THE DEVELOPMENT OF SPECIFICATIONS FOR SOIL NAILING

by R T Murray

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THE DEVELOPMENT OF SPECIFICATIONS
FOR SOIL NAILING

ABSTRACT

The method of Soil Nailing is a recent introduction that may be regarded as a form of in-situ reinforced soil in which reinforcement is installed in natural soils rather than in selected fills. As a result the procedures employed for its design and construction differ from conventional reinforced soil in several respects and therefore require special consideration for purposes of specifying its use for different applications. This Report describes the procedures and background to a specification on Soil Nailing. It also provides a selection of suggested specification clauses that could be used in both earthworks and structural applications of highway engineering. The suggested clauses have been drafted to apply to the two principal methods currently used, namely drilled and grouted and driven systems, and could be employed directly or adapted to conform to a particular application.

1. INTRODUCTION

The reinforced soil method is now reasonably well established in the United Kingdom. The design and specification for reinforced soil retaining structures largely follows the procedures laid down in the Technical Specification (BE 3/78, Dept Transport, 1987) for highways and other types of scheme. However, the technique of soil nailing has not yet had any significant application for highways, although several schemes are currently at the design stage.

In many respects soil nailing is very similar to conventional reinforced soil but there are significant differences that can greatly influence the requirements for design and construction. Important among these are:

a) The natural soil properties as regard strength and corrosion may be greatly inferior to those that would be permitted in a conventional reinforced soil structure where selected fill is used.

b) The reinforcements are installed by drilling and grouting or by driving rather than by placement and compaction within fill.

c) The construction process will often involve starting at the top and working downwards rather than from the base upwards as occurs with conventional reinforced soil.

d) The facing to structures is usually formed on site from sprayed concrete rather than by using precast concrete or other prefabricated units. Suitable geotextile fabrics have also been used for facing.

e) Drainage requirements must be introduced as part of an installation process rather than by forming part of the construction.

f) Most commonly soil nails are installed at an inclination to the horizontal in contrast to conventional reinforced soil where the elements are installed horizontally.

Because of these principal differences the specification requirements for corrosion, strength, and construction have many features that are specific to soil nailing. Moreover, additional requirements are necessary to cover supplementary items such as the characteristics of grout, sprayed concrete and associated facing reinforcement. This Report describes the basis and requirements of a specification for Soil Nailing. Some controversy has arisen over the bases of soil and reinforcement interaction, particularly as regards the amount of shear resistance developed (Bridle & Barr, 1990; Jewell & Pedley, 1990; Juran et al, 1990). In this Report the soil nailing technique envisaged involves reinforcements that primarily develop resistance through tension and would be typically 15 - 300 mm diameter. For such nails the shear component is small and can be neglected (Jewell and Pedley, 1990).

A selection of suggested specification clauses are provided that could be suitable for using the technique in both earthworks and structural applications of highway engineering where soil nailing is likely to be very cost-effective (Dept. of Transport, 1991a). The suggested clauses have been drafted to apply to the two principal methods currently used, namely drilled and grouted and driven systems, and could be employed directly or adapted to conform to a particular application.

2. SPECIFICATION PROCEDURES FOR SOIL NAILING

Because of the relatively recent introduction of soil nailing, the procedures for design and specification are not yet fully established. Various publications are available on the methods of design, and reference may be made to Schlosser (1982), Juran et al (1988), Gassler (1990) and Jewell and Pedley (1990), as examples. It is not proposed, therefore, to consider design further in this report as it will be fully covered in a later publication. At this time the lack of established specification procedures is likely to be a greater hindrance to wider implementation of soil nailing than the design aspects. This Report has been prepared to alleviate the problems of specification by providing suggested clauses that could be adopted for
particular applications. The clauses are listed in Appendix 1 and are directed towards the two commonest methods involving drilled and grouted soil nails and driven soil nails.

It would not be practicable to attempt to cover every possible specification requirement likely to arise for an extensive range of projects. However, the selection of clauses is sufficiently comprehensive to cover the main requirements in a Contract for the two types of soil nailing considered. The relevant clauses for a particular application would need to be selected and adapted as necessary. Ancillary clauses may be sometimes required that could be covered in a Particular Specification. Other clauses may be required occasionally to cover topics such as:

(a) Qualifications and experience of Contractor in carrying out soil nailing work.

(b) Health and safety requirements in applying sprayed concrete.

(c) Use of piles for shear reinforcement possibly in association with soil nailing.

(d) Durability of geotextile facing.

The use of the suggested specification clauses for Department of Transport schemes would need to interface with the Specification for Highway Works (1986) current at the time of the Works and would need the approval of the Department prior to their use on a highway project. Clauses not already covered in the Specification would be used by incorporating them as Additional clauses while alternative versions to existing clauses would be included by employing them in the usual way as Substitute clauses. An Advice Note on the design and preparation of Contact Documents for highway schemes has been recently published by the Department of Transport (1991b).

The soil nailing project may be designed and constructed by a specialist company as the design requirements may be only achievable by a particular method of construction. To allow for this situation some clauses have been included to cover the design aspect. These clauses would not be required for the more conventional situation where the design is the province of the Engineer.

The remainder of this Report describes the soil nailing procedures in some detail to serve as a supplement and general background to the suggested specification clauses.

3. APPLICATIONS AND DEFINITIONS

Table 1 lists applications of soil nailing in association with details of the range of ground conditions and structural geometry that have been published relating to permanent structures. As most of these have been constructed overseas, the design life requirements generally differ from that expected for Department of Transport bridge abutments and retaining structures in the United Kingdom. Therefore it may not be possible to cover the same range of soil conditions and geometry for these structures to achieve the required design life in the U.K. of 120 years.

<table>
<thead>
<tr>
<th>Application</th>
<th>Soil types</th>
<th>Types of nail</th>
<th>Height (max)</th>
<th>L/H range</th>
<th>Slope range (deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retaining Wall</td>
<td>Sands, Gravels, O.C. clays, Boulder clay, Silty clay, Marls</td>
<td>Drilled/grouted (D/G) and Driven (D)</td>
<td>14m (D/G) 12m (D)</td>
<td>0.5 - 1.2 (D/G) 0.5 - 1 (D)</td>
<td>80 - 90</td>
</tr>
<tr>
<td>Cut &amp; cover tunnel</td>
<td>Sands</td>
<td>Driven</td>
<td>11.5m</td>
<td>1.0</td>
<td>90</td>
</tr>
<tr>
<td>Embankment</td>
<td>Boulder clay</td>
<td>Drilled/grouted</td>
<td>10m</td>
<td>1.0</td>
<td>75</td>
</tr>
<tr>
<td>Cutting</td>
<td>Sand, Boulder clay, Plastic clay, Weathered shales, Weathered schists</td>
<td>Drilled/grouted</td>
<td>19m</td>
<td>0.55 - 1.15</td>
<td>60 - 80</td>
</tr>
</tbody>
</table>

Where H = height of structure and L = length of nail
For purposes of this Report a retaining wall is considered to have a face constructed at an angle of at least 70° to the horizontal and will usually have a 'hard' facing. Permanent structures are designed for a long life, namely 120 years, and for situations where failure could have serious consequences. The soil nails and other components will therefore need to have adequate durability and acceptable serviceability and strength characteristics, both during the construction period, and over the life of the structure. There may be difficulties in achieving such durability requirements if the soil conditions are especially aggressive and with sprayed concrete facings generally.

