure;

b) a solid steel bar, used as a reinforcing element, shall conform to EN 10080;

c) a hollow steel bar, used as a reinforcing element, shall conform to EN 10210 (all parts) or EN 10219 (all parts);

d) a hot rolled steel product, used as a reinforcing element, shall conform to EN 10025-2;

e) pre-stressed steel products, used as a reinforcing element, shall conform to EN 10138 (all parts).

6.2.2.2.2 The reinforcing element shall have a minimum thickness, which guarantees its mechanical behaviour during the entire design life.

6.2.2.2.3 When using a steel reinforcement element, consideration should be taken to design life due to corrosion, see Annex B.

6.2.2.2.4 Coatings and compounds for corrosion protection shall comply with the design specifications. The continuity of the protection, close to the connection elements shall comply with the design specifications.

6.2.2.2.5 The corrosion protection of high strength steel and pre-stressing steel shall be in accordance with EN 1537.

NOTE The steel can be classified as high-strength steel if it has f_y > 600 MPa and if no other information is available.

6.2.2.2.6 If a steel reinforcing element is galvanised, the hot dip galvanised coating shall comply with the requirements of EN ISO 1461.

6.2.2.3 Non-metallic reinforcing element

6.2.2.3.1 Other materials may be used as a soil nail reinforcing element provided they comply with 6.1.2.

6.2.2.3.2 Other materials used shall have ductile behaviour.

6.2.2.4 Joints and couplings

6.2.2.4.1 Joints and couplings can govern the strength of the soil nail system.

6.2.2.4.2 The corrosion protection of the coupler shall be compatible with the protection of the reinforcement element.

6.2.3 Grout

6.2.3.1 Cementitious or non-cementitious grouts shall be compatible with the reinforcing element.

6.2.3.2 If cement grout is used as a part of a soil nail system, then the cement shall conform to EN 197-1 and the provisions of this standard.

NOTE The selection of the type of cement for the grout should consider the aggressiveness of the environment, the permeability of the ground and the design life of the nail. The aggressiveness of the environment may be determined in accordance with EN 206-1.

6.2.3.3 Water/cement ratios (weight-ratio) should be appropriate to the ground conditions, nail system construction method, durability and strength requirements.

NOTE A typical maximum value is 0,55.

6.2.3.4 Admixtures may be used for improving workability, durability, reducing bleed, reducing shrinkage or adjusting rate of setting and strength development.

6.2.3.5 Admixtures should not contain any product liable to damage the reinforcing element or the grout itself. Admixtures that contain more than 0,1 % by mass of chlorides, sulphates or nitrates should not be used.

6.2.3.6 Inert fillers may be incorporated within the grout, for example the introduction of sand or an acceptable proportion of known drilling spoil, provided the agreed specifications are met.

6.2.3.7 Typically, grout should achieve a minimum characteristic strength of 5 MPa prior to load being induced in the soil nail, and the 28 days characteristic strength of the grout mix should not be less than 25 MPa.

6.2.4 Sheaths and ducts

Where used, sheaths and ducts shall not compromise the load transfer between the reinforcing element and the ground.

6.3 Facing systems

6.3.1 General

6.3.1.1 Facing systems are constructed using a variety of materials, configurations and connections to the reinforcement. Facings exposed to frost should be protected by frost insulation and extra drainage. Typical facing systems are described in Annex A.

6.3.1.2 All facing systems, including connections between facings and reinforcement, shall comply with 6.1.2.

6.3.1.3 The facing system shall enable construction and performance over the design life within specified tolerances of vertical and horizontal alignment.

6.3.1.4 The facing system shall be able to sustain differential settlements required by the design without structural damage to the facing.

6.3.1.5 The suitability of the facing system shall be proven by comparable experience or by tests, proving the serviceability of the system and the durability of the materials used for the design life of the soil nail construction.

6.3.1.6 Connections between the facing and the soil nails shall be capable of transferring load between facing and soil nails, as required by the design, and be able to sustain differential displacement between the facing and soil.

6.3.1.7 Connections between the facing and the soil nails should be capable of compensating misalignment due to installation.

6.3.2 Panels and blocks (normally precast)

6.3.2.1 Concrete panels should comply with EN 206.

6.3.2.2 If the concrete panels are reinforced, steel reinforcement shall comply with EN 10080.

6.3.2.3 The concrete cover of the face in contact with the ground shall be as specified by EN 1992-1-1 for humid environment or other more severe environments.

6.3.3 Sprayed concrete and cast in place concrete

6.3.3.1 The cement used shall conform to EN 197-1 and concrete shall conform to EN 206-1. Sprayed concrete shall conform to EN 14487-1.

6.3.3.2 Admixtures and additives may be used in sprayed concrete.

6.3.3.3 The concrete cover of the face in contact with the ground shall be specified by EN 1992-1-1 for humid environment or other more severe environments.

6.3.3.4 The aggregates used for sprayed concrete shall be stored under cover and shall be well graded to achieve the required spray rate.

6.3.4 Mesh

6.3.4.1 If reinforcing steel mesh is used as facing, it shall be in accordance with EN 10080.

6.3.4.2 If welded wire mesh is used as facing, it shall be constructed of cold-drawn steel wire conforming to EN 10079 and be welded into the finished mesh fabric in accordance with EN 10080.

6.3.4.3 If metallic mesh is galvanised, then it shall comply with EN ISO 1461.

6.3.4.4 If woven wire mesh is used for the facing, it shall be constructed of cold drawn steel wires and the finished product will be woven in accordance with the appropriate European Standards. The coatings on wire shall comply with the minimum requirements of EN 10244 (all parts) and EN 10245 (all parts) for extruded organic coating.

6.3.5 Other materials

6.3.5.1 If geosynthetic materials are used for the construction of a textile facing, they shall comply with EN 13251.

6.3.5.2 All natural and geosynthethic materials shall comply with 6.1.2.

6.4 Drainage systems

All drainage systems, including materials and products, shall comply with 6.1.2.

NOTE Examples of drainage systems are given in 8.5 and in Annex A.

7 Design considerations

7.1 General

7.1.1 A soil nail construction relies on the composite interaction of the soil, the reinforcing elements, and the facing (if applicable) to perform satisfactorily for the duration of its design life.

NOTE The stabilising force provided by a soil nail is generated passively.

7.1.2 The design of soil nailing works should be based on the general principles of EN 1990, EN 1991, EN 1997-1 and EN 1997-2.

NOTE Further guidance on the design of the soil nail system is given in informative Annex B.

7.1.3 Where the observational method is applied, particular attention shall be paid to 2.7 of EN 1997-1:2004.

7.1.4 The design shall consider the performance of the works, both during the temporary stages of construction and for the period of the design life, once construction is complete.

7.1.5 The soil nail system shall be compatible with the existing and anticipated ground conditions.

7.1.6 If the soil nail system to be used is not specified in the design, the design brief shall emphasise the particular requirements of the project. These requirements shall determine the final selection decision.

7.1.7 The design of the soil nail construction shall consider all relevant limit states in accordance with EN 1997-1.

7.1.8 Considerations should be given to the ability of the soil nail works to tolerate the expected magnitudes of total and differential settlements, frost heave, deformations and movements. Where necessary, such settlements, deformations and movements of soil nail constructions should be monitored during and after construction (see Clause 9).

7.1.9 For flexible facing the manufactures recommendation should be considered.

7.2 Design output

7.2.1 The design output should contain all the relevant information required for construction, some of which may be used in the preparation of the technical specification.

7.2.2 The design of a soil nailed construction should include the following:

a) design life of the construction;

b) Geotechnical Category of the construction in accordance with EN 1997-1:2004;

c) geometry: plan view, representative cross sections, elevation;

d) type of construction: for example, new construction or remedial work of an existing retaining structure;

e) stages of the works;

f) construction tolerances;

g) suitability of the ground to mobilise adequate forces within the soil nails;

h) sacrificial and production nails testing;

i) serviceability requirements: for example, permissible deflection and/or displacement of the works and retained ground;

j) monitoring of deflection and/or displacement;

k) possible existing and expected constraints, imposed by site boundaries and adjacent buildings or structures to the nailed zone;

l) buried services within or adjacent to the nailed zone;

m) relevant specification of materials or products assumed in the design.

7.2.3 The ground investigation report shall, when applicable, contain the following information according to EN 1997-2:

a) mechanical and physical properties: strength parameters, unit weight, grading curve, permeability, water content, compressibility, stone and boulder content;

b) hydrogeology, water levels, frost susceptibility where appropriate;

c) chemical, electro-chemical and biological properties of the ground and groundwater;

d) suitability of the ground excavated to stand unsupported, in the temporary condition, as the works are undertaken.

7.2.4 The design report shall include, when relevant, the following specifications about the soil nail system:

a) type, configuration and stagger pattern (nail section, length, orientation and spacing);

b) short-term and long-term design strength, pullout capacity;

c) installation of test nails and sacrificial nails;

d) type of grout and strength;

e) design life and corrosion protection system;

f) restrictions on installation methods.

7.2.5 The design report shall include, when relevant, the following specifications about the facing system:

a) mechanical requirements;

b) environmental requirements;

c) aesthetic requirements.

7.2.6 The design report shall include, when relevant, the following specifications about drainage system:

a) type and specification;

b) construction phases;

c) durability and maintenance of the drainage system.

7.3 Design amendments

7.3.1 Design amendments may be necessitated by either unforeseen conditions or planned modifications.

7.3.2 Design amendments necessitated by unforeseen circumstances, such as changes in ground or hydraulic conditions, shall be reported immediately in accordance with Clause 4.

7.3.3 If construction activity requires a change of the final construction, as defined in the design documents, this shall only be carried out after the design has been checked and modified accordingly.

8 Execution

8.1 General

8.1.1 The sequence of soil nail construction can include five main processes:

a) preliminary work;

b) excavation / face preparation;

c) nail installation;

d) drainage installation;

e) facing installation and connection with nail heads.

NOTE The order of these processes depends on compliance with the design construction sequence and requirements and can vary.

8.1.2 Unforeseen circumstances, such as changes in ground or hydraulic conditions, shall be reported immediately in accordance with Clause 4.

8.1.3 Where material properties, or construction processes, can be adversely affected by climatic conditions (e.g. extreme heat, cold or heavy rain), then consideration shall be given to the implementation of special measures to mitigate the detrimental effects.

8.2 Preliminary work

The following preliminary works can be required:

a) preparation of the existing vegetation and facing;

b) setting out the position of the slope;

c) construction of safe and appropriate access systems (for example: scaffolding platforms, excavated benches, access by crane);

d) installation of drainage to control surface runoff and groundwater to allow soil nailing to be undertaken;

e) installation and testing of nails to verify the design characteristics and assumptions (see Clause 9);

f) installation of geotechnical monitoring instrumentation (see Clause 9) and verification required for control of the soil nailing works and of their effects on adjacent structures and services.

8.3 Excavation / Face preparation

8.3.1 The stability of the excavation, the face preparation and any adjoining or adjacent land property or services shall be examined before the beginning of the soil nailing work.

8.3.2 Excavation may comprise a bulk operation followed by trimming of the face (see Annex A).

8.3.3 Restrictions can be imposed on progressive levels of excavation.

8.3.4 Superficial soils, near the ground surface, are often of made ground and poor quality and may require special measures to prevent their collapse.

8.3.5 Even if defined in the design, the stand up time of the cut face should be verified. From this, an estimate should be made of the maximum length of the face, which can be trimmed in advance of soil nail installation (see Clauses 5 and 9).

8.3.6 The period between trimming of the face, soil nail installation and facing construction should be minimised to prevent risk of face collapse.

8.3.7 Where stand up times are short and face stability cannot be maintained, then consideration should be given to the use of excavation in small sections and using berms for temporary support.

8.3.8 Excavation tolerances, such as slope angle, temporary bench levels and line of the proposed excavation, shall be agreed before the start of excavation.

8.3.9 Excavation limits shall be agreed in advance of the start of excavation.

8.3.10 Before the start of excavation, monitoring procedure shall be in place with the required action to be taken to ensure that the agreed excavation limits are not exceeded.

8.3.11 Bulk excavation may proceed in advance of the benching and local face trimming for soil nail and facing installation, subject to the stability and displacement requirements.

8.3.12 Where the stability of the cut face has not been assessed, it shall be investigated prior to full excavation by trial pits and/or observation of the initial bulk excavation.

8.3.13 If soil nail installation or facing construction does not follow face trimming within the anticipated stand up time, then consideration shall be given to local back filling of the face to maintain stability.

8.3.14 In the event of actual face collapse, an investigation shall take place and actions shall be taken to prevent a reoccurrence.

8.3.15 At each level of excavation the soil type and level of any groundwater encountered should be observed and compared with those anticipated from the ground investigation. Where differences are observed, these shall be reported and any necessary actions to be taken.

8.4 Nail installation

8.4.1 General

8.4.1.1 There are two principal methods of installing soil nails: direct installation (driving), and drilling and grouting. Direct installation can be performed by percussive, vibratory or ballistic methods. For drilling and grouting technique, grouting methods can involve either gravity or pressure grouting procedures.

8.4.1.2 The nail installation method shall be appropriate to the ground conditions.

8.4.1.3 Soil nail components shall be handled with care during transportation, storage and installation. Inspection shall be carried out to ensure the integrity of the components before installation, with particular attention to coatings and corrosion protection components.

8.4.1.4 Nail installation shall be carried out in a controlled manner with minimum disturbance and detriment to the stability of the ground or previously installed nails.

8.4.1.5 Nail installation shall be carried out to the tolerances and the sequence required by the design. Generally attainable construction tolerances are reported in Annex A.

8.4.1.6 Nails shall be installed so that the reinforcing element projects a sufficient distance beyond the face of the slope to allow the connection to the facing system in accordance with the design requirements. All locking nuts, plates and other fasteners shall be securely fastened.

8.4.1.7 If couplers are used to join sections of reinforcing elements, precautions shall be taken to ensure proper and durable coupling.

8.4.1.8 If the presence of obstructions (or unexpected ground conditions) prevents the complete installation of a nail or causes it to deviate from the design alignment, then the installation method shall be reviewed and consideration given to relocation of the nail. Nails already or partially installed shall not be removed.

