

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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Execution of special geotechnical works - Soil nailing

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Ausführung von Arbeiten im Spezialtiefbau -
Bodenvernagelung

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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of an identical text or by endorsement, at the latest by December 2010, and conflicting national standards shall be withdrawn at the latest by December 2010.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_0 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 geosynthetic 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.