In contrast to retaining walls reinforced earthwork slopes are defined as having angles not exceeding 45° from the horizontal. They may have a 'soft' facing or sometimes be constructed without a face. These structures may be designed for a long life, although this maybe somewhat less than that of a retaining structure as they are more amenable to methods of repair. Moreover, the consequences of failure may be less serious so that some long-term risk may be acceptable to minimize construction costs. In addition, the loads in nails used to stabilize an embankment overlying soft ground may decrease with time allowing the durability requirements to be reduced. However, if the presence of the nails act to reduce differential settlements there may be a gradual increase in tensile force with time that would need to be considered at the design stage.

In the range 45° to 70° the soil nailing application may be considered either as a retaining wall or slope. This will be dependent on such factors as the consequences of failure and the mode of interaction with other elements of the highway system.

The basic mechanism of soil reinforcement relies on tensile strains developing in both the soil and reinforcement. To be effective, the direction of the nails must correspond closely to the principal tensile strain field of the soil. Adequate bond strength must be developed at the soil-reinforcement interface or at the soil-grout interface, as appropriate, to prevent slippage. In addition, the resistance of the nails to tensile rupture must allow for some reduction in properties over the longer term without failure.

Note that the mechanism by which the nails develop tensile resistance requires some relative movement between the soil and the nails. This differs from conventional reinforced soil in which the fill is compacted next to the reinforcement so allowing tension to be mobilized. The magnitude and distribution of movement will be dependent on the type of structure and soil and the mode of construction, but for retaining structures constructed as shown in Fig. 1, it would generally occur as each excavation level is stabilized. Once tensile loads are developed in the nails, further deformation of this part of the structure would be resisted and the load carrying capacity would be increased.

Within the general context of soil reinforcement techniques, the use of piles to provide shear resistance against slip failures is sometimes referred to as soil nailing. The reinforcements in this application are usually installed normal to the potential or actual slip plane and their inclination generally varies with position. Moreover, to mobilize shear resistance, the diameter or other cross-section dimensions are much larger than those for tensile resistance applications as these latter are typically in the range 15mm to 30mm. Such reinforcement methods are not considered further in this Report.

4. GROUND INVESTIGATION

4.1 GENERAL

The objective of the ground investigation is to determine the nature, variation, strength and aggressiveness of the material into which the nails are to be installed. For a safe and economic design of nailed structure, a good knowledge of the ground conditions is clearly essential. The type of soil into which the nails are to be installed is an important consideration and unsuitable materials would preclude the use of soil nailing. For example the material should not be excessively corrosive otherwise problems may be encountered in ensuring the required design life. Soils which have a low shear strength (say less than 50 kN/m²) or are very creep susceptible are usually unsuitable as the stability and serviceability of the structure could be impaired. Fissured and fractured rocks, very open structured materials and loose granular materials could also prove unsuitable as grouting requirements then may be extremely expensive.

The ground conditions beneath and next to a proposed structure can also have a considerable influence on behaviour and performance and need to be investigated. The influence of the potential change to the ground water conditions after excavation should be also considered as this may affect long term stability. General guidance on site investigation may be obtained from BS 5930 (1981) but specific requirements for soil nailing are as follows.

(a) Prepare a general plan of the site and surrounding area, including possible means of access, working areas, and buried inclusions, services or structures. If there are any adjacent buried services or structures, it may be necessary to establish acceptable deformations.

(b) Obtain soil profiles and samples both for the ground to be nailed and any adjacent ground that may affect external stability and corrosion behaviour. As a guide, for structures with a level surface the investigation should extend to at least 1.5 to 2 times the height of the structure (length of nails) into the regions behind and beneath. Where the structure is retaining a sloping surface the investigation into the soils behind the nails may need to extend up to 3 times the height.

(c) Carry out an assessment of potential corrosion problems by resistivity and relevant electrochemical tests.
The first layer is excavated

The reinforcement is fixed and a layer of shotcrete applied

Installation of the soil nails

The second layer is excavated

Figure 1. Soil nailing used for retaining wall construction
(d) Investigate perched or other water table conditions or springs that may be present in winter. Observations made during boring for samples usually require to be supplemented by readings from standpipes or other apparatus.

(e) Determine the location of existing failure planes when present, if necessary by monitoring movement over a period.

(f) For repairs to an existing structure, obtain details of its construction, performance history and present condition.

(g) For lengths of reasonably consistent formation with a known failure mechanism, and where the consequences of failure are not severe, it may be possible to limit the scope of items (b) to (d) (e.g. shallow slips in cuttings).

4.2 SOIL PROPERTIES

The design of a soil nailing system follows that of conventional reinforced soil in that no consideration is given to soil and reinforcement strains and their relations with mobilized strength. The soil properties usually obtained from a ground investigation, therefore, are generally restricted to strength, interface friction and corrosion properties besides the usual classification information. The following requirements are specifically for the design of soil nailing systems although additional information may be required if the soil nailing is only part of the works, e.g. if strengthening of the formation, or ground anchors, is also involved.

(a) Determine peak and if necessary the constant volume angle of shearing resistance under effective stress conditions.

(b) Determine cohesion under effective stress conditions, the coefficients of consolidation and swelling, and the undrained cohesion for clays. Cohesion must be accurately determined to assess the face height that may be exposed during construction; a trial exposure or back analysis of failures is advisable.

(c) For some design methods, the pressuremeter or cone penetrometer may provide useful data.

(d) Drainage measures are most likely to be required, and the existence of aquifers, natural drainage paths and the in-situ permeability of the relevant soil layers should be determined as necessary.

(e) The pullout resistance of the nails must be determined, either by calculation from the measured friction coefficient between the soil and the nail or grout, or preferably by pullout tests.

(f) As appropriate, information on grading, index properties, moisture content, density, stress history and over-consolidation ratio may be relevant. Grading curves are particularly useful indicators of soil behaviour that can provide information on likely permeability, bond resistance, time limitations on unsupported excavations and other properties.

(g) As natural ground is involved, there is always a possibility of unexpected changes in ground conditions being revealed during construction; in particular it may be necessary to modify the height of unsupported face exposed during construction. The programme of work, specification and bill of quantities must be sufficiently flexible to accommodate this possible requirement. Note that the use of a design and construct approach can avoid many of the limitations that arise in traditional civil engineering practice.