8.4.2 Driven installation methods

8.4.2.1 Nails may be driven into the ground using jacking, screwing, percussive, vibratory or ballistic action to displace the soil. The reinforcing element is normally in direct contact with the ground.

8.4.2.2 To avoid buckling during installation, the reinforcing element shall be sufficiently stiff, with regard to its length, the nature and state of compaction of the soil and the power of the driving tools used.

NOTE The reinforcing element may be guided whilst being driven.

8.4.3 Drilled installation methods

8.4.3.1 General

8.4.3.1.1 Nails can be installed into the ground using rotary or rotary-percussive drilling methods to remove the ground.

8.4.3.1.2 The drilling method used and the rate of drilling shall ensure that the nominal hole diameter specified in the design is achieved along the entire length of the nail.

8.4.3.1.3 The borehole shall be drilled to a depth sufficient to ensure that the design length of the reinforcing element can be installed.

8.4.3.1.4 If the nail transfers load between the ground and the reinforcing element by grout bond, unless the cover is assured otherwise, spacers may be fitted to ensure that the minimum annulus of grout required by the design is formed around the reinforcing element.

8.4.3.1.5 If the nail relies on grout as a part of the corrosion protection system, then spacers shall be fitted to ensure that the minimum grout cover, specified by the design, is achieved.

8.4.3.2 Uncased drilling

8.4.3.2.1 Open hole drilling can be used in stable ground or in unstable ground with suitable stabilising fluid.

NOTE 1 Where ground is stable, air-flushing techniques are commonly used with rotary, rotary-percussive or down-the-hole hammer drilling techniques.

NOTE 2 In certain ground conditions, the use of water as a flushing medium may be more appropriate, due to its greater density, capacity to support the borehole and its increased efficiency in drill spoil lift at lower flushing rates. Water should not be used if it increases the risk of soil mass instability and decreases the bond capacity between ground and nail.

NOTE 3 Where a dense drill fluid is required to support the hole in less stable soils, cement grout as a flush medium and also as the load transfer medium is commonly applied. Associated with its use are demands for efficient recovery of the flush returns, effective removal or partial removal of the drill spoil from the grout return, utilisation of re-circulation pumping systems and disposal of excess grout and grout contaminated spoil.

8.4.3.2.2 Where a non-return flush condition is encountered, the drill bit or down-the-hole hammer should be withdrawn until flush return is recovered.

8.4.3.2.3 If introducing the reinforcing elements or corrosion protection ducts into the borehole, care should be taken to ensure that they are not smeared against the sides of the hole and contaminated by the ground.

8.4.3.2.4 It is recommended that soil nail system is installed in boreholes immediately after drilling.

8.4.3.3 Cased hole drilling and hollow stem auger drilling

8.4.3.3.1 Cased hole drilling and hollow stem auger drilling are methods, which should be used in ground conditions where the borehole will not stand open for its entire length before grouting.

8.4.3.3.2 Open hole drilling may continue to the base of the hole beyond the drill casing, where the borehole will stand open for part of its length before grouting.

8.4.3.3.3 Where the flush return is lost, the drilling equipment should be withdrawn into the casing to recover flush so that flush penetration of the soil mass does not occur.

8.4.3.3.4 If the ground is not stable, then grouting of the borehole shall be carried out prior to removal of the casing or augers. If a reinforcing element is pushed into a freshly grouted hole, measures shall be taken to ensure that it enters the hole centrally and that contaminants are not introduced.

8.4.3.4 Self-drilled hollow bar soil nails

8.4.3.4.1 With this technique, the reinforcing elements are fitted with a drill bit and they are installed into the ground during drilling. Hollow bar soil nails are typically installed using rotary percussion.

NOTE The installation of reinforcing elements by rotary drilling and simultaneously flushing with grout is sometimes referred to as self-drilled hollow bar soil nails or simultaneously drilled and grouted.

8.4.3.4.2 The rate of drilling, grout pressure and flow rate should be adjusted to suit the ground conditions to ensure the correct borehole diameter.

NOTE In some ground conditions, simultaneous drilling and grouting can result in an enlarged grout body, compared to the size of the drill bit.

8.4.3.4.3 If self-drilled hollow bar is used in unstable ground, a suitable stabilising fluid shall be used.

NOTE Water should not be used if it increases the risk of soil mass instability and decreases the bond capacity between ground and nail.

8.4.3.4.4 A flush return should be observed at all times during drilling when the drill is advanced. If lost, the drill string should be retracted until the flush returns.

8.4.3.4.5 If structural grout is not used as stabilising fluid, then the structural grout shall be introduced when the final borehole depth is achieved, and it shall be visually observed that the stabilising fluid is replaced by the structural grout.

8.4.4 Grouting procedures

8.4.4.1 General

8.4.4.1.1 If using a driven nail system, grout may be injected under pressure, during driving or on completion, via the reinforcing element to improve nail pullout resistance.

8.4.4.1.2 If using a drilled nail system, the grout may be introduced to the hole during drilling via the reinforcing element on completion of drilling, or after reinforcement installation via a grout tube. Pressure may be applied to the grout to improve the nail pullout resistance.

8.4.4.1.3 If using a self-drilled hollow bar nail system, the grout may be placed by either simultaneous drill and grout or subsequent grouting immediately upon completion to depth.

8.4.4.1.4 Any grouting construction method should ensure it does not introduce any features, for example air voids that reduce the capacity and the durability of the designed nail system.

8.4.4.1.5 Grouting should be continued without interruption until a neat, non-diluted, non-contaminated mix emerges from the top of the bore. Where drill spoil emerges within the grout, the contaminated mix should be removed and disposed of in a controlled manner.

8.4.4.1.6 Grout mixing should be carried out in a mixer capable of producing a grout of uniform consistency with the workability and strength characteristics required by the design. Grout should be used immediately after mixing, unless a facility is available to agitate the mix.

8.4.4.1.7 Weight or volume batching of constituents may be used.

8.4.4.2 Gravity grouting

8.4.4.2.1 When grouting an open hole via a grout tube, the grout pressure in the borehole cannot exceed gravity pressure.

8.4.4.2.2 Gravity grouting should be performed, using a grout tube of internal diameter not less than 15 mm, which is advanced to the base of the borehole, prior to grouting commencing.

8.4.4.3 Pressure grouting

8.4.4.3.1 Pressure grouting can enhance the pullout capacity of a soil nail. The most effective procedure for pressure grouting is normally established by means of trials (grout pressure and injection volumes).

8.4.4.3.2 Pressure grouting of driven nails can be performed by connecting a grout pipe to the head of the reinforcing element and injecting grout on completion of driving.

8.4.4.3.3 On completion of gravity grouting through a drill casing, or auger stem, a grout pipe may be coupled to the casing or auger head and a pressure exerted on the grout within the borehole during casing/auger withdrawal.

8.4.4.3.4 For self-drilled hollow bars, the grout-flushing medium, which is commonly a cement grout, is introduced into the reinforcing element via a grout swivel fitted into the drilling rig. The grout injection pressure and flow rate should be adjusted during drilling depending on the grout's susceptibility to penetrate the ground, loosened by the drilling process and contained within the annulus around the reinforcing element. Grout flushing should be carried out at a constant rate, and the flush should be re-established each time new sections of the reinforcing element are added, prior to advancing the drill bit.

8.4.4.3.5 Some types of drilled and grouted nails allow the installation of a post-grouting pipe, which may allow single-stage grouting or high-pressure multi-stage post grouting of the soil nail to enhance pullout capacity.

8.4.5 Other nail installation methods

8.4.5.1 If using another soil nailing technique, it shall be installed in accordance with the design specifications.

8.4.5.2 Specific tests with definite performance criteria shall be conducted in order to verify that the method will achieve the performance requirements specified by the design.

8.5 Drainage installation

8.5.1 General

8.5.1.1 The effective control of surface and groundwater is essential during construction and service life of a soil nail construction. Drainage measures shall therefore be constructed to a high standard to protect the soil nail works from the detrimental effects of surface water and groundwater, both during construction and the design life.

8.5.1.2 If groundwater or surface water flows are greater than anticipated, then the design shall be reviewed.

8.5.1.3 The effects of surface water can be controlled by a variety of measures, such as cut-off trenches, channels, bunds, sumps and sheeting. Measures to control surface water should generally be installed prior to commencing excavation or the stripping of vegetation.

8.5.1.4 The effects of groundwater can be controlled by internal drainage measures, such as upwardly inclined well screen drains and trenched drains, or by the construction of a drainage blanket immediately behind the facing, often in combination with weep holes.

NOTE Pockets of water or perched water tables known to exist, or revealed during soil nail execution, are normally controlled through the deep drain system.

8.5.1.5 Where adverse hydraulic conditions are encountered, then measures required for controlling water during soil nail construction and preventing erosion of excavated faces shall be implemented and agreed before further excavation.

8.5.1.6 Surface water and groundwater from drains should be channelled to collection points, where it can be discharged safely and in accordance with environmental regulations.

8.5.2 Surface drainage

8.5.2.1 If surface drains are employed, they shall have sufficient capacity to collect and control rainwater flows arising from the storm with a return period equivalent to the design life of the works.

8.5.2.2 If sheeting is employed to collect surface water, attention should be paid to the jointing and overlapping of sheets to prevent water entering between the sheeting and ground. Where necessary, it should be pinned or weighted to keep it in intimate contact with the ground surface and prevent it from lifting under wind loading. Sheeting should be inspected regularly for damage and repaired as necessary to maintain serviceability.

8.5.2.3 If drainage channels are constructed, they should have a continuous fall to a collection point and shall prevent ponding of water. If collecting surface water from a slope, they should be detailed to ensure the water runs into the channel and does not pass into the ground below the channel. Where constructed directly on the ground surface, the ground should be well compacted. Construction joints should be watertight to prevent ingress of water and erosion of the soil below the channel. Details should be included to prevent damage to the channel due to differential or thermal movement.

8.5.2.4 Trenched drains should be excavated to ensure that the invert falls continuously to the collection point and ponding of water is prevented. Excavation should be carried out in controlled lengths to minimise the period the trench is open and where necessary trench support should be employed. If excavated in wet conditions, the excavation should commence from the lowest point working upwards.

8.5.2.5 Prior to back filling the trench, the sides and base of the trench can be lined with an appropriate geotextile to prevent fines from clogging the drain in the long-term.

8.5.2.6 If a perforated pipe or well screen is to be placed in the base of the trench, it should be inspected for damage and any joints checked to ensure the drain will act as a continuous duct.

8.5.2.7 On completion of the above, the trench should be back-filled, using a granular filter material complying with the design requirements with respect to grading and durability. Samples of backfill shall be tested for compliance as specified in the design.

8.5.3 Facing drainage

8.5.3.1 If used, a filter layer behind the face normally comprises strips of drainage filter running up and down the face or diagonally across it.

8.5.3.2 If required by the design, the drainage filter should not adversely affect the quality of the facing concrete or the friction between ground and facing.

8.5.3.3 Where there is a risk of water build-up behind the face, weep holes shall be constructed to allow free flow of water through them. They shall have an internal diameter that allows for cleaning and inspection.

NOTE Where placed directly in contact with the soil, they should be lined or wrapped with a geotextile filter fabric or similar. If placed before construction of a sprayed concrete facing, they should be fixed securely in position and protected to prevent blockage or damage during spraying. When fixed into predrilled holes through a facing, then the annulus between the weep hole and facing should be sealed to ensure that seepage water passes through the weep hole.

8.5.3.4 The connection of the facing drainage system and the weep holes shall be inspected and tested prior to the application of the facing.

8.5.4 Subsurface drainage

8.5.4.1 If subsurface drainage is used, it should be installed with a minimal fall of 5 % towards the facing of the construction.

8.5.4.2 The location, diameter, length and inclination shall be specified in the design.

8.5.4.3 The filter characteristic shall be specified in the design in order to ensure the compatibility between the soil grading and the filter characteristics.

8.5.4.4 The method of installing deep drains shall ensure that the pipe is not damaged and that soil is not smeared over the filter surface impairing its efficiency. Joints between sections of pipe shall be securely fastened.

8.5.4.5 Where the subsurface drain meets the facing or surface of the works, a seal shall be provided between the filter and surrounding ground to ensure that water exits through the pipe and does not erode the soil in this region. A mortar, concrete or other suitable compound may provide this seal.

8.5.4.6 Observation of water flows, fine particles, or otherwise, from deep drains shall be recorded and investigated if necessary.

8.5.5 De-watering systems

If soil nailing is carried out below the ground water level, or if unexpected flows of water are causing construction difficulties, a de-watering system shall be employed.

8.6 Facing installation and connection with nail heads

8.6.1 Hard facing

8.6.1.1 Single layer sprayed concrete without steel mesh may be applied if only to protect against erosion.

8.6.1.2 When using steel mesh and sprayed concrete, the steel mesh shall not create voids during spraying. Consideration shall be given to connections between each stage, tests for the sprayed concrete, protection of weep holes during spraying. When problems of stability of the mass or local stability appear, possible solutions are:

a) construction by alternate slots;

b) installation of the nails before earthworks operations;

c) spraying a thin protective concrete layer immediately after earthworks (avoids surface instability and effects of weathering on the ground).

8.6.1.3 Application of cast-in-place concrete may be used in accordance with the design requirements or the requirements of the system. The concrete shall comply with EN 13670.

8.6.1.4 Pre-cast facing elements may be used in addition to sprayed concrete at points of significant load transfer (e.g. nail heads).

8.6.1.5 The facing and the nail connection to the slope surface should fulfil the same requirement concerning durability as the rest of the soil nailing system.

8.6.2 Flexible facing

8.6.2.1 Facing, such as steel mesh, a suitable geosynthetic or steel netting, shall be installed according to the manufacturer's recommendation and according to the design requirement.

8.6.2.2 The connection to the slope surface shall be undertaken according to the requirements of the system. Connection shall be made of the flexible facing to the nails with suitable system in accordance with design requirement.

8.6.2.3 The facing and the soil nail connection to the slope surface should fulfil the same requirement concerning durability as the soil nail of the soil nailing system.

8.6.3 Soft facing

8.6.3.1 A soft facing of light metal mesh or grid with a geosynthetic sheet shall be placed and fixed in accordance to the system requirements.

NOTE Where specified, an underlying fine mesh or geo-grid may be installed for erosion protection. This may be a biodegradable geosynthetic for a temporary erosion control, which is to be replaced by vegetation cover.

8.6.3.2 The specified soft facing system shall be placed according to the system requirements.

8.6.3.3 Vegetation of slope: climatic and local conditions, such as site location, gradient, altitude, amount and frequency of precipitation, may influence the choice of a suitable seed mix and the greening method (e.g. hydro seeding, seeded geotextile).

8.6.3.4 The necessity for special vegetative cover and artificial irrigation shall be taken into account during both construction and service life.

8.6.3.5 Connection to the slope surface shall comply with the design specifications.

8.6.3.6 To ensure good connection between the facing, the soil nails and the slope appropriate soil nail head plates, claw plates or system fixtures should be used.

8.6.3.7 Around a facing boundary that is not reinforced by soil nails, pre-tensioning of connectors to appropriate fixed anchors can be required.

8.6.3.8 The facing and the nail connection to the slope surface should fulfil the same requirement concerning durability as the rest of the soil nailing system.

8.6.4 No modification to existing surface

8.6.4.1 The soil nail works can be constructed without any modification to the existing surface.

8.6.4.2 The existing low vegetation and structures shall be preserved.

8.6.4.3 If trees need to be removed, the root ball should be preserved.

9 Supervision, testing and monitoring

9.1 General

9.1.1 Supervision, monitoring and tests shall be performed by qualified and experienced persons and comply with EN 1997-1, specifications based on the design and other specified requirements.

9.1.2 Any deviations from the expected situation or ground conditions or any cases of non-conformity shall be reported immediately as stated in Clause 4.

9.1.3 All necessary information concerning the works shall be recorded (see Clause 10).

9.1.4 An assessment of the results of nail tests shall be made before the beginning or continuation of the nail installation.

9.2 Supervision

9.2.1 The level of supervision (type, extent, accuracy, monitoring and testing) shall take into account the contents of this clause and shall be clearly established and defined before work commences.

9.2.2 Records of the construction works shall be made in accordance with Clause 10.

9.2.3 Particular quality control checks (performed according to technical specification) can include:

a) visual inspection of the excavated material to confirm that it is in accordance with the ground conditions considered in the design;

b) visual inspection of the drill spoil to confirm that it is in accordance with the ground conditions considered in the design;

c) assessment of conformity of the ground (type, thickness, fractured zones, etc.) and its hydro-geological nature (sources of water, seeps or oozing, etc.) with the geotechnical data assumed for the design;

d) monitoring for the duration of operations;

e) ensuring the maximum excavation height is not exceeded;

f) minimum time allowance between successive excavation phases to achieve sufficient strength of nail grout;

g) the nail orientation, bore-hole diameter, spacing and length;

h) the bore hole is clean and has not collapsed (if applicable);

i) the integrity of the corrosion protection system;

j) where used, grouting technique, installation of reinforcing element, mesh and sprayed concrete or geotextile/establishment of vegetation;

k) where required, installations of drainage system(s); it is essential that hydraulic continuity of the vertical drains is assured if installed incrementally;

l) placement of the bearing plate, avoiding any unacceptable deviation of placement by using tapered washers below the nut;

m) connection between reinforcement and facing;

n) verification of the material delivered at the site being in accordance with the design requirements;

o) function of centralisers or spacers;

p) quality of grout.

9.3 Testing

9.3.1 Testing during execution can comprise three different categories of tests:

a) soil nail load tests to verify the ultimate pullout resistance and creep characteristics of the soil nails;

b) material tests to verify the ultimate pullout resistance and creep characteristics of the soil nails;

c) face stability assessment tests to evaluate the stand-up time of the ground during excavation.

9.3.2 Soil nail load tests

9.3.2.1 The frequency and procedures for soil nail load testing should be based on a consideration of the consequences of failure, as defined in EN 1990 and EN 1997.

9.3.2.2 Table 1 describes the principal types of soil nail load tests, their purpose, when they are required and actions to be taken in the event of a non-compliant test result. Annex C gives guidance on test procedures, acceptance criteria and the equipment to be used for soil nail load tests. Table 2 suggests the frequency of soil nail load tests based on the Geotechnical Category.

9.3.2.3 Sacrificial test nails are the preferred method to validate the resistance of a soil nail. Length of the nails may be de-bonded as described in Annex C.

9.3.2.4 If load tests are conducted on production nails, consideration should be given to downgrading the capacity, and additional nails may be installed to provide sufficient resistance and long-term stability.

9.3.2.5 The test procedures and locations of test nails shall be agreed.

9.3.2.6 Test nails, wherever possible, should be evenly distributed throughout the body of the soil nail works to assess nail performance across the site.

NOTE Active and passive zones are functions of particular limit equilibrium analyses and are not helpful for execution. The key issue during testing is to ensure that local boundary effects do not result in overestimating bond and therefore it is desirable to de-bond the head of the nail a sufficient distance from the reaction system. A minimum de-bonded length is 1 m.

Table 1 — Definition of soil nail load tests

	Type of Soil Nail Load Test	
	Sacrificial nail test	**Production nail test**
Purpose of test	to verify the ultimate soil nail to ground bond resistance used in the design (1) the bond in the passive zone; (2) the bond in the active zone; (3) the bond along the entire length of the nail.	to demonstrate satisfactory soil nail performance at a load designated by the designer. The test is performed on the entire length of the nail.
When tested	Before, during or after production works.	During or on completion of production works.
Type of nail used	Sacrificial	Production
Action taken in case of non-compliant test result	Review soil nail installation method and/or consider alternative soil nail length and layout.	Consult designer for action to be taken and approval to continue.
Comments	If necessary at each different soil layer.	Caution should be exercised when testing production nails not to overstress the nail to grout bond or cause damage to corrosion protection. When a structural facing is used the test nail should be debonded within the zone of influence of the facing.

Table 2 — Suggested frequency of soil nail load tests based on density of nails and geotechnical structure category

Test type	**Suggested Minimum Frequency of Load Tests**	
	Sacrificial nail test	**Production nail test**
Geotechnical Category 1: negligible risk to property or life.	Optional	Optional
Geotechnical Category 2: no abnormal risk to property or life.	If no comparable experience of soil type: a minimum of three sacrificial nails with at least one sacrificial nail per soil type. Where direct experience exists then sacrificial nail tests are optional.	2 %, min. three tests.
Geotechnical Category 3: all other structures not in Category 1 or 2.	A minimum of five sacrificial nails with at least two sacrificial nails per soil type.	For number of nails: 3 %, min. five tests.

NOTE 1 Geotechnical Category of structure as defined in EN 1997.

NOTE 2 Test nails should be evenly distributed throughout the structure.

NOTE 3 The frequency of testing is a suggested minimum.

NOTE 4 Where sacrificial nail tests are carried out the number of production nail tests can be reduced on a pro-rata basis.

NOTE 5 For spacing, less then 0,8 m, a group test of four nails is recommended.

9.3.3 Material tests

9.3.3.1 These clauses are relevant to the testing of materials produced during the execution soil nailing works such as grouts, sprayed or cast *in-situ* concrete.

9.3.3.2 Grout shall be sampled and tested in accordance with the requirements set out in EN 196-1 to ensure compliance with the characteristic strengths and other properties specified in the design. Grout in the annulus between a corrugated sheeting and a bar should be tested according to EN 445, taking EN 446 and EN 447 into consideration.

9.3.3.3 Testing of sprayed concrete should include tests on constituent materials (grading, moisture content, etc.), samples from preliminary test panels and from the completed works. Where sampling involves coring of the completed works, then reinstatement shall be carried out as necessary. Test methods shall be in accordance with EN 14488 (all parts).

9.3.3.4 Concrete shall be sampled and tested in accordance with the requirements set out in EN 206-1.

9.3.3.5 The sampling and testing of other materials shall be in accordance with Clause 6.

9.3.4 Face stability tests

9.3.4.1 Where soil nail execution involves excavation and there is uncertainty about the stability of the ground at the proposed face angle, then face stability assessment tests should be undertaken. It is important to note that face stability assessment tests are not precise and are only intended to give an indication of face stability.

9.3.4.2 The test involves the excavation of a trial pit to a batter and depth equal to the slope angle and bench height used in the design. The width of excavation should not be less than twice the bench height and the period of observation should be representative of the anticipated time between the installations of rows of nails.

9.3.4.3 Where possible, these tests should be undertaken before execution of the works. Where soil nail execution involves excavation to significant depths and in varying strata, then consideration should be given to carrying out additional tests as execution proceeds or as changing ground conditions are encountered.

9.4 Monitoring during construction

9.4.1 The type, extent and accuracy of monitoring and testing requirements shall be in accordance with Clause 4 of EN 1997-1:2004.

NOTE Where the observational method is used particular attention needs to be made to 2.7 of EN 1997-1:2004.

9.4.2 The details of monitoring records to be made both during and after execution of the works are specified in Clause 10.

9.4.3 Monitoring the horizontal and vertical movement of the works should be performed.

NOTE An appropriate monitoring program can vary (from visual inspection to full instrumentation) depending on Geotechnical Category or project specification.

9.4.4 If movements approach or exceed threshold values, then stabilisation measures, defined in the design, shall be implemented and the construction procedures reviewed.

NOTE Changes to construction procedures that may permit construction to continue include reducing bench depths and lengths, time to install facing and groundwater control.

9.4.5 Visual inspection of excavated ground for signs of ground water shall be carried out. Where encountered, the adequacy of the drainage system for the observed water level shall be confirmed.

9.4.6 If the design is sensitive to changes in ground water, then piezometers should be installed and monitoring undertaken.

9.5 Measures to facilitate long-term monitoring

9.5.1 The need for long-term monitoring should be assessed on the Geotechnical Category of the structure.

9.5.2 If long-term monitoring is deemed necessary, then the purposes, provisions to be made, instrumentation required and monitoring frequency shall be clearly specified. Where appropriate limit values and actions are to be taken shall also be clearly specified.

9.5.3 Long-term monitoring of the soil nail construction may include, but is not limited to:

a) movement of the works or adjacent structures and slopes;

b) load-tests to sacrificial nails or production nails;

c) efficiency of drainage systems;

d) changes in groundwater and hydro-geology;

e) degradation of soil nails and facing systems;

f) forces in soil nails;

g) suggestions for long-term monitoring are found in A.6.

9.5.4 When considering long-term monitoring, the safety of personnel shall be considered and safe access provided.

9.5.5 If the design of the soil nail works incorporates the observational method, then the monitoring requirements of 9.4 and 9.5 shall be considered.

10 Records

10.1 Records of construction shall be made in accordance with Clause 4 of EN 1997-1:2004.

10.2 A construction and nail installation plan shall be prepared and shall be available on site containing the technical specification related to the nail system to be used.

10.3 A nail installation plan shall contain at least the following information:

a) nail type with designation;

b) number of nails;

c) location, orientation and inclination of each nail and tolerances in position, to an agreed datum;

d) required load carrying capacity of the nail;

e) installation technique;

f) known obstructions and any other constraints on nail activities;

g) method of corrosion protection;

h) nail testing undertaken;

i) schedule of work.

10.4 An execution record shall be kept. This record shall include any special features of construction.

10.5 The following information as appropriate should be included in the execution record for each nail installation:

a) project/element;

b) nail designation;

c) installation date;

d) nail type, diameter, length, orientation;

e) installation method;

f) drilling method;

g) bore hole cased/not cased and borehole diameter;

h) flush method;

i) underground conditions (short description);

j) hydro-geologic conditions;

k) grout consumption;

l) remarks (climate, weather and temperature);

m) special measures;

n) test results (if performed) and actions taken (if any).

10.6 As-built plans shall be compiled after completion of the nails and kept with the construction records. Any acceptance certificates issued by regulatory authorities for materials used in the nail installation shall be held with the construction records.

11 Special requirements

11.1 General

When executing soil nailing works, the relevant national standards, specifications or statutory requirements shall be observed regarding:

a) security of the site;

b) safety of the working procedures;

c) operational safety of plant and auxiliary plant, equipment and tools.

11.2 Noise

11.2.1 Precautions shall be taken to ensure that operators are not exposed to noise levels that exceed the limits prescribed in international or national regulations.

11.2.2 Measures shall be taken not to cause danger or unreasonable nuisance to those living, working or passing nearby the works.

11.2.3 Measures should be taken to minimise the noise at source and/or shield it from the general public.

11.2.4 It can be necessary to erect warning signs where it is likely that motorists or others could be subject to danger by an unexpected noise.

11.3 Environmental damage

Appropriate measures shall be taken in order to limit or avoid adverse effects on the environment. The following environmental impact risks shall be considered:

a) excessive induced movement in the construction itself or in adjacent ground or structures;

b) pollution of groundwater or surface water;

c) unacceptable changes in the natural groundwater flow;

d) air pollution;

e) tree falling and damage;

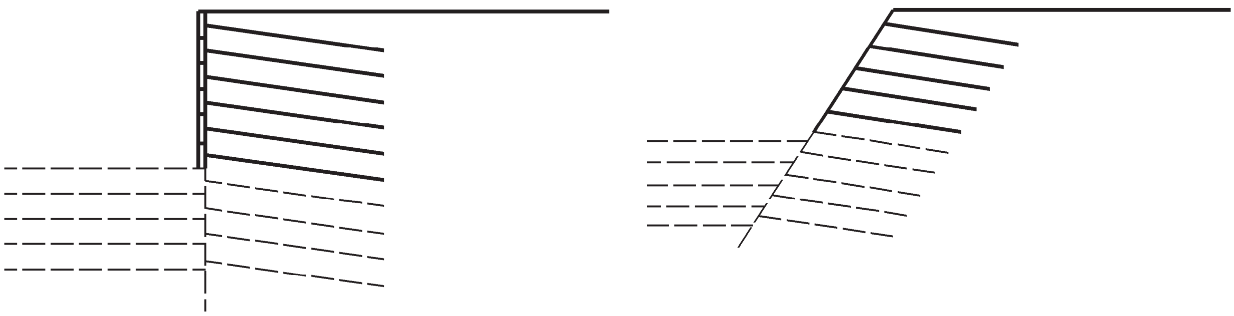
f) visual impact of completed works.