4.3 CORROSION ASSESSMENT

In contrast to conventional reinforced soil structures in which selected fill is employed in the reinforced zone with 'acceptable' corrosion properties towards metal reinforcement, the soil nailing system has no such control on the types of soil to be reinforced. The methods of assessing the corrosion properties and the sacrificial allowances by which to increase the nails in addition to that required for structural needs could thus embody every conceivable soil condition. Such a requirement would be far too onerous for specification purposes and an alternative approach is therefore proposed involving the following four soil categories:

a) Non-aggressive,
b) Mildly aggressive,
c) Aggressive,
d) Highly aggressive.

These categories are identified based on the approach described by Eyre and Lewis (1987) and involve a ranking procedure determined from a range of tests. The ranking values and the assessment of the soil conditions is given in Table 2.

<table>
<thead>
<tr>
<th>Soil aggressivity based on ranking values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil condition</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Non-aggressive</td>
</tr>
<tr>
<td>Mildly aggressive</td>
</tr>
<tr>
<td>Aggressive</td>
</tr>
<tr>
<td>Highly aggressive</td>
</tr>
</tbody>
</table>
The range of tests proposed by Eyre and Lewis (loc. cit.) for ranking soil aggressivity are listed in Tables 3 and 4. Table 3 is a general category that is used on every assessment. Table 4 provides supplementary tests needed if the ranking based on Table 3 is -4 or less.

Soil nails may be either drilled and grouted (i.e. the nail is inserted and grouted into a previously drilled hole), or driven (i.e. hammered, vibrated, or fired) directly into the ground. These procedures involve different corrosion considerations.

(a) Grouted nails. Information on this topic may be obtained from Section 8 of BS 8081. Guidance is given on the constitution of cement grouts for different concentrations of sulphate, and for other ions. A minimum protection for the nail is provided by careful placement of the grout surrounding it. Further protection may be obtained by the addition of a plastic sheath or other means such as coating of the nail. Where aggressive soil conditions apply, the drilled and grouted system will provide much better protection for metallic nails. For non-aggressive conditions with this system of construction, the

**TABLE 3**

General soil aggressivity assessment

<table>
<thead>
<tr>
<th>Property</th>
<th>Measured Value</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil composition</td>
<td>Material containing not more than 10% of particles passing the 63 micron BS sieve size. The material passing the 425 micron BS sieve size, when tested in accordance with BS 1377 shall have a plasticity index less than 2.</td>
<td>+2</td>
</tr>
<tr>
<td></td>
<td>Material containing not more than 75% and 10% of particles passing the 63 and 2 micron BS sieve sizes respectively. The material passing the 425 micron BS sieve size, when tested in accordance with BS 1377, shall have a plasticity index less than 6.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Material for which the particles passing the 425 BS micron sieve size, when tested in accordance with BS 1377, shall have a plasticity index less than 15.</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Material for which the particles passing the 425 BS micron sieve size, when tested in accordance with BS 1377, shall have a plasticity index 15 or greater.</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>Material having an organic content of 0.2% or greater</td>
<td>-4</td>
</tr>
<tr>
<td>Groundwater level at buried position</td>
<td>Well drained area</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>Poorly drained area</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Above foundation level of structure</td>
<td>-4</td>
</tr>
<tr>
<td>Resistivity (ohm-cm)</td>
<td>10,000 or more</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10,000 - 3,000</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>3,000 - 1,000</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>1,000 - 100</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>100 or less</td>
<td>-4</td>
</tr>
<tr>
<td>Moisture content</td>
<td>20% or less</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>more than 20%</td>
<td>-1</td>
</tr>
<tr>
<td>pH</td>
<td>6 or more</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>less than 6</td>
<td>-2</td>
</tr>
<tr>
<td>Soluble sulphate (ppm)</td>
<td>200 or less</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>200 - 500</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>500 - 1,000</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>1,000 or more</td>
<td>-3</td>
</tr>
<tr>
<td>Cinder and coke or made ground</td>
<td>None Exist</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-4</td>
</tr>
</tbody>
</table>
TABLE 4

Supplementary soil aggressivity assessment

<table>
<thead>
<tr>
<th>Property</th>
<th>Measured value</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redox potential</td>
<td>+400 mV or more</td>
<td>+2</td>
</tr>
<tr>
<td></td>
<td>+400 - +200</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>+200 - 0</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>0 or less</td>
<td>-4</td>
</tr>
<tr>
<td>Presence of sulphide and hydrogen sulphide</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Trace</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>-4</td>
</tr>
<tr>
<td>Presence of carbonate</td>
<td>Copious</td>
<td>+2</td>
</tr>
<tr>
<td></td>
<td>Present</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>Trace</td>
<td>0</td>
</tr>
<tr>
<td>Chloride ion (ppm)</td>
<td>50 or less</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>50 - 250</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>250 - 500</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>500 or more</td>
<td>-4</td>
</tr>
</tbody>
</table>

The use of galvanizing or other form of protective coating would seem unnecessary. Moreover, the grout surrounding the nail could be regarded as enhancing the soil environment so that the requirements for sacrificial allowances may be reduced. One strategy, for example, would be to regard the soil as falling within the adjacent lower category of aggressiveness in Table 2.

(b) Driven nails. The nail is in direct contact with the soil into which it is driven. If the nail has any protective coating, possible damage to the coating during driving must be evaluated. It is difficult to accurately assess corrosion rates in more aggressive soils but a recent study gives details of corrosion behaviour of conventional earth reinforcement over an extended period (Darbin et al, 1988). It should be noted that the Code of Practice on Ground Anchorages (BS 8081, 1989) suggests that steel should not be used in permanent works in aggressive conditions without protection.

The approach suggested for dealing with corrosion considerations in soil nailed structures is similar to the requirements of buried corrugated steel structures for the Department of Transport (1988). In this approach the corrosion allowances for the design life of the structure vary according to the aggressivity of the soil. An exception applies to highly aggressive soils in which construction is not recommended for permanent structures. Suggested corrosion allowances for soil nailing structures are provided in Fig. 2 for the first three categories of soil aggressivity given in Table 2. These corrosion allowances correspond with those presently used for a design life of 120 years in reinforced earth structures (Dept. of Transport, 1987) but are somewhat greater than presently adopted for corrugated culverts.

The soil categories for reinforced earth fill of ‘frictional’ and ‘cohesive-frictional’ are regarded herein as being synonymous with those of non-aggressive soil and mildly aggressive soil, respectively, in Table 2. Note that Fig. 2 gives the corrosion allowance for each exposed surface. Thus a bar of circular cross-section, for example, would have the radius increased by the appropriate value shown.