Annex A
(informative)

Practical aspects of soil nailing

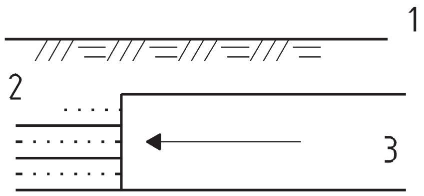
A.1 Introduction

The objective of soil nailing is to improve the stability of the soil in cases where the stability conditions are adverse. The stability is achieved by inserting soil nails, consisting of reinforcing bars, into the soil. Soil nailing is generally applied in connection with excavations, slopes and occasionally tunnelling, as shown in Figures A.1 and A.2, and for improvement of soil stability. The soil nails mobilise frictional forces along their entire length, which contributes to increasing the stability condition. The amount of nails and the length of installation of the nails have to be adjusted in relation to the stability conditions, encountered during the ongoing activities. Protection against corrosion in case of long-term stability problems is required in aggressive soil conditions.



a) Vertical walls **b) Slopes**

Figure A.1 — Safeguarding stability of excavations by the use of soil nailing

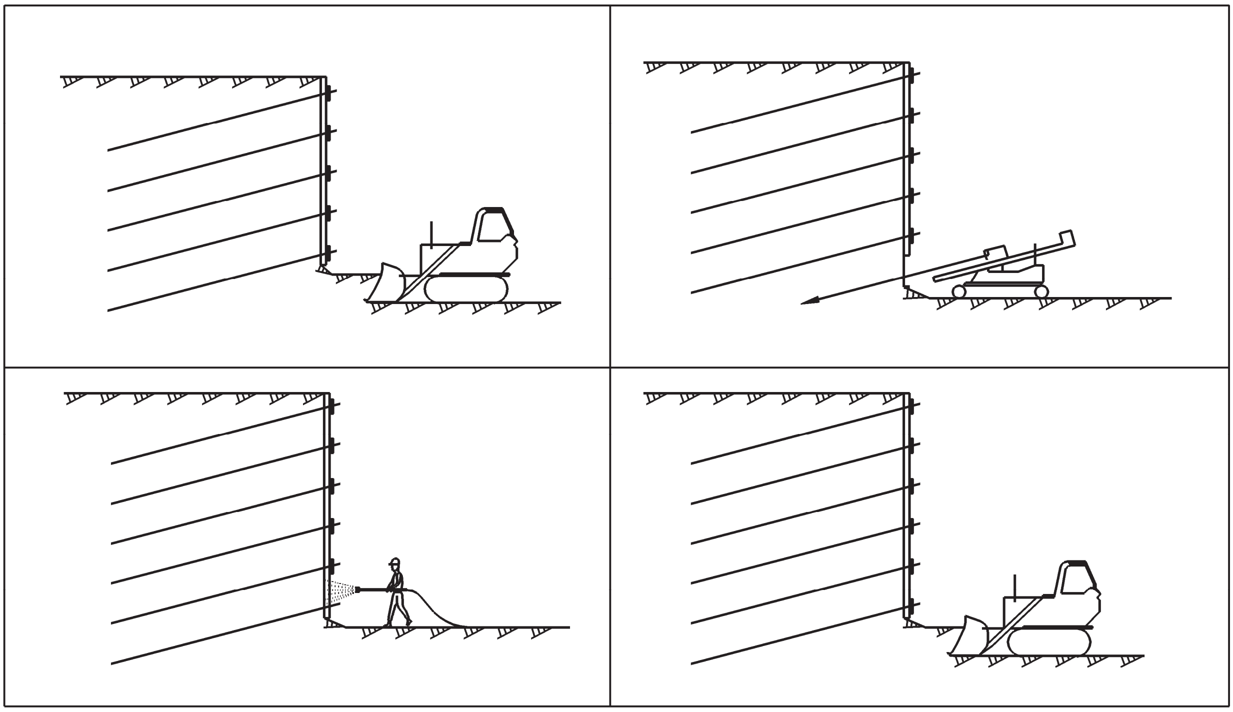


Key

1 ground surface
2 soil nails
3 tunnel advances

Figure A.2 — Safeguarding tunnelling operations by the use of soil nailing

In the case of excavations, the sequence of excavation and soil nailing has to be adjusted in order not to comprise the stability conditions of the site. Typical methods of excavation in combination with soil nailing operations are illustrated in Figures A.3 and A.4.



Key

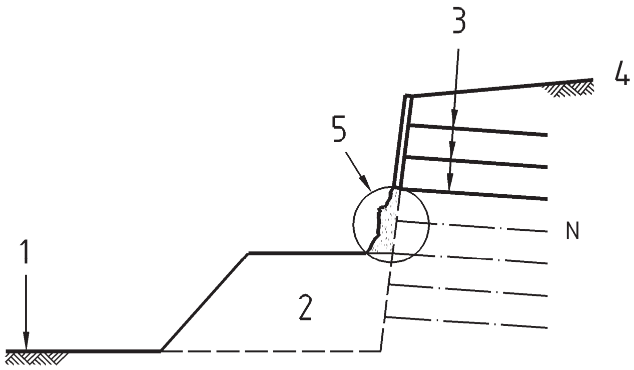
1 excavation

2 installing the nails

3 reinforced shotcrete (or prefabricated facing panels)

4 next excavation

Figure A.3 — Typical sequences of excavation and installation



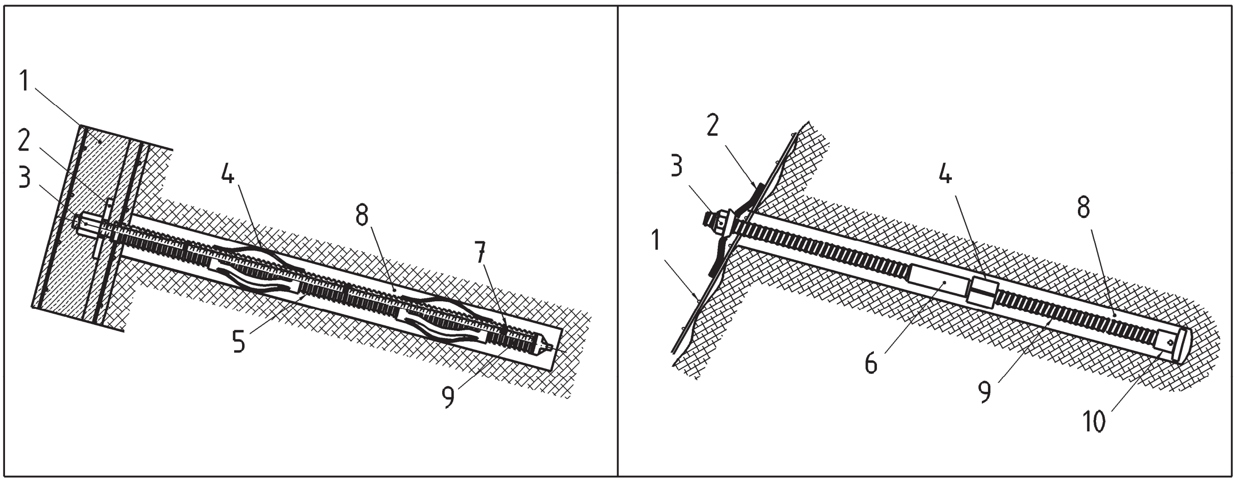
Key

1 bulk excavation to proposed formation
2 berm
3 installed nails
4 existing ground
5 local trimming of face required to achieve agreed tolerances prior to nail installation of nail row "N"
N Nth row

Figure A.4 — Bulk excavation to form benches and face for row "N" of soil nails

A.2 Examples of soil nail systems

The soil nail systems include reinforcement bars, usually steel bars, inserted into and bonded with the ground to the depth required with regard to safety conditions, and often provided with a head plate and a facing system to ensure stability between the nails and also to avoid erosion problems. There is a number of different soil nailing systems. Typical examples are given in Figure A.5.



a) Pre-bored and grouted **b) Self-boring**

Key

1 facing
2 head plate
3 locking nut
4 outer spacer
5 duct
6 coupler
7 inner spacer
8 grout annulus
9 reinforcing element
10 drill bit

Figure A.5 — Typical components of soil nail system, pre-bored & grouted shown with hard/flexible facing

NOTE Other systems may not use grout/duct/couplers/facing/spacers.

A.3 Examples of facing systems used in a soil nail structure

A.3.1 Hard facing

The combination of soil nails and facing has to fulfil the function of stabilising the slope between the nails, and shall therefore be dimensioned to sustain the expected maximum destabilising forces. Examples of hard facing methods are shown in Figures A.6 and A.7.

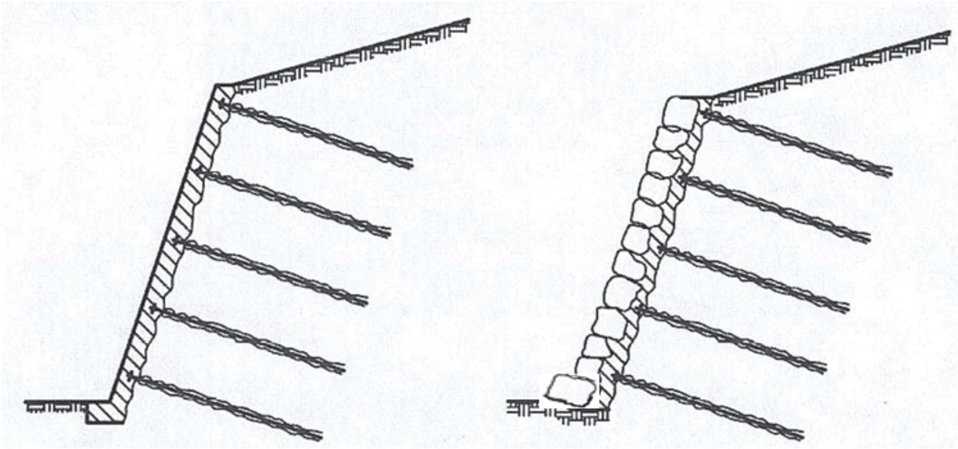


Figure A.6 — Constructed hard facing with concrete (either sprayed or placed or precast)

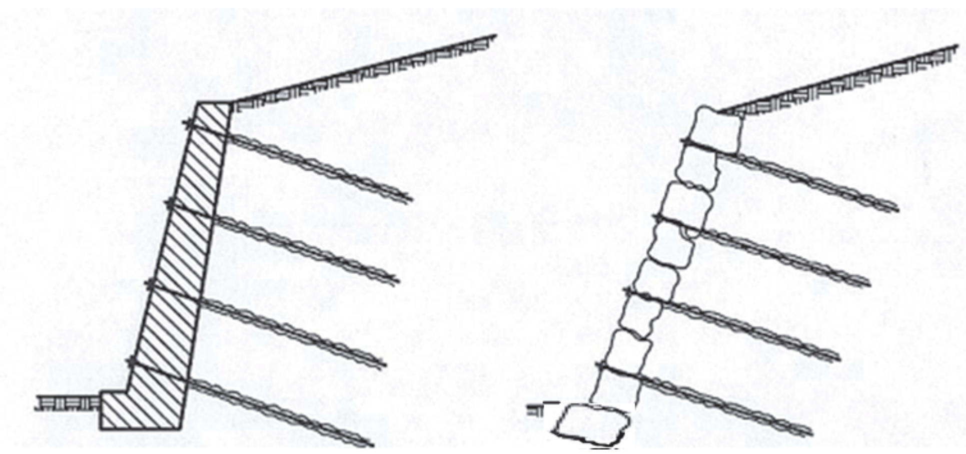
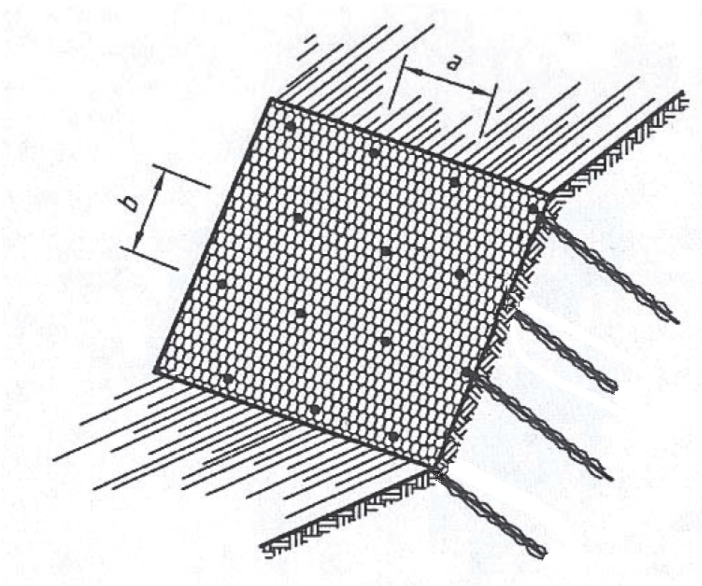


Figure A.7 — Strengthening of existing retaining structures

A.3.2 Flexible facing

Flexible facings are designed to provide the necessary restraint to the areas of slope face between the bearing plates, as well as erosion control. The selection of type of flexible facing is dependent upon slope angle, soil friction angle value, slope height and predicted loading. The common flexible facings include geogrids steel fabrics and geosynthetic.



Key

a nail spacing
b nail spacing

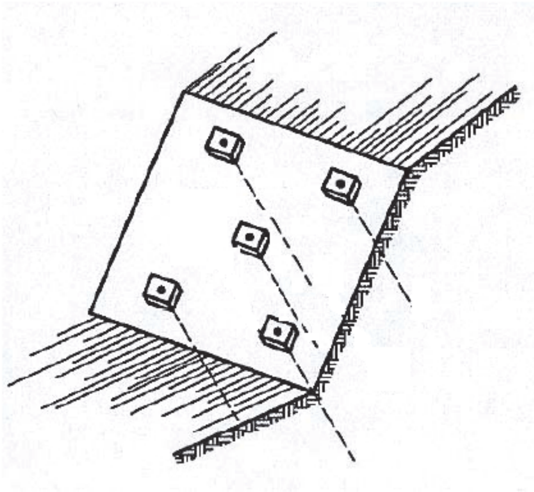
Figure A.8 — Wire mesh

A.3.3 Soft facing

The primary function of soft facing is erosion control and protection against surface ravelling. In many cases, the soft facing has to reinforce the vegetation layer, either in the temporary or the permanent situation. In some instances, nails serve only to retain the facing and not to stabilise the slope.