The rates of loss of galvanizing is also based on the Department of Transport Standard (1988) for buried corrugated culverts with the addition of a mildly aggressive category for the soil. The rates of loss per year on this basis are as given in Table 5. Note that galvanizing thickness may be regarded as corresponding to a coating weight of 7.15 g/m² per micron. Alternative proprietary coatings may be used in place of galvanizing but the characteristics, use and design life of these coatings should be based on a British Board of Agreement Roads and Bridges Certificate or other approved European Equivalent certification.

4.4 DEFORMATION OF NAILED STRUCTURE

A characteristic of nailed walls or slopes is that some movement of the nailed ground is required to enable the nails to mobilize their required stresses. Referring to Fig 3, the report of the French Clouterre project (1991) gives
Figure 2. Sacrificial thickness of buried steel surfaces

the values in Table 6 for expected deformations. The distance $\lambda$ back from the facing at which these deformations become negligible is given by:

$$\lambda = F \times H \times (1 - \tan \beta)$$

Where $H$ = perpendicular height of structure

$F$ = empirical constant given in Table 6

$\beta$ = initial angle of inclination of the face relative to the vertical

### TABLE 5
Rates of annual galvanizing loss for different categories of soil aggressivity

<table>
<thead>
<tr>
<th>Soil Category</th>
<th>Rate of galvanizing loss per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-aggressive</td>
<td>4 micron</td>
</tr>
<tr>
<td>mildly aggressive</td>
<td>8 micron</td>
</tr>
<tr>
<td>aggressive</td>
<td>14 micron</td>
</tr>
</tbody>
</table>

### TABLE 6
Typical movements in soil nailing structures

<table>
<thead>
<tr>
<th>Vertical or horizontal deformation</th>
<th>Coarse sand/gravel</th>
<th>Sand</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_v = \delta_h$</td>
<td>$H/1000$</td>
<td>2$H/1000$</td>
<td>4$H/1000$</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>---</td>
<td>4H/10000</td>
<td>---</td>
</tr>
<tr>
<td>$F$</td>
<td>0.8</td>
<td>1.25</td>
<td>1.5</td>
</tr>
</tbody>
</table>
8v,6h,8 o = vertical and horizontal deformations at front and rear of structure respectively as shown in Fig. 3.

5. SOIL NAILING SYSTEMS

5.1 GENERAL

The two most common methods of installing soil nails are by pre-drilled holes and grouting or by direct driving. Several possible variations have been proposed, such as driving followed by grouting or expanding. If these methods become more widely adopted the procedures given below for deciding the most appropriate choice of system may need to be modified. Factors to consider are:

(a) The access, working area, and available installation distance for the nails.

(b) Property or other restrictions on distance to which nails can be driven into the ground.

(c) Noise or other environmental restrictions.

(d) Need to accommodate drainage measures (Fig. 4).

(e) Need to accommodate other features, e.g. ground anchors in a mixed construction or other structures.

(f) Freedom to select the slope of the face or wall.

(g) The type of facing required.

(h) The design life, in particular whether temporary or permanent.

(i) Economic considerations, in particular the cost of mobilizing equipment for a small project.

(j) The size and nature of the structure. Many larger structures have been erected using the drilled and grouted system as greater pull-out resistance and durability are usually obtained from this system.

5.2 GROUTED SYSTEMS

The main characteristics of grouted systems are as follows;

(a) Because a hole is pre-drilled for the nail, it is possible to check that the nail will be correctly aligned.

(b) The nail is placed, not driven, into the ground. With correct handling it is easier to ensure that any protective coating is preserved.

(c) It is possible to protect the nail against corrosion, both with grout and other protective barriers.

(d) The placing of the grout is critical to the effective functioning of the nails. Adequate arrangements must be made to control the materials and process.

(e) More expensive equipment and control procedures are usually required for grouted systems, which will therefore tend to incur higher initial costs.

(f) Water flushing techniques should not be used.

Figure 3. Definitions in soil nailing structure
5.3 DRIVEN SYSTEMS

The requirements for a satisfactory driven system should include the following:

(a) Nails must not buckle during driving or be permanently deformed. They must be sufficiently rigid, therefore, for use with an appropriate impact or vibratory driving system. To a large extent buckling can be reduced or eliminated by using a suitable support frame that provides slide-through guides along the length of the frame. The tendency to buckling may be also reduced by using nails that have greater stiffness and are not necessarily circular in cross-section. Examples of nails that have been used are cruciform-section, T-section, angle-section, tube and sheet piling. Note also that hollow sections such as tubing or ducting may be infilled with grout to enhance stiffness.

(b) Anti-corrosion protective coating must not be damaged; this can be checked by excavating test nails or by pulling out nails during test trials.

(c) The nails must not deviate unduly from their angle of entry when driven into the ground; i.e. the nails should enter the ground and remain within about 2 - 3 degrees of the intended inclination. Although this condition is difficult to check, the use of an appropriate support frame will assist in ensuring proper entry alignment. Because of the difficulties of ensuring alignment and avoiding damage, the driven nail system is less suitable in hard, stony and heterogeneous soil.

An alternative form of driving is the air launcher in which the nail is fired by an explosive release of compressed air (Myles and Bridle, 1991). This method may reduce the problem of buckling of the nail as it is apparently in tension during flight but is still subject to deviation and variable penetration in non-homogeneous strata and in stony soils. Nails are usually steel rods of 15mm to 30mm in diameter but other cross-sections are feasible. It is not known to what extent the protective coatings are damaged by this technique. It would be desirable to perform field trials and could be regarded as a mandatory requirement for some Contracts.

5.4 FACINGS

5.4.1 General

The type of facing will often be dictated by appearance. For permanent structures such as retaining walls, these will be hard facings of sprayed or precast reinforced concrete although metallic facing panels have been used occasionally. Shallower slopes are normally constructed with soft facings having a grass or other vegetative cover to blend in with the immediate surroundings. The primary objective of the facing is to protect the surface of the wall or slope from erosion, damage by vandalism or other cause of deterioration, and vehicle impact. In steep
slopes and walls, to assist in stability the head of the nail is attached to the facing. For shallow slopes the nail is attached to a bearing plate on, or just below, the surface of the slope.

5.4.2 Soft facings

Where soft facing requires the establishment of vegetation, temporary protection must be provided to prevent short term erosion of the face. The usual methods of establishing vegetation are by hydro-seeding or by the use of geotextiles. For shallower slopes, the roots of appropriate vegetation may also contribute to long-term stability. The feasibility of establishing vegetation will depend on the steepness and orientation of the face and the soil type. Guidance is given in a CIRIA review by Coppin and Richards (1990). Guidance for Department of Transport structures can be obtained from the Horticultural Adviser. The requirements for Topsoiling, Grassing and Seeding earthworks are specified in Clause 618, Part 2 in the Specification for Highway Works (Dept of Transport, 1986).