A.3.4 Without facings

Nailing in case of critically inclined sliding surfaces (e.g. rock strata with reduced shear resistance), however with a stable surface.

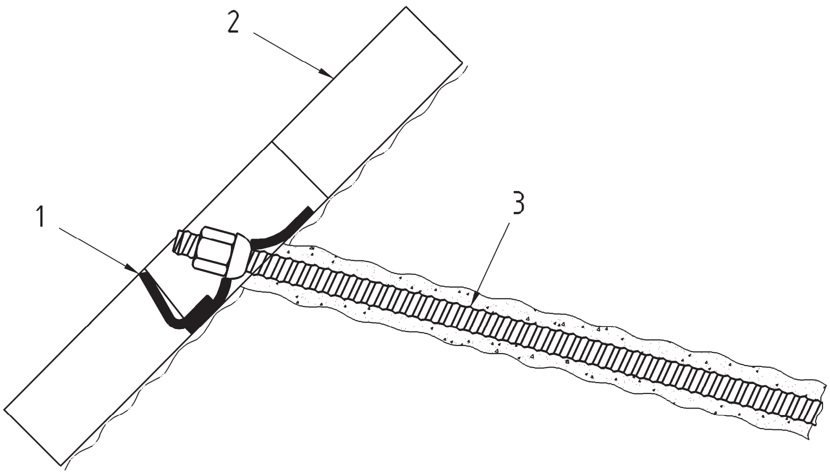


Key

1 nail head lowered and mortared

Figure A.9 — With or without nail head plates

A.3.5 Examples of soil nail heads and connections with soil nail facings



Key

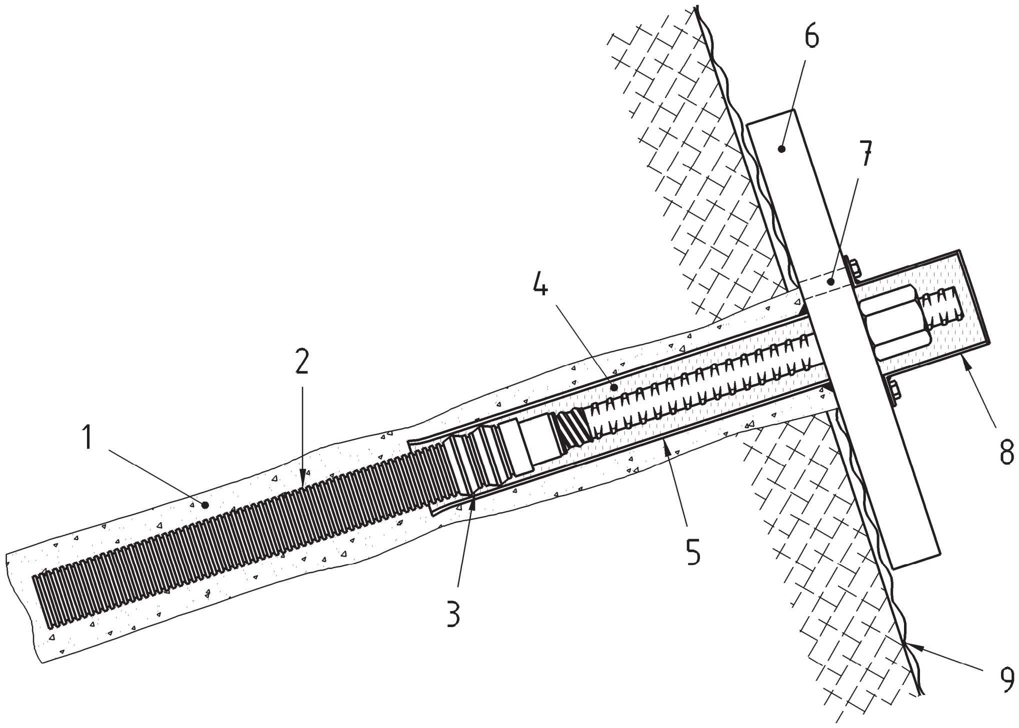
1 hooked plate to retain cellular facing

2 cellular facing [1]) filled with topsoil and seeded

3 hollow bar, soil nail

Figure A.10 — Example of bearing plate-retaining geogrid facing with additional cellular facing for top soiling

1) Geoweb® or Krismer 3D® are examples of suitable products available commercially. This information is given for the convenience of users of this European Standard and does not constitute an endorsement by CEN of these products.



Key

1 borehole grout washed back 1,0 m – prior to top up
2 plastic tabbed sheath
3 sealing rings
4 anti-corrosion compound
5 steel tube
6 flat bearing plate
7 hole for top-up grout
8 protection cap
9 geogrid facing

Figure A.11 — Example of corrosion protection using corrugated plastic duct and a head detail for soil nails in aggressive environments

A.4 Examples of drainage systems used in a soil nail structure

A.4.1 General remarks

Water is detrimental to slope stability and has to be drained away from the surface as much as possible. In this way, general or local erosion, etc. and critical water pressures behind facings may be minimised (specially important in case of a full cover or with a vegetation layer).

Three essential measures have to be distinguished:

a) prevention of surface runoff water;

b) surface drainage;

c) subsurface drainage.

A.4.2 Interception of surface water run off

Figures A.12 and A.13 show examples of drainage above the soil nailing structure.

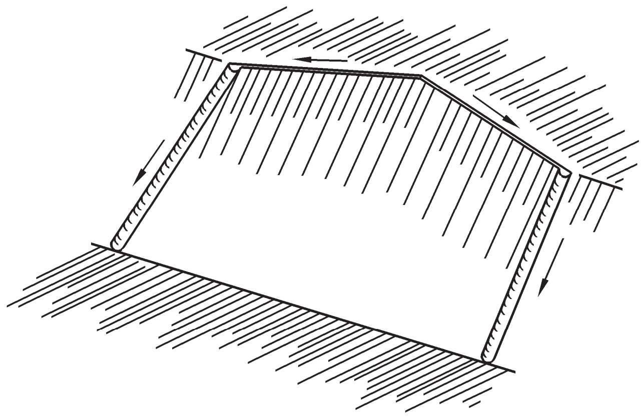


Figure A.12 — Trenched drains above the soil nail structure guided to the sides of the slope

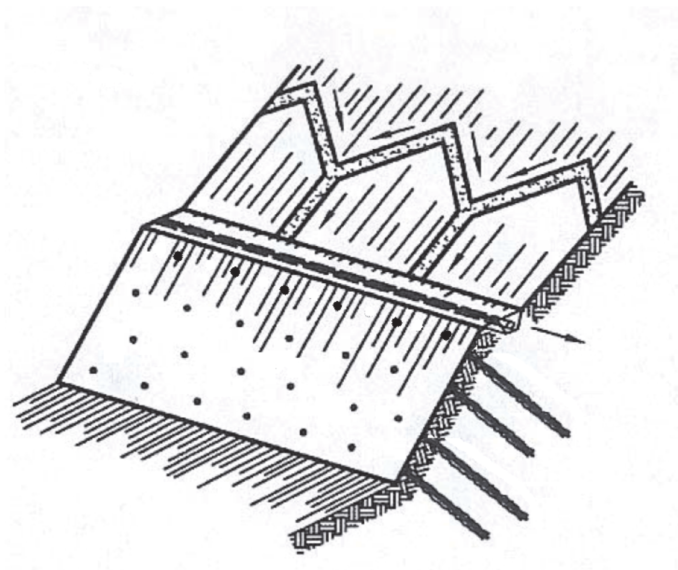
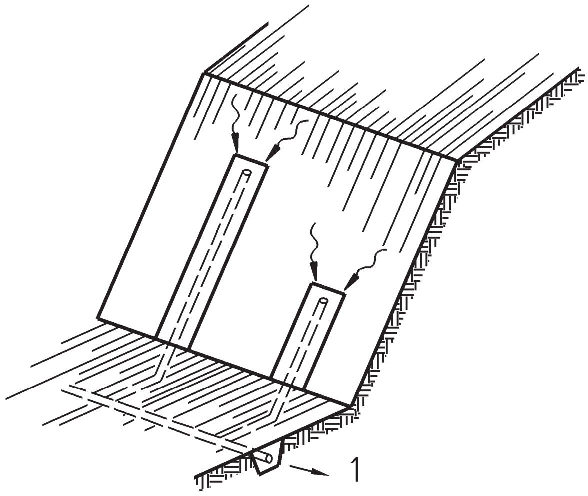


Figure A.13 — Surface drainage above the soil nail structure (e.g. in case of stratum water) (e.g. Y-drains)

A.4.3 Surface drainage

Systems for flexible and soft facings with vegetation layers but also possible behind hard facings (sprayed concrete).



Key

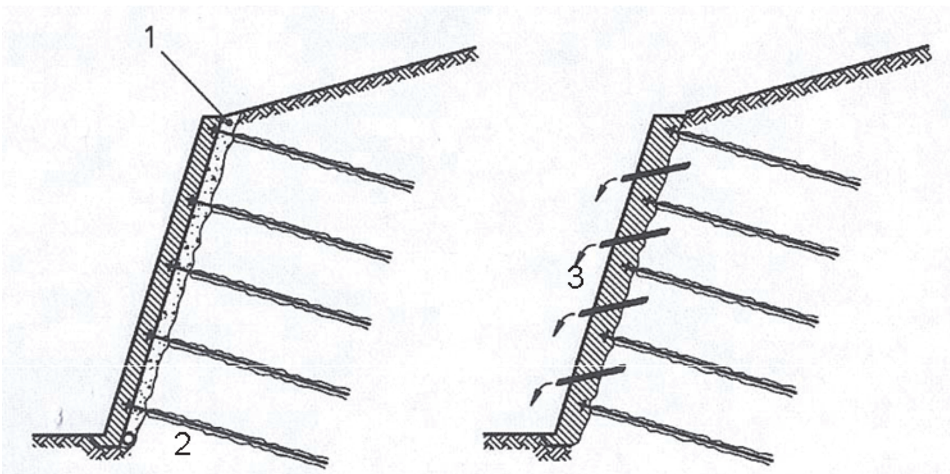
1 foot drainage

Figure A.14 — Seepage

A.4.4 Drainage systems for hard and impermeable facings

In case of concrete walls, prefabricated or cast in place, spread filters made of drainage material and collector drains can be applied.

In any case, with impermeable facings, sufficient leakage holes have to be placed, as shown in Figure A.15.



Key

1 drainage material

2 collector drain

3 "weep-hole" drain

Figure A.15 — Hard and impermeable facings

A.4.5 Subsurface drainage

Subsurface drainage will be required if water-bearing strata are predicted or encountered. Subsurface drainage may be required if the groundwater table has to be lowered.

Drainage boreholes normally contain slotted or perforated pipes. They are normally wrapped with a geotextile filter to prevent the ingress of fines. The characteristic opening size of the geotextile should be chosen to minimise clogging while permitting water into the pipe.

The number, length and pattern of the drainage pipes depend on the expected amount and regime of water. The inclination of the boreholes is typically ≥ 5 %.

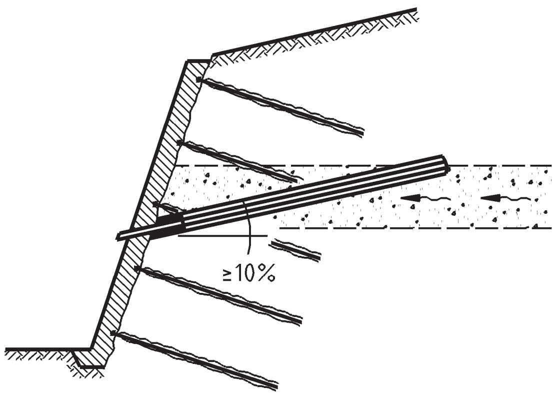


Figure A.16 — Subsurface drainage

A.5 Tolerances

A.5.1 The completed soil nail location at the ground surface should be within ± 100 mm of that intended within the final structural face. Where pre-cast facing is used, a greater accuracy may be required.

A.5.2 The orientation measured at the head of the completed soil nail should be within ± 5° of the design alignment.

A.5.3 Although borehole deviation over the length of the bore may not be critical, it should rarely exceed 1/30 of the bore length.

A.5.4 Where soil nails are installed closely, or are located in close proximity to existing services, drains or structures, the designer may specify tighter tolerances.

A.6 Long-term monitoring

The following points are intended as guide of long-term monitoring:

a) crest levels (minimum intervals 20 m);

b) toe levels (minimum intervals 20 m);

c) crest line (minimum intervals 20 m);

d) partial height line and level (recommended for retained heights over 5 m);

e) inclinometers;

f) ground water level;

g) water flow through weep holes;

h) corrosion test samples (wired for recovery).

Annex B
(informative)

Aspects of design

B.1 General

B.1.1 This annex is not intended to be a design guide, but its purpose is to introduce the soil nail design concepts to those involved in the execution of soil nail works.

B.1.2 Design of soil nailing is not explicitly covered by EN 1997. However, some general geotechnical matters, which are common to soil nailing and to other techniques, are included. This annex provides some guidance on the design of the soil nails.

B.1.3 EN 1997 defines three Geotechnical Categories: 1, 2 and 3. The design advice given in this annex would generally apply to a Category 2 structure. Category 3 structures are very large or unusual and require individual consideration and provision for special factors in addition to the design requirements of Category 2.

B.2 General design philosophy

B.2.1 Normally it is necessary to carry out calculations to assess the stability of the proposed works. In general, a limit equilibrium analysis is used and has been proven to give satisfactory results. One key parameter that requires careful consideration is the determination of the pullout resistance between the nail and the ground, as this is fundamental to the nailing process. The retention effect of soil nails is demonstrated in Figure B.1.

B.2.2 Any stability analysis should assess all the potential failure surfaces passing through the zone into which soil nails are proposed, and those passing behind and below the proposed zone of soil nailing, (Figure A.1). If any of the potential failure surface results in a lower factor of safety than required, then the proposed lengths and spacing of the nails should be adjusted until a satisfactory value can be achieved.