Soft facings of geotextile or coated steel mesh may be employed, either alone or with vegetation where the soil exposed on the surface is liable to erosion. Particular consideration must be given to the durability and protection of geotextiles against ultra-violet radiation and vandalism in these circumstances. Such protection is most commonly obtained by a surface covering of topsoil or other material.

5.4.3 Hard facing

The direct use of precast panels, such as employed in reinforced earth structures, does not appear to have been widely used in soil nailing, possibly because of the difficulty of ensuring a sufficiently uniform face and nail spacing. If nailing is being used for the repair of an existing wall, it may be possible to repair or utilize the existing face.

Sprayed Concrete (Shotcrete) has been widely used in France and Germany, but its appearance may not be acceptable as a finish to permanent structures. However, the use of secondary precast reinforced concrete panels or other cladding can be employed to provide a suitable appearance.

5.4.4 Footing depth

Although there are many similarities with reinforced soil, the stability requirements may be better suited to the exclusion of footings for soil nailing. An exception could be where precast concrete facing panels are employed. In this case the facing to retaining structures and steep slopes will usually extend below ground surface at the base of the wall. The rules applicable to conventional reinforced soil structures for determining embedment depth could then be employed as follows:

Level or shallow sloping surface in front of wall (≤ 18° to horizontal)

\[ D = \frac{H}{10} \]

Moderate sloping surface in front of wall (> 18° ≤ 27° to horizontal)

\[ D = \frac{H}{7} \]

Steep sloping surface in front of wall (> 27° ≤ 34° to horizontal)

\[ D = \frac{H}{5} \]

Where \( D \) = embedment depth  
\( H \) = height of structure

For structures less than say 5m in height, a minimum embedment depth would need to be specified of the order of 0.5m.

6. CONSTRUCTION METHODS

6.1 GENERAL

The construction procedures to be used in a soil nailing project are dependent on the type of application and are dealt with separately below. However, there are some aspects that are common to several different applications. In particular, where there is a need to excavate the soil surface prior to installation of the nails, 'the soil must be self-supporting by having a small degree of cohesion, \( c' \). The presence or absence of a temporary cohesion will have been established at the ground investigation stage and could well have been a deciding factor in selecting the soil nailing approach. The magnitude of \( c' \) needed will depend on the required unsupported depth of equivalent vertical face (\( h' \)). The value of cohesion required can be determined from the following equation:

\[ c' = \frac{h' \times \gamma \times \sqrt(K_s)}{2} \]

Where  
\( K_s \) = coefficient of earth pressure  
\( \gamma \) = unit weight of soil

The application of this equation should be restricted to ensure that the depth of excavation for an equivalent vertical face in granular soils is in the range 0.5 to 1.5m. Experience has shown that such a range has enabled structures to be successfully erected in the past. In some circumstances the soil may be strengthened by installing nails prior to excavation. With this approach, the nails will need to be cut to length, and possibly have their exposed ends threaded in place, to finalize the installation process. The absence of any cohesive strength could be overcome by pretreatment of the ground by a cement or chemical stabilization process but as this would be relatively expensive such a technique would only be employed in special circumstances. Note that an important factor in ensuring a cost-effective process is to minimize the period between excavation and nail installation. Stability is maintained during this phase by the use of berms where possible.
Construction in over-consolidated clays has sometimes involved depths of excavation in excess of 2m but special care is needed to ensure that stability can be sustained during the period when the nails are being installed in an unsupported section. Particular problems may arise if rapid equilibration of pore pressures occurs. Note that this could occur more rapidly with an effective drainage system. For all types of soil, the dangers of facing instability or the possibility of erosion and weathering will be reduced if a relatively short period is specified between exposing the face by excavation and applying the relevant facing.

Stability of both over-consolidated clays and granular soils may also be influenced by the installation process. Problems could occur because of dynamic forces in driving nails or by the method of drilling if pneumatic flushing creates excessive cavities. Moreover, grouting operations may produce contamination of the drainage system or high grouting pressures may induce hydraulic fracturing. To avoid the latter grout is best introduced under gravity.

6.1.1 Site restrictions

Possible problems of access should be considered at the outset and these should be drawn to the attention of tenderers. Some restrictions are normally imposed on the weight of construction plant permitted to operate near to the face of a structure or slope. Guidance on compaction for earthworks such as road embankments is given in the Specification for Highway Works, Clauses 610 and 612 (Dept. of Transport, 1986).

6.1.2 Drainage measures

Water may have a deleterious effect on the nailed structure in two respects. First, free water at the facing may cause instability of soft Facing, particularly vegetation, or staining and deterioration of hard facings. Second, water in the nailed ground may reduce the factor of safety, or may introduce aggressive ground or surface water that will increase corrosion. The following drainage measures should be considered (Fig. 4).

(a) It will usually be necessary to include a cut-off drain to intercept surface water at the top of the nailed slope. This should include a geomembrane or other means of preventing the drain feeding water into the nailed ground if at any time it should become defective.

(b) If there are any water mains or sewers in the vicinity, the consequences of a leak and the possibility of precautionary measures should be considered.

(c) If there is a road or other feature that can introduce chemicals such as road salt into the structure, adequate measures should be taken either to exclude these or to allow for them in assessing corrosion. Similar considerations apply if there are any waste materials or sources of aggressive ground water.

(d) Soil nailing is often considered less suitable in poorly drained soils, or ground containing a water table or springs. It should, however, be practicable if adequate drainage measures are designed and incorporated in the scheme. Bored drains may be particularly suitable since they can be interspersed with the nails.

(e) Weep holes, if necessary with pipes to conduct water away, should be incorporated in hard faces.

6.2 RETAINING STRUCTURES

The construction of a retaining wall by the soil nailing method generally commences at the top surface and the stabilization process extends downwards (Fig. 1). The width and depth of excavated region will be determined by stability and deformation considerations but the treatment of large regions is likely to be more cost-effective. To allow the drilling and grouting equipment access to the excavated face, a level benched section is created at the current base of the excavation. The bench would need to be several metres in width, dependent on the type of equipment being used. Near to the top of steep slopes, it may be necessary to start with a deeper excavated section to obtain an adequate width of benching. Special measures may be needed for stabilizing this deeper excavation.

Stability during construction will be enhanced and deformations reduced if the nailing process is carried out in alternate bays of short sections involving say 10 - 12 metres lengths at intervals. Further untreated regions could then be continued using the same pattern arrangement until the whole length is completed. In using this approach, consideration should be given to the requirements for extensions and joints in the facing, particularly to the arrangements for overlapping reinforcement mesh in the lateral and vertical directions. Thus about 300mm of reinforcement mesh at both ends and at the base of the treated section would be left exposed to provide continuity in forming the facing. In addition, the edges of the sprayed material at these construction joints are best tapered to provide a suitable transition zone to the new sections. The angle of the tapers would be generally about 30° to provide a good overlap with the new sections of sprayed concrete.