B.2.3 A variety of potential failure mechanisms may be used in a stability analysis (for example: single wedge, two-part wedge, log spiral and slip circle). However, the chosen mechanism should be compatible with the slope geometry and geology and external factors such as seismic activity.

B.2.4 Normally it is necessary to carry out the stability analysis for each stage of construction, as the completed works may not be representative of the lowest factor of safety.

B.2.5 The use of numerical modelling methods, such as the finite element method, may also be used for soil nail design and may provide useful predictions of movement. Analysis based on the finite element method is most efficient in cases where the relevant mechanism of failure differs from conventional circular failure surfaces.

B.3 Soil nail design

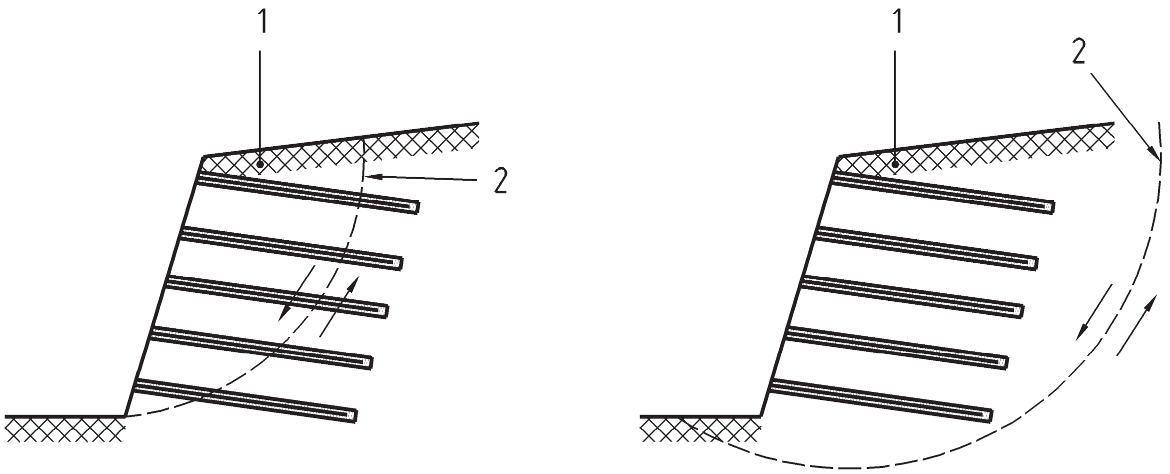
B.3.1 The design of a soil nail concerns mainly the ability of the nail:

a) to sustain the required design load (strength);

b) to limit displacements (serviceability);

c) to sustain these criteria throughout the specified period of its design life (durability);

d) the proposed lengths and spacing of the nails should be adjusted until a satisfactory value can be achieved.



a) Check potential failure mechanisms passing through proposed nails

b) Check potential failure mechanisms passing around proposed nails

Key

1 proposed soil nail

2 potential failure surface

Figure B.1 — Limit equilibrium stability analyses of soil nail structures

B.3.2 Design considerations

B.3.2.1 There are three main aspects influencing the performance of the soil nail structure:

a) ground conditions;

b) strength of the reinforcing elements;

c) pullout resistance between the soil nail and the ground.

B.3.2.2 The pullout resistance of the soil nail can be determined, either by estimation from measured ground properties (laboratory tests or field tests), or established directly from measured properties (nail load tests).

B.3.2.3 These methods should consider behaviour of the ground and groundwater over the design life of the structure and, where possible, be verified with directly measured properties.

B.3.2.4 Tests to assess or confirm the pullout strength of a soil nail are described in Annex C.

B.3.2.5 Pullout resistance partial factors for design should be appropriate to the applicable standard.

B.3.3 Serviceability

B.3.3.1 There are currently no methods for accurately predicting in-service deformations of soil nail constructions. However, estimates can be based on empirical observations or numerical predictions. If numerical predictions are used, the parameters used in the analysis should be carefully selected and the model calibrated.

B.3.3.2 Nail head displacements, measured during load testing, may give some limited assistance in assessing the likely overall lateral displacement at the face. The limiting values for the overall structure shall comply with the requirements of EN 1997.

B.3.3.3 The displacement and deformation of a soil-nailed construction may be influenced by factors outside the soil-nailed zone. Particular attention should be paid to the settlement or the erosion of the soil below the construction, lateral soil creep adjacent to the construction and changes in the ground water level.

B.3.4 Design durability

B.3.4.1 General

B.3.4.1.1 For metallic reinforcement the primary form of degradation is electro-chemical corrosion. However, synthetic reinforcement and components can be subject to deterioration by hydrolysis, oxidation, environmental stress cracking, etc. The rate of degradation depends on the electro-chemical environment in the ground, the material of the reinforcement, its temperature and stress level.

B.3.4.1.2 The protection against corrosion of steel elements in a nail shall take into account the aggressiveness of the environment, the nail type, the type of load (tension or compression), the type of steel and design service life required.

B.3.4.1.3 For connecting elements, the same rules of corrosion protection shall be applied as for the other steel elements.

B.3.4.1.4 Particular care should be taken to the continuity of the corrosion protection at connecting elements.

B.3.4.1.5 Care should be taken that specific precautions do not reduce other properties.

B.3.4.2 Corrosiveness assessment

B.3.4.2.1 The required design life for a particular situation may be achieved by a variety of methods or combination of methods. Normally, a corrosiveness assessment of the ground will be required to determine which level of corrosion protection is required.

B.3.4.2.2 Table B.1 suggests four different soil categories based on a ranking procedure, to determine the aggressiveness of the soil condition and hence the necessity of corrosion protection.

Table B.1 — Classification of soil condition

Soil features	*Classification*	*Index ΣA*
Highly corrosive	I	13 or greater
Corrosive	II	9 to 12
Average corrosive	III	5 to 8
Slightly corrosive	IV	4 or less

NOTE Table B.1 is an excerpt from Clouterre (Soil Nailing Recommendation – 1991). Further information regarding the soil features can be found in Clouterre.

B.3.4.2.3 Table B.2 gives a general method for corrosiveness assessment, highlighting factors that are important to consider.

B.3.4.2.4 The assessment should be based on the best-known values or estimates for the considered site. If no information is available, the worst relevant case shall be considered.

B.3.4.2.5 Then the general method implies that the soil condition is aggressive or highly aggressive; a more detailed assessment should be performed according to national requirements.

Table B.2 — General method for corrosiveness assessment

Criterion	*Features*	*Weight* A *of Criterion*
Type of soil [2)]	**Texture**	
	— heavy, plastic, sticky impermeable;	2
	— clayey sand;	1
	— light, permeable, sandy, cohesionless soils	0
	Peat and bog/marshlands	8
	Industrial waste	
	clinker, cinders, coal	8
	builders waste (plaster, bricks)	4
	Polluted liquids	
	waste water, industrial	6
	water containing de-icing salts	8
Resistivity	p < 1 000	5
(Ω·cm)	1 000 < p < 2 000	3
	2 000 < p < 5 000	2
	5 000 < p	0
Moisture content	Water table – brackish water	8
	(variable or permanent)	
	Water table – pure water	4
	(variable or permanent)	
	Above water table – moist soil	2
	(water content > 20 %)	
	Above water table – dry soil	0
	(water content < 20 %)	
pH	< 4	4
	4 to 5	3
	5 to 6	2
	> 6	0
	Global Index	Sum of above ΣA

NOTE Table B.2 is an excerpt from Clouterre (Soil Nailing Recommendation – 1991). Further information regarding the soil features can be found in Clouterre.

2) The value of the weight of criterion for "Types of soil" would be the maximum value applicable to that soil from subgroups "texture", "peat", "industrial waste" and "liquid". The maximum weight for each of the four criteria is less than or equal to 8.

B.3.4.3 The following approaches for achieving the desired service life are commonly applied to metallic, usually steel reinforcement:

a) sacrificial thickness allowance;

b) a cover of appropriate grout, mortar or concrete;

c) surface coating;

d) corrugated duct with grout;

e) stainless steel;

f) a combination of the above.

B.3.4.4 Sacrificial thickness allowance

This method assumes no surface treatment or grout encapsulation. It relies on the cross section of the reinforcing element and other components being over-dimensioned to allow for corrosion. The predicted thickness-loss due to corrosion is based on historical data, taken from soil nails, sheet piling and corrugated buried steel structures, installed in similar environments with varying levels of soil aggressiveness. Table B.3 gives an indication of rates for sacrificial corrosion losses.

NOTE 1 This method is not recommended for reinforcing elements with a small cross sectional area or for steels with a high carbon content. The sacrificial steel concept is generally used for soil nails, where the percentage loss of cross section does not exceed half of its initial cross section. It is normally used, where the nails are installed at fairly close centres and a degree of redundancy exists.

NOTE 2 In aggressive and highly aggressive soil conditions, it is important to consider that the soil nail is expected to take not only tension forces but also some shear.

Table B.3 — Indication loss of steel thickness (in millimetres) due to corrosion (total reduction of diameter or thickness including both sides)

Overal index I [3]/Classification	*Short-term* $\leq$ *18 months*	*Short-term* *1,5 years to* $\leq$ *30 years*	*Long-term* *30 years to* $\leq$ *100 years*
$\leq$ 4/IV	0	2 mm	4 mm
5 to 8/III	0	4 mm	8 mm
9 to 12/II	2 mm	8 mm	plastic sheath [a]
$\geq$ 13/IV	Plastic sheath shall be provided [a]		

[a] A metal casing is not recommended unless there are special reasons for using it.

NOTE 3 Table B.3 is an excerpt from Clouterre (Soil Nailing Recommendation – 1991). Similar tables can be found in other documents, such as EN 14199.'

B.3.4.5 A cover with appropriate grout, mortar or concrete

B.3.4.5.1 The corrosion protection provided by the alkalinity of hydrated cement grout may be accepted provided that a high level of alkalinity (pH 9,5 to pH 13,5) is maintained.

3) Overal index $I = \Sigma A + C$, there ΣA is based on Table B.2 and C is a factor related to the class of structures. C = 2 for critical structures and C = 0 for standard structures.

NOTE Research has shown that crack widths controlled to less than 0,1 mm can be considered to be self-healing. Therefore, cement grout is considered acceptable as an impermeable protective encapsulation, provided that the crack width within the grout body can be demonstrated not to exceed 0,1 mm.

B.3.4.5.2 As guidance, grout cover to the reinforcing element and any couplers should be greater than values in Table B.4 depending on soil condition and service life.

B.3.4.5.3 Grout may be placed during or after drilling and may be injected via a hollow reinforcing element or a separate grout pipe. The use of pressure grouting techniques may enhance the thickness and quality of the cement grout and improve its properties as a corrosion barrier.

B.3.4.5.4 The values in Table B.4 are related to grout cover with no other precautions added. The table is based on experience from other types of structures and shall only be considered as guidance. In combination with other actions (such as galvanization or duct) a longer service-life may be achieved.

Table B.4 — Guidance on minimum grout cover to metallic parts in the borehole depending on soil condition and service life

		Service – life of the structure (years) ***Grout cover (mm)***				
	Soil condition	***5***	***25***	***50***	***75***	***100***
IV	Non aggressive	10	20	25	35	a_1
III	Sligthly aggressive	20	30	40	50	a_1
II	Aggressive	30	40	50	75	a_1
I	Highly aggressive	n.a.	n.a.	n.a.	n.a.	n.a

a_1 Special consideration, required for determination of necessary grout cover.

NOTE The values given are only for guidance. Local conditions should be considered and suitable values taken into account.

B.3.4.6 Surface coating

B.3.4.6.1 Steel coatings, such as galvanising and epoxy coating, offer protection of the steel against corrosion. The period of protection is dependent upon the thickness and quality of the coating.

B.3.4.6.2 Metallic coatings are robust and self-healing and the consequence of surface damage is less severe. The zinc coating imparts a protective surface to the steel, which remains after the loss of galvanising thickness. This surface reduces the subsequent rate of corrosion of the parent metal and thus the magnitude of the secondary sacrificial thickness. It is important to note that the rates of corrosion of a galvanised coating can vary markedly with both time and position.

B.3.4.6.3 Epoxy coating is sometimes considered equivalent to zinc coating but the process of protection differs between the two. Epoxy coatings have theoretically a long life in soil, often in excess of the service life of the structure. It is essential that care is employed when handling and installing epoxy coated soil nails since local damage may lead to local corrosion.

B.3.4.6.4 Galvanised coating shall be performed according to EN ISO 1461.

B.3.4.6.5 Special precaution should be taken to avoid damage of the galvanisation during transportation, handling and installation of the galvanised soil nail.

B.3.4.7 Corrugated duct with grout

B.3.4.7.1 Ducts are used in conjunction with grout. The inclusion of a duct within the grout cover prevents ingress of water or corrosive substances where cracking of the grout occurs.

B.3.4.7.2 The effectiveness of the duct will depend on the sealing efficiency of the system and the ease and practicability of sustaining the systems integrity during the installation and subsequent grouting of the borehole.

B.3.4.7.3 Ducts provide the primary source of protection for reinforcing elements in aggressive ground conditions. It is important that care is exercised when handling and installing duct protected soil nails.

B.3.4.8 Stainless steel

B.3.4.8.1 There are a number of different types of stainless steel. If stainless steel is proposed for soil nailing, its resistance should be shown to corrosion in the actual ground condition for the service life.

B.3.4.8.2 A connection between stainless steel and other steel should be avoided, to prevent galvanic corrosion.

B.4 Matters of importance specific to soil nailing design

B.4.1 Where soil-nailing construction involves excavation, the stability of the works at various stages of construction technique shall be considered in the design, as the factor of safety may be lower during temporary works than for the final installation.

B.4.2 Soil nailing is an *in-situ* technique; hence the possible options for modifying the design should be considered if unforeseen ground conditions are encountered on site.

B.4.3 Groundwater, infiltration of rainfall and drilling with high-pressure water as a flushing medium have an important effect on most geotechnical structures. For soil nailing this is especially the case since increased pore water pressure may reduce both the stability of the soil and the pullout resistance of the nails. Because of the risk of drainage becoming blocked over time, the design should include for some redundancy to the subsurface drainage system.

Annex C
(informative)

Testing of soil nail systems

C.1 Testing

C.1.1 Two different types of tests can be performed. sacrificial nail tests (see C.3.3) and production nail tests (see C.3.4).

C.1.2 The designer should specify the bond length of the test nail (the length of the nail in contact with the surrounding ground).

When designing the bond lengths for the nail test programme, the following should be taken into account:

a) geological stratigraphy and potential variations;

b) the location of the potential slip surfaces, defining active and passive zones in the design model;

c) the typical (or average) nail length within the passive and active zones used in the design model (i.e. the test nail bond length shall be representative of the lengths, providing the stabilising force within the structure).

C.1.3 It is essential that the test nail be axially loaded; this can be achieved by cutting the slope perpendicular to the nail or with a stressing chair.

C.1.4 The proof load, P_p, should be defined in the design.

C.2 Equipment

C.2.1 Proof loading set-up

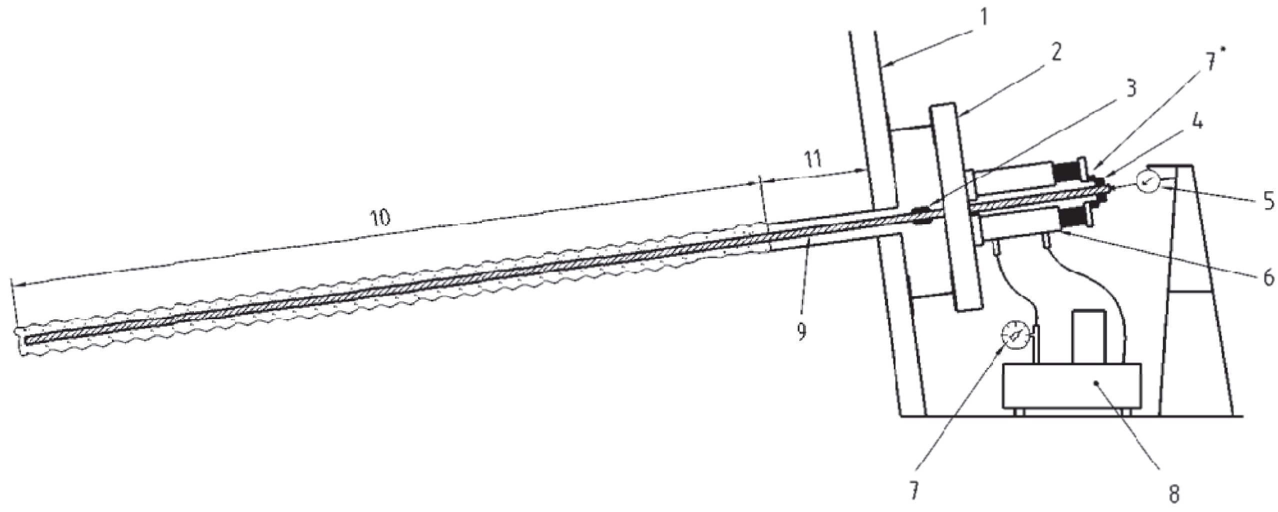
C.2.1.1 The proof loading system comprises the jack or stressing device, displacement and load monitoring devices, a reaction system, associated locking nuts, extension pieces, etc. A schematic nail proof loading system is shown in Figure C.1.

C.2.1.2 The proof loading system should be capable of functioning safely without excessive deformation at the maximum proof load.

C.2.1.3 Where the facing system, or the load test reaction system, could influence the test result, then the test nail should be de-bonded over the zone of influence.

C.2.1.4 Prior to final assembly of the displacement monitoring system, it may be necessary to apply a datum load to minimise the movement of the nail test arrangement on initial loading. The datum load P_o should not exceed 10 % of P_p.

NOTE The datum load is the initial force P_o applied to a test nail before commencing the load test to take up slack in the test system (sometimes referred to as a seating load).



Key

1 facing
2 rigid reaction frame
3 extension of soil nail for testing
4 locking nut and plate at top of jack
5 displacement gauge on independent support frame
6 hydraulic jack for stressing
7 calibrated pressure gauge to control jack force (load cell can be used as alternative, see 7* in the figure)
8 pump
9 soil nail
10 bonded length
11 de-bonded length

Figure C.1 — Schematic layout of the nail load test system

C.2.2 Reaction system

C.2.2.1 The reaction system shall be designed to have a structural resistance at least equal to the maximum proof load (P_p), according to the relevant European Standards.

C.2.2.2 The reaction system should be designed so as not to affect the measured pullout resistance of the test nail or to impose bearing pressures in excess of the safe bearing capacity of the facing.

NOTE This could be accomplished by using a special load distribution device at the front of the facing. This is especially important for soft facing.

C.2.3 Loading service

The loading device, normally a hydraulically operated jack, should have a nominal capacity at least equal to the maximum proof load, P_p. The extension of the jack should preferably be sufficient to avoid reseating during the test. The design of the loading device should permit the proof load to be applied smoothly and axially to the test nail, in both increasing and decreasing load increments.

C.2.4 Load measurement

The load in the test nail may be measured either indirectly by means of a calibrated pressure gauge, monitoring the hydraulic pressure in the loading device, or directly by the use of a load cell. Pressure gauges and load cells should be calibrated to an accuracy of ± 2 % of the maximum proof load, P_p. If load cells are used, it is recommended that a secondary method of measurement is used due to the difficulties of their use in the field.

C.2.5 Displacement measurement

The displacement monitoring system should be calibrated to have a reading accuracy of ± 0,1 mm. The support for the displacement gauges should be remote from the loading device and reaction system. The independent support should be sufficiently rigid, so as not to be influenced by climatic effects or background vibrations. Displacement gauges should be capable of monitoring the extension of the test nail throughout the test, without the need for reseating.

C.2.6 Time and temperature measurement

C.2.6.1 The accuracy of the equipment for measuring time shall be ≤ 1 s.

C.2.6.2 The accuracy of the equipment for measuring temperature shall be ≤ 1 °C.

C.3 Test procedure

C.3.1 Testing requirements

The test method, frequency and acceptance criteria should be agreed with the designer, if not specified.

NOTE There are two different types of soil nail load tests, sacrificial nail test and production nail test, both with different purpose and requirement. The test procedure is described below.

C.3.2 Testing methods

For soil, nailing static load tests should be used. This annex will describe the static load test in details, but relevant requirements listed in this annex shall be applied if other test methods are used, such as the displacement controlled test.

C.3.3 Static load test – General

C.3.3.1 Static load test methods involve incremental loading of the test nail, up to a maximum value, and measuring of the corresponding displacement of the nail at each increment. The number of load increments, duration of load increment and criteria for increasing the load, will vary depending on the purpose of the test.

C.3.3.2 Static load tests can be conducted in a single cycle of load application, or in a number of cycles. Long-term creep characteristics can also be investigated by static load test methods by maintaining the load for longer periods. This latter type of test is normally termed a "sustained" or "creep" load test.

C.3.3.3 Static load testing can be used for a variety of purposes, including to verify the ultimate soil nail to ground bond resistance, used in the design, and to demonstrate satisfactory soil nail performance at the service load.

C.3.3.4 Table C.1 gives a summary of the differences in test procedures between sacrificial nail tests and production nail tests, where guidance is given on the number of cycles, the maximum cycle load, the minimum number of load increments and maximum proof load.

Table C.1 — Suggested criteria for static load testing of soil nails

Test type	Sacrificial nail test	Production nail test
Estimation of maximum proof load	The value of P_p shall be decided in the design, considering the relevant design approach according to EN 1997 and appropriate partial factors of safety.	The value of P_p shall be decided in the design, considering the relevant design approach according to EN 1997 and appropriate partial factors of safety.
Number of load cycles	If more than one cycle is applied, the bond resistance in the first cycle should not exceed the characteristic value of the load assumed in the design.	A single cycle is normally satisfactory.
Number of load increments	The maximum increment size should be sufficient to define the shape of the load displacement graph and should not normally exceed 20 % of the maximum cycle load.	The minimum number of load increments is 5.
Interpretation of results	The sacrificial nail test result is acceptable provided that the creep rate at the maximum proof load P_p is less than 2 mm per log cycle of time, unless no smaller creep rate is specified in the design. The measured extension at the head of the nail at proof load is not less than the expected elastic extension of any debonded length of the test nail L_{db}.	The production nail test result is acceptable provided that the creep rate at the maximum proof load P_p is less than 2 mm per log cycle of time, unless no smaller creep rate is specified in the design. The measured extension at the head of the nail at proof load is not less than the expected elastic extension of any debonded length of the test nail L_{db}.

NOTE The creep rate is defined as $(s_2 - s_1) / \log_{10}(t_2/t_1) < 2$ mm, where s_1 and s_2 are the measured nail displacements at time 1 and time 2 respectively.

C.3.4 Static load test – Sacrificial nail test procedure

C.3.4.1 General

C.3.4.1.1 The sacrificial nail test is a test in which an axial load is applied step-wise to a soil nail up to the proof load P_p to confirm that a particular soil nail design will be adequate in particular ground conditions. This normally involves loading the test nail to failure, or to the characteristic value of the resistance anticipated in the design. A suggested frequency for sacrificial nail test is given in Table 2, 9.3.

C.3.4.1.2 Each load is kept constant during a specified period. The test involves measurement of nail head displacement versus applied load and, for each or at least one load step, measurement of nail head displacement versus time.

C.3.4.2 Test nails

The sacrificial nail test shall be carried out on sacrificial soil nails, which are not part of an actual structure, installed and tested prior to the installation of production nails in the same area.

C.3.4.3 Location

C.3.4.3.1 Soil conditions at the test location shall be representative of the soil conditions for production nails.

C.3.4.3.2 The results of the site investigation shall be considered when selecting a soil nail test location.

C.3.4.4 Execution

C.3.4.4.1 Test nails shall be representative of production nails.

C.3.4.4.2 Test nails shall be installed using the same installation procedures as productions nails.

C.3.4.4.3 The method used for the installation of proof nails shall be fully documented.

NOTE Records should be made of relevant aspects of the installation, including installation procedure, soil and hydro-geological conditions and, if applicable, results of the tests and checks, carried out on the soil nail material, and any difficulties encountered during execution.

C.3.4.4.4 Test soil nails should have the same inclination as production nails.

Test soil nails and any extension pieces, required for testing, shall be designed to satisfy the lower value of the following inequalities:

$P_p < 0,80\ R_{t,k;}$

$P_p < 0,95\ R_{t0.1,k}$

where

$R_{t,k}$ is the characteristic value of the structural tensile resistance of the test soil nail or any of the extension pieces;

$R_{t0.1,k}$ is the characteristic value of the 0,1 % yield resistance of the test soil nail or any of the extension pieces;

P_p is the maximum test load (the proof load) to which the test soil nail is subjected.

C.3.4.5 Date of test

Between the installation of test soil nail and the beginning of the test, adequate time shall be allowed to ensure that the required strength of the soil nail materials is achieved.

NOTE Adequate time depends for example on weather, soil condition, and grout components.

C.3.4.6 Execution of test

C.3.4.6.1 Test preparation

a) Prior to commencement of the test, the preparation shall at least include:

   1) installation of measurement devices and checking its normal and safe functioning;

   2) establishing a perimeter of safety around the test nail;

   3) installation of the loading system and checking its normal and safe functioning (e.g. it shall be checked that the loading device is in the axis of the test nail).

b) The displacement reference system shall be located in such a way that it is not affected by any displacement of the reaction system and it shall be protected against climatic effects.

C.3.4.6.2 Maximum proof load

The maximum proof load P_p shall be defined prior to the test in the design.

C.3.4.6.3 Datum load

A datum load P_o shall be applied. This load shall not exceed 0,10 P_p.

C.3.4.6.4 Loading procedure

a) A suggested procedure for conducting static load tests can be described as follows:

   1) following application of the datum load P_o, the initial displacement s_o is recorded;

   2) the load is then increased smoothly and incrementally up to the maximum cycle or proof load, or until pullout failure occurs at R_t. The maximum increment size should be sufficient to define the shape of the load displacement graph and should not normally exceed 20 % of the maximum cycle load;

   3) following application of each load increment, the load is held constant until the nail displacement stabilises, i.e. the displacement between two consecutive readings at times ($s_1 - s_2$) is less than 0,5 mm with readings taken at time t = 0 min, 1 min, 2 min, 5 min, 10 min, 15 min, 20 min.

b) Where stabilisation has not been achieved, the nail should be loaded to the next load increment to try to achieve displacement stabilisation. There are two reasons for this:

   1) on fully bonded test nails (i.e. self-drilled hollow bars), for load to be mobilised in the passive (stable) zone, progressive de-bonding during nail loading shall be induced in the active wedge zone for the proof load to be transferred directly to the stable zone;

   2) to induce bond breaking in the wedge zone with hold periods up to 60 min would take many days.

c) If for any load increment the nail cannot sustain the applied load and the 0,5 mm movement criterion cannot be achieved, then no further load should be applied and the residual load in the nail should be recorded (this will generally represent the ultimate pullout force R_t).

d) On reaching either the maximum cycle load R_t or P_p and observing the hold period, the test nail shall be unloaded to the datum load P_0 and residual displacement recorded s_r; if required, further load cycles may be carried out.

e) It is optional to perform the test as a single cycle test or a two-cycle test. If the test is performed as a two-cycle test, the load in the first cycle should not exceed the characteristic value of the load assumed in the design.

f) For self-drilled hollow bars (installed with simultaneous drill and grout), the inability to sustain 0,5 mm under an applied load does not necessarily mean that the ultimate pullout load has been reached, because for load to be mobilised in the passive (stable) zone it is often necessary to break the bond in the active zone to achieve loading of the stable zone.

C.3.4.6.5 Measurements and checks

a) Prior to commencement of the test, it shall be ensured that external sources cannot affect the measurements. Normal functioning of the measurement equipment shall be checked.

b) The following measurement procedure shall be followed for performing a sacrificial nail test:

   1) if necessary, after application of the datum load P_0 , the initial displacement s_0 shall be recorded;

   2) during the stressing stage, at each load step if necessary, the load and the nail head displacement shall at least be recorded at the successive monitoring times (in minutes) as indicated below:

$$1 \rightarrow (2) \rightarrow (3) \rightarrow (4) \rightarrow (5) \rightarrow (7) \rightarrow (10) \rightarrow (15) \rightarrow (20)$$

NOTE The necessary testing period will be defined by national regulation.