The thickness of the sprayed concrete facing to the structure will be determined by design requirements. Thicknesses are in the range 100 mm to 200mm thick and usually incorporates one or two layers of steel mesh reinforcement. Where there are two layers of reinforcement it is more common to place the concrete around the first layer before fixing the second layer and completing the spraying operations. Each layer of reinforcement mesh needs to be firmly fixed to prevent sagging and deformation as a result of self-weight of the concrete and associated vibrations. Limitations on the size of the aggregate are usually imposed to allow free flow of the concrete and placement behind and within the mesh reinforcement. Because the excavated face of the soil may be uneven, problems can arise in accurately establishing the finished surface of the facing. To ensure a minimum thickness and relatively plane surface, the usual method involves driving steel pins into the excavated face on a square pattern grid at 1 - 2m centres.
The projecting ends of the pins can be accurately positioned by surveying methods to produce the required geometry of the facing.

### 6.3 SLOPES

The use of soil nailing in new or reconstructed slopes is normally to allow them to be constructed at a steeper angle than would be feasible based on available soil strength. An ancillary reason for using soil nails could be to allow a slope to support additional external loading. The soil nailing method applied to slopes may require some differences of approach from that for a vertical wall.

A particular example would be where construction of the slope does not provide sufficient excavation to form working benches. In such circumstances the installation of nails directly from the face of a slope could require very specialized equipment. Alternatively temporary working platforms could be used. Where the slope height is not excessive and access is available at the top and bottom, installation of the nails may be feasible using equipment with an adequate length of boom. With high slopes it may prove more cost effective to construct a steeper face to allow scope for incorporating working benches at appropriate intervals.

The type of nails used in slopes will generally be the same as for a retaining structure. However, the construction of the face will normally only involve relatively small bearing plates to provide passive restraint for the nails. These may be covered with a layer of topsoil and grassed, possibly in association with a geotextile or other method to reduce problems of erosion.

### 6.4 REPAIR OF EXISTING STRUCTURES

The method of repairing an existing retaining structure will depend on several factors as follows:

(a) Type of structure  
(b) Extent and form of damage or deterioration  
(c) Freedom of access  
(d) Type of backfill  
(e) Proximity of structures and buried services.

In circumstances where the structure is in need of repair because of the onset of instability, consideration will need to be given to methods that do not propagate further movements. Thus the drilled and grouted method is likely to minimize the disturbance effects and avoid creating excess pore pressures in cohesive soils that could result from driving nails. However, to avoid these problems, the grout is usually introduced by hydraulic flow under gravity. Where the grout is injected under pressure, these would need to be kept low. In addition, there may be ancillary work in removing an external source of the instability such as, for example, the installation of drainage measures or other ground treatment. Repair by soil nailing will be feasible if the structure or slope is generally intact. Ideally, the soil nailing repairs would be best carried out when some early indication of movement becomes apparent.

### 6.4.1 Retaining structures

Few papers have been published on methods of repair, but one describes the procedure for repairing a conventional reinforced soil wall that had suffered localized damage as a result of freezing of saturated backfill directly behind the facing (Long et al, 1984). Essentially the method of repair involved reconstructing the damaged face with cast in situ panels that were connected to existing undamaged reinforcement. Drilled and grouted nails 4.2m in length and 28mm diameter were then installed to overlap the existing damaged nails. These nails had threaded ends to allow load spreading plates to be attached against the facing and provide passive restraint for the nails. The authors do not describe whether drainage measures were taken to alleviate the saturated conditions in the backfill but this seems an important requirement in such circumstances.

The soil nailing repair technique has been also employed to reinstate dry stone walls. Details of the repairs are provided in a paper by Bruce and Jewell (1987). Although the reported height of the walls undergoing repair was only 3m, there are many miles of such walls in a deteriorating condition throughout the U.K.. The soil nailing procedure is likely to be a very cost effective method for dealing with these structures.

### 6.4.2 Slopes

When soil nailing is used in the repair of failed slopes, it is often necessary to restrict the area in which the Contractor may work because of the danger of further instability. The viability of repairing a slope by the soil nailing method will depend to a considerable extent on the nature of the soil and the profile of the slope. With shallow slopes the depth of soil above a nail is often insufficient to allow adequate bond resistance to be developed. Very soft soils are also unlikely to be suitable as the amount of reinforcement required would normally be uneconomic. However, it may prove possible to carry out some ground treatment work to improve the condition of the soil prior to the nailing installation.

A highly degraded slope profile would be also unsuitable for repair by soil nailing as the slope would normally require reinstatement and regrading. Conventional reinforcements could be incorporated at this stage if required and would be less expensive than soil nailing (Murray et al., 1982). However, soil nailing could be employed in a complementary sense by stabilizing adjacent sections of slope where failure had not yet occurred but was clearly a possibility. In other respects the methods of repairing slopes is the same as for new construction as described above. Note that the repair will usually involve stabilizing existing slip zones by installing the nails through these into intact soil. It is clearly important at this stage to ensure that deeper seated failures are unlikely to occur otherwise the nails would need to extend even further to prevent further slip failures.
7. FIELD OBSERVATION, MONITORING AND IN SITU TESTING

A particular advantage of the soil nailing method is that the design and construction procedures can usually be readily altered to conform better to unexpected conditions. This is especially true where drilling is employed for installing the nails, as much greater detail on soil conditions will emerge than would normally be available from a site investigation. Thus the most economic procedure for the design and construction of soil nailing structures is likely to involve a flexible approach that permits some adjustment to the spacing and length of nails as further information is obtained during the construction stage. An important consideration to ensure the success of this approach is the availability on site of suitably qualified staff able to respond to a changing situation.

One such approach could involve taking a relatively optimistic view of the ground conditions but having a fallback position if the field observations indicate that the optimistic assertions in the design are not fulfilled. On this basis the use of field monitoring forms an integral part of the project and the approach is often referred to as the observational method (of design and construction). To ensure that the use of this method did not result in claims for changes to the Contractor's programme, it would be necessary to identify all of the strategies that could be adopted and to include these in the tender documents. Note also that the bill of quantities would allow for payment in accordance with relevant strategies.

Besides the usual ground investigation and assessment of soil properties, there are essentially four further categories of in-situ testing and field monitoring that may need to be carried out for a soil nailing project as follows:

1. In-situ performance tests
2. Pre-construction field trials
3. Field testing and monitoring during construction
4. Post-construction monitoring.

7.1 IN-SITU PERFORMANCE TESTING

Reliable performance data for purposes of a design may be only obtainable from in-situ tests. Particular examples of such tests could involve the assessment of:

(a) pullout behaviour and resistance
(b) damage to protecting coatings during nail installation
(c) strength of connections
(d) size of end bearing plates
(e) drainage characteristics
(f) strength of nail couplers or on-site fabricated nail splices

Pullout tests will normally be carried out to

a) establish that the nails meet the design requirements at the pre-construction stage,
b) establish suitability criteria,
c) monitor quality control during construction.