3) during the de-stressing stage, the load and the nail head-displacement shall be recorded at least at the end of each step and 5 min after the total de-stressing;

4) where relevant, the displacement of the reaction system shall be recorded at least at the end of each load step.

c) At each load step, the stressing and reaction devices shall be visually inspected in order to detect any degradation.

d) At each load, the stability of the installation shall be ensured.

C.3.4.6.6 Test results

a) Based on the collected data, at least the following relationships shall be graphed:

1) plot "soil nail head displacement versus load" at the end of each load step;

2) and, If relevant, also plot "soil nail head displacement versus time" for each load step.

b) The sacrificial nail test result is acceptable provided that:

1) at the maximum proof load P_p the creep rate is less than 2 mm per log cycle of time unless no smaller creep rate is specified in the design;

2) the measured extension at the head of the nail at proof load is not less than the expected elastic extension of any debonded length of the test nail L_{db}.

C.3.5 Static load test – Production nail test procedure

C.3.5.1 General

A production nail test is used to demonstrate that production soil nail installation methods and the ground conditions encountered result in soil nails with satisfactory load displacement characteristics at the proof load. The proof load should be established in accordance with the design. A suggested frequency for acceptance testing is given in 9.3, Table 2.

C.3.5.2 Test nails

A production nail test shall be carried out on productions nails.

C.3.5.3 Date of test

Between the installation of test nails and the beginning of the test, adequate time shall be allowed to ensure that the required strength of the nail materials is achieved.

NOTE Adequate time depends for example on weather, soil condition and grout components.

C.3.5.4 Execution of test

C.3.5.4.1 Test preparation

a) Prior to commencement of the test, the preparation shall at least include:

1) installation of measurement devices and checking its normal and safe functioning;

2) establishing a perimeter of safety around the test nail;

3) installation of the loading system and checking its normal and safe functioning (e.g. it shall be checked that the loading device is in the axis of the test nail).

b) The displacement reference system shall be located in such a way that it is not affected by any displacement of the reaction system and it shall be protected against climatic effects.

C.3.5.4.2 Proof load

The proof load P_p shall be defined in the design.

C.3.5.4.3 Datum load

A datum load P_0 shall be applied. This load shall not exceed 0,10 P_p.

C.3.5.4.4 Loading procedure

The loading procedure according to C.3.4.6.4 can be applied for production nail test as well as for sacrificial nail test. For the production nail test the load cycle is optional.

C.3.5.4.5 Measurements and checks

The measurements and checks according to C.3.4.6.5 can be applied to production nail tests as well as sacrificial nail tests.

C.3.5.4.6 Test results

The test results shall be plotted according to C.3.4.6.6.

C.4 Test reports

C.4.1 Production nail test

a) The test report shall at least include:

1) reference to all relevant standards;

2) the following specifications concerning the test nail:

i) location and type of soil nail;

ii) date of installation;

iii) observations related to the installation of the soil nail, likely to have an influence on the test results;

iv) geometrical data of the soil nail and mechanical properties of the soil nail material;

v) level of its top, its base and of the ground around it;

3) the following factors concerning the soil nail test:

i) reference of the tester which has carried out the test;

ii) date of the test;

iii) value of the prescribed maximum load;

4) if relevant, the following test results based on collected data:

i) plot "nail head displacement versus nail load";

ii) plot "nail head displacement versus time" at the maximum load.

b) Tables of numerical values of the collected data shall be provided in the annexes of the test report.

C.4.2 Sacrificial nail test

For sacrificial nail test, the test report should at least include the following material in addition to that included in the test report for the production nail test:

a) the following factors concerning soil conditions:

1) location of the closest geotechnical investigation profiles;

2) reference to the site investigation report;

b) the following factors concerning the nail test:

1) characteristics of the loading system;

2) description of all monitoring systems and their components;

3) sketch of the instrumentation of the test nail;

4) observations related to the execution of the test, likely to have an influence on the results;

c) if relevant, the following test results based on collected data:

1) plot "soil nail head displacement versus soil nail load" at the end of each load step;

2) plot "soil nail head displacement versus time" for each load step;

3) soil nail pullout resistance;

4) plot "load-loss versus time" for each load step and after lock-off;

5) plot "load-loss versus soil nail load";

6) plot "elastic and plastic displacements versus soil nail load";

7) plot "increase of displacements versus number of cycles".

Annex D
(informative)

Degree of obligation of the specifications

The provisions are marked corresponding to their degree of obligation:

(*REQ*) requirement;

(*REC*) recommendation;

(*PER*) permission;

(*POS*) possibility;

(*ST*) statement.

1. Scope

1.1 – 1.6 Provisions

2. Normative reference

List

3. Terms, definitions and symbols

3.1.1 – 3.1.20 List
3.2 List

4. Information needed for the execution of the works

4.1 General

4.1.1 (*REQ*)
4.1.2 (*REQ*)

4.2 special features

4.2.1 (*REQ*)
4.2.2 (*REQ*)
4.2.3 (*REQ*)

5 Geotechnical investigation

5.1 General

5.1.1 (*REQ*)
5.1.2 (*REQ*)
5.1.3 (*REQ*)
5.1.4 (*REQ*)

5.2 Special aspects of soil nailing

5.2.1 (REQ)
5.2.2 (*REQ*)
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6 Materials and products

6.1 General

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6.2 Soil nails systems

6.2.1 General

PER

6.2.2 Reinforcing element

6.2.2.1 General

6.2.2.1.1 (*ST*)
6.2.2.1.2 (*PER*)
6.2.2.1.3 (*REQ*)

6.2.2.2 Metallic reinforcing element

6.2.2.2.1 (*REQ*)
6.2.2.2.2 (*REQ*)
6.2.2.2.3 (*REC*)
6.2.2.2.4 (*REQ*)
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6.2.2.2.6 (*REQ*)

6.2.2.3 Non-metallic reinforcing element

6.2.2.3.1 (*PER*)
6.2.2.3.2 (*REQ*)

6.2.2.4 Joints and couplings

6.2.2.3.1 (*POS*)
6.2.2.3.2 (*REQ*)

6.2.3 Grout

6.2.3.1 (*REQ*)
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6.2.3.3 (*REC*)
6.2.3.4 (*PER*)
6.2.3.5 (*REC*)
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6.2.3.7 (*REC*)

6.2.4 Sheaths and ducts

(REQ)

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6.3.1 General

6.3.1.1 (*REC*)
6.3.1.2 (*REQ*)
6.3.1.3 (*REQ*)
6.3.1.4 (*REQ*)
6.3.1.5 (*REQ*)
6.3.1.6 (*REQ*)
6.3.1.6 (*REC*)

6.3.2 Panels and blocks (normally precast)

6.3.2.1 (*REC*)
6.3.2.2 (*REQ*)
6.3.2.3 (*REQ*)

6.3.3 Sprayed concrete and cast in place concrete

6.3.3.1 (*REQ*)
6.3.3.2 (*PER*)
6.3.3.3 (*REQ*)
6.3.3.4 (*REQ*)

6.3.4 Mesh

6.3.4.1 (*REQ*)
6.3.4.2 (*REQ*)
6.3.4.3 (*REQ*)
6.3.4.4 (*REQ*)

6.3.5 Other materials

6.3.5.1 (*REQ*)
6.3.5.2 (*REQ*)

6.4 Drainage systems

(*REQ*)
NOTE

7 Design consideration

7.1 General

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7.1.2 (*REC*)
7.1.3 (*REQ*)
7.1.4 (*REQ*)
7.1.5 (*REQ*)
7.1.6 (*PER*)
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7.2 Design output

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7.2.2 (*REC*)
7.2.3 (*REQ*)
7.2.4 (*REQ*)
7.2.5 (*REQ*)
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7.3 Design amendments

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7.3.3 (*REQ*)

8 Execution

8.1 General

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8.1.2 (*REQ*)
8.1.3 (*POS*)

8.2 Preliminary work

(*POS*)

8.3 Excavation / Face preparation

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8.3.3 (*POS*)
8.3.4 (*PER*)
8.3.5 (*REC*)
8.3.6 (*REC*)
8.3.7 (*REC*)
8.3.8 (*REQ*)
8.3.9 (*REQ*)
8.3.10 (*REQ*)
8.3.11 (*PER*)
8.3.12 (*REQ*)
8.3.13 (*REQ*)
8.3.14 (*REQ*)
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8.4 Nail installation

8.4.1 General

8.4.1.1 (*POS*)
8.4.1.2 (*REQ*)
8.4.1.3 (*REQ*)
8.4.1.4 (*REQ*)
8.4.1.5 (*REQ*)
8.4.1.6 (*REQ*)
8.4.1.7 (*REQ*)
8.4.1.8 (*REQ*)

8.4.2 Driven installation methods

8.4.2.1 (*PER*)
8.4.2.2 (*REQ*)

8.4.3 Drilled installation methods

8.4.3.1 General

8.4.3.1.1 (*POS*)
8.4.3.1.2 (*REQ*)
8.4.3.1.3 (*REQ*)
8.4.3.1.4 (*PER*)
8.4.3.1.5 (*REQ*)

8.4.3.2 Uncased drilling

8.4.3.2.1 (*POS*)
8.4.3.2.2 (*REC*)
8.4.3.2.3 (*REC*)
8.4.3.2.4 (*REC*)

8.4.3.3 Cased hole drilling and hollow auger drilling

8.4.3.3.1 (*REC*)
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8.4.3.3.3 (*REC*)
8.4.3.3.4 (*REQ*)

8.4.3.4 Self-drilled hollow bar soil nails

8.4.3.4.1 (*ST*)
8.4.3.4.2 (*REC*)
8.4.3.4.3 (*REQ*)
8.4.3.4.4 (*REC*)
8.4.3.4.5 (*REQ*)

8.4.4 Grouting procedures

8.4.4.1 General

8.4.4.1.1 (*PER*)
8.4.4.1.2 (*PER*)
8.4.4.1.3 (*PER*)
8.4.4.1.4 (*REC*)
8.4.4.1.5 (*REC*)
8.4.4.1.6 (*REC*)
8.4.4.1.7 (*PER*)

8.4.4.2 Gravity grouting

8.4.4.2.1 (*ST*)
8.4.4.2.2 (*REC*)

8.4.4.3 Pressure grouting

8.4.4.3.1 (*POS*)
8.4.4.3.2 (*POS*)
8.4.4.3.3 (*PER*)
8.4.4.3.4 (*REC*)
8.4.4.3.5 (*PER*)

8.4.5 Other nail installation methods

8.4.5.1 (*REQ*)
8.4.5.2 (*REQ*)

8.5 Drainage system

8.5.1 General

8.5.1.1 (*REQ*)
8.5.1.2 (*REQ*)
8.5.1.3 (*REC*)
8.5.1.4 (*POS*)
8.5.1.5 (*REQ*)
8.5.1.6 (*REC*)

8.5.2 Surface drainage

8.5.2.1 (*REQ*)
8.5.2.2 (*REC*)
8.5.2.3 (*REC*)
8.5.2.4 (*REC*)
8.5.2.5 (*POS*)
8.5.2.6 (*REC*)

8.5.3 Facing drainage

8.5.3.1 (*ST*)
8.5.3.2 (*REC*)
8.5.3.3 (*REQ*)
8.5.3.4 (*REQ*)

8.5.4 Subsurface drainage

8.5.4.1 (*REC*)
8.5.4.2 (*REQ*)
8.5.4.3 (*REQ*)
8.5.4.4 (*REQ*)
8.5.4.5 (*REQ*)
8.5.4.6 (*REQ*)

8.5.5 De-watering

(*REQ*)

8.6 Facing installation and connection with nail heads

8.6.1 Hard facing

8.6.1.1 (*PER*)
8.6.1.2 (*REQ*)
8.6.1.3 (*PER*)
8.6.1.4 (*PER*)
8.6.1.5 (*REC*)

8.6.2 Flexible facing

8.6.2.1 (*REQ*)
8.6.2.2 (*REQ*)
8.6.2.3 (*REC*)

8.6.3 Soft facing

8.6.3.1 (*REQ*)
8.6.3.2 (*REQ*)
8.6.3.3 (*PER*)
8.6.3.4 (*REQ*)
8.6.3.5 (*REQ*)
8.6.3.6 (*REC*)
8.6.3.7 (*POS*)
8.6.3.8 (*REC*)

8.6.4 No modification to existing surface

8.6.4.1 (*POS*)
8.6.4.2 (*REQ*)
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9.1 General

9.1.1 (*REQ*)
9.1.2 (*REQ*)
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9.2 Supervision

9.2.1 (*REQ*)
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9.3.2 Soil nail load tests

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9.3.3 Material tests

9.3.3.1 (*ST*)
9.3.3.2 (*REQ*)
9.3.3.3 (*REC*)
9.3.3.4 (*REQ*)
9.3.3.5 (*REQ*)

9.3.4 Face stability tests

9.3.4.1 (*REC*)
9.3.4.2 (*REC*)
9.3.4.3 (*REC*)

9.4 Monitoring during construction

9.4.1 (*REQ*)
9.4.2 (*ST*)
9.4.3 (*REC*)
9.4.4 (*REQ*)
9.4.5 (*REQ*)
9.4.4 (*REC*)

9.5 Measures to facilitate long-term monitoring

9.5.1 (*REC*)
9.5.2 (*REQ*)
9.5.3 (*PER*)
9.5.4 (*REQ*)
9.5.5 (*REQ*)

10 Records

10.1 (*REQ*)
10.2 (*REQ*)
10.3 (*REQ*)
10.4 (*REQ*)
10.5 (*REC*)
10.6 (*REQ*)

11 Special requirements

11.1 General

(*REQ*)

11.2 Noise

11.2.1 (*REQ*)
11.2.2 (*REQ*)
11.2.3 (*REC*)
11.2.4 (*POS*)

11.3 Environmental damage

(*REQ*)

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