The tests should provide data on load, displacement and time that will allow the suitability of the proposed soil nailing system and method of construction to be assessed against the design requirements. A number of possible methods are available for carrying out these tests and reference should be made to BS 8081: (1989) for details. Note that tests results from pull-out tests over the full length are susceptible to error from surface boundary effects and a more reliable approach involves decoupling a portion of the nail near the face. The decoupled length is typically in the range 25 - 50 % of the total length dependent on its magnitude. In essence the method used should provide load versus displacement data for a minimum of two load cycles as indicated schematically in Fig. 5. During the first cycle of loading the maximum pullout force applied corresponds to 50 percent of design ultimate unit bond stress. The second cycle of loading should attain 100 percent of the design ultimate bond stress. As shown in the figure, the nail is loaded in a series of increments to some proportion of the design ultimate pullout load and then unloaded in decrements. The reading of displacement after completion of a loading-unloading cycle provides a measure of the permanent displacement.

It would be necessary to sustain the load for a short period after each load increment or decrement, a period of 10 minutes is suggested but this value may need to be varied dependent on particular conditions. Plotting the readings of displacement against elapsed time during the 10 minute wait period will provide a better indication of creep behaviour and also identify any need to increase the delay period if creep is continuing.

To obtain suitable acceptance criteria for tests carried out during construction, the pullout tests during the pre-construction stage should be carried out at a number of time intervals after installation. For example, the design pullout resistance for drilled and grouted nails will usually be specified in terms of 7 day strengths. However, to avoid extensive remedial works because nails have not attained the acceptance criteria during construction, early indications of this situation could be obtained by also establishing corresponding acceptance criteria for 3 days after installation.

7.2 PRE-CONSTRUCTION FIELD TRIALS

Field trials are carried out to assess the effectiveness of the proposed construction methods. The trials could involve an assessment of some or all of the following...
Figure 5. Pullout test data shown schematically for two loading cycles.
procedures during the pre-construction phase:

(a) drainage installation
(b) grout pressures and effectiveness of treatment
(c) size of temporarily unsupported excavation area for treatment
(d) procedure for applying sprayed concrete and constructing facing
(e) drilling method and casing requirements
(f) driving method
(g) method of repairing facing defects
(h) method of constructing facing joints

The pre-construction testing programme assists the Engineer, and possibly also the Contractor, in establishing the construction techniques to be employed. Where access is possible, excavation and exposure of a vertical face may be helpful in determining the maximum unsupported height, and in obtaining undisturbed samples for laboratory testing. Care must be taken to ensure that excavation does not induce significant instability. A trial insertion of one or more nails may be helpful both in establishing a satisfactory technique, and in confirming the pull-out characteristics.

7.3 FIELD TESTING AND MONITORING DURING CONSTRUCTION

Testing and monitoring are carried out during construction to assess the characteristics of structural behaviour and to evaluate the quality of the work as it is being carried out. It would also be as essential component of the observational method of design and construction. The in-situ testing may involve some or all of the following:

(a) proof tests of pull-out resistance
(b) excavation and sectioning of trial nails
(c) test of grout strength and consistency of strength
(d) core testing of facing
(e) evaluation of structural movements and soil strains

The testing programme and monitoring carried out during construction is intended to ensure that the nailed structure is behaving in the manner anticipated by the designer. Observations of movement of completed sections of the face are desirable, at least in major structures, to ensure that such movements are of the order anticipated. This is important in constructing the lower part of the structure, as any failure at this stage will be difficult to rectify.

It is essential that the results of any monitoring or testing are communicated promptly to the engineer, so that any necessary modifications to the construction programme are initiated. If there are adjacent services or structures, it may be desirable to check their initial condition and set up arrangements to monitor any subsequent movement or damage, possibly by agreement with the owners. This may consist of photographic records, installation of telltales, or accurate surveying.

7.4 POST-CONSTRUCTION MONITORING

Post-construction monitoring of structures can provide valuable data to allow enhancements to future design procedures and also give early warning of possible problems. The observations may vary from only basic measurements of facing movement to a comprehensive range of data involving force, stress, strain, corrosion or degradation. Additionally monitoring of a drainage system may be carried out involving the rate of flow, the accumulation of silt, and the water table in the structure. It is also necessary to consider appropriate inspection and maintenance procedures, for example to ensure that vegetation is properly established and drains continue to function, and that there is no serious damage through vandalism, vehicle impact, or surface corrosion.

7.5 SPECIAL CONSIDERATIONS FOR MONITORING FAILED STRUCTURES

In using soil nailing to repair a failed slope or wall, the design should be based on an accurate knowledge of existing slip planes, and the full extent of any instability. Whenever possible, movements associated with the failure should be made for a period before repairs are undertaken. Surface movements may be monitored by surveying or photogrammetric techniques. Deeper movements may be monitored by slip indicators or extensometers and inclinometers. If a period of observation is not possible, the slip surface may be located by partial excavation and observation, although experience is needed to detect a failure surface by this means.

8. CONCLUSIONS

Because of the relatively recent introduction of soil nailing, the methods of design and specification are still undergoing development. Although some publications provide information on the design methods that can be used, virtually nothing has been published on specification procedures. It is considered that the lack of suitable specifications is restricting the use of the technique at present. It should be recognised, however, that specifications should be produced that allow a diverse range of appropriate techniques to be used and that do not inhibit technological development.

This Report reviews the procedures involved in the installation of the two most common systems currently used, namely drilled and grouted nails and driven nails,
for both retaining structures and slopes. The descriptions provided are a basis for developing suitable specification clauses and a selection of suggested clauses that could be adopted for particular applications are also presented. It is believed that the range of suggested clauses are sufficiently comprehensive to cover the main requirements in a Contract for the two types of soil nailing considered.

In contrast to reinforced earth structures that use selected fill in the reinforced zone, soil nailed structures can be subject to much more onerous soil conditions. Considerations in regard to the corrosion of metallic reinforcement could embody virtually any type of soil. The Report describes an approach for dealing with aspects of metal corrosion that allow corrosion allowances to be determined for a range of soil conditions and structural design lives.

The soil nailing method offers a very suitable basis on which to employ the observational method of design and construction. Such an approach would permit the design to be optimized in the light of detailed information on the soil conditions and structural behaviour as this becomes available from the field monitoring. However, to avoid changes to the Contractor's programme resulting in contractual claims, all the alternative strategies likely to be employed would need to be identified and included in the tender documents as well as the relevant procedures for payment in Bills of Quantities.

9. ACKNOWLEDGEMENTS

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10. REFERENCES


APPENDIX 1: SUGGESTED SPECIFICATION CLAUSES FOR SOIL NAILING

1.0 INTRODUCTION

This Appendix contains suggested specification clauses for permanent works. They should only be used on Department of Transport schemes after obtaining written approval from the Department.

1.1 METHOD, STANDARDS AND CODES OF PRACTICE

1.1.1 Description

The work shall be carried out in accordance with a detailed Method Statement which has been approved by the Engineer. Approval for this document shall be sought at least (1) days prior to installing the first soil nails or carrying out associated earthworks. Where appropriate the document shall provide details of:

1. earthworks including maximum unsupported excavation width and depth,
2. method of nail installation,
3. method of forming the facing,
4. method of connecting the nails to the facing,
5. drainage methods,
6. methods of performing field tests,
7. method of assessing damage to protective coating where appropriate,
8. grouting procedures,
9. temporary support,
10. the time after installation before a nail is considered to be fully operational,
11. maximum exposure period for untreated sections of excavation,
12. form of the test records.

The form that the daily records take shall be agreed at this stage.

1.1.2 Standards and Codes of Practice

Materials and workmanship shall conform to the Department of Transport Specification for Highway Works and appropriate International, European and British Standards current at the time of tender, unless in conflict with this Specification when the latter shall take precedence.

1.1.3 Working Drawings

The Contractor shall submit Working Drawings, for the approval of the Engineer at least (1) days prior to installation of any nails or carrying out any associated excavation. The Working Drawings shall include the following details where appropriate:

1. location and pattern of nail installation,
2. location of connections and splices or couplers,
3. location of drainage,
4. location of test nails.

1.1.4 Variations

Once approval has been given to the Method Statement and Working Drawings, variations shall only be permitted with the prior approval of the Engineer.

1.1.5 Design

Where the design is being carried out by a Specialist Contractor, or as part of a sub-contract that involves carrying out the design, the following suggested clauses may also be included:

The design shall be carried out using an established procedure for drilled and grouted or driven/fired nails. It shall be executed with due care and skill and shall embody the structural integrity and overall stability of the Works. The design shall take account of the following information where appropriate:

1. Ground water conditions including the presence of aquifers and other sources of free water;
2. Geotechnical conditions including the soil strength, bearing capacity, existing slip planes and fractures.

Where blank parentheses are shown this is regarded as scheme specific and appropriate values specified by the Engineer.
or fissures, and characteristics affecting durability of the soil nailing system,

(d) Performance criteria including influence of external loading on structure, collapse and serviceability aspects of the structure and required service life,

(e) Influence of structure and associated loading on adjacent structures, buried services and other utilities.

(f) Construction method and stability at all stages of excavation.

The design shall take account of relevant codes of practice, and CEN or British Standards and manufacturers' recommendations for materials, components and equipment forming part of the Works. Where appropriate, the design shall embody the results of field tests and trials to validate the design assumptions and design properties.

1.1.6 Design life

The corrosion allowances, creep behaviour and other time dependent aspects of the structure shall be determined in respect of the required design life of the structure. The design life of permanent (retaining/earthwork) structures for the Department of Transport is (120/60) years.

2. MATERIALS AND COMPONENTS

2.1 SOURCES OF SUPPLY

The source of supply of the soil nails and such other materials as are covered by this Specification shall be approved in writing by the Engineer and sources of supply shall not be changed without prior approval by the Engineer.

2.2 SOIL NAILS

The soil nails shall be prefabricated and delivered to site ready for installation in the Works.

2.2.1 Reinforcement

Mild steel soil nails shall comply with BS 4449 or equivalent European national standard. The characteristic yield stress for nails of nominal diameter 20, 25, 32, 40 and 50 mm conforming to this Standard is 250 N/mm². The fabricated nail shall be hot dip galvanized according to BS 729 or equivalent European national standard and have a coating thickness of (**) mm. Alternatively proprietary coatings may be used in place of galvanized coatings but such proprietary coatings shall have an Agreement Board Roads and Bridges Certificate or other equivalent European Approval Certification consistent with the intended application. Proprietary soil nails shall have an Agreement Board Roads and Bridges Certificate or other equivalent European Approval Certification registered with the Department of Transport.

2.2.2 Splices/Couplers

These shall be according to the Particular Specification and in addition shall not involve any method which requires removal or damage to the protective coating. Only nails greater than 9 metre in length may be spliced or coupled using a mechanical splicer or coupler. The tensile, bearing and shear strength of a splice or coupler shall not be less than (90) percent of the soil nail when considering the influence of the combination of stresses.

2.2.3 Plastic sheaths

Where appropriate, plastic sheaths shall encapsulate the nail and shall be fabricated from high density corrugated polyethylene or polypropylene tubing with a minimum uniform wall thickness of 1 mm. To ensure effective load transfer between the encapsulated nail and grout the pitch of the corrugations shall be in the range 6 to 12 times the wall thickness of the sheath and the amplitude of corrugation not less than 3 times the wall thickness. A screw-on cap shall be placed on the end of the sheath in contact with the soil and bonded with an appropriate solvent glue. Sheath joints shall be kept to a minimum and such joints will be screw-jointed and bonded with a solvent glue. The bond strength of the joint shall be at least (90) percent of the parent material.

2.2.4 Centralizers

A minimum of (3) centralizers shall be provided at suitable intervals over the total length of the encapsulated nail with the last centralizer 0.3 metre from the end of each nail to ensure the required minimum cover of (10) mm of grout is achieved along the encapsulation. The centralizers shall be fabricated from materials which have no deleterious effects on the soil nailing system. To permit free flow of grout, the centralizers shall have a minimum diameter 10 mm less than the nominal diameter of the drill hole. Alternatively they may be manufactured with cut-outs that permits free flow of grout but retains the correct centralizing function. Examples of suitable types of centralizers are presented in Section 7 of BS 8081. Spacing shall be provided both inside and outside of encapsulated nail assemblies.

2.2.5 Cementitious grouts

Unless otherwise approved by the Engineer, grout for nails shall comprise a neat cement grout consisting of a pumpable mixture of Portland cement and water and can reach a cube strength of (40) kN/m² in 28 days. Cubes shall be made and tested according to BS 1881. The water cement ratio shall not exceed (0.45) to reduce loss of grout into surrounding ground. The grout shall not be subject to bleeding in excess of (2) percent after (3) hours. Admixtures which can control, bleed or retard set of the grout shall be used only when approved in writing by the Engineer. Their use shall be strictly according to the manufacturer’s instructions.

2. Numbers in parentheses are suggested values that may need to be changed for particular applications.
2.2.6 Grouting method for encapsulation

Grouting of encapsulated nails shall be carried out in a rigid frame assembly with the encapsulation held in a vertical or inclined position in the frame. The annular space between the nail and the sheath shall be not less than (10) mm at any point and shall be achieved by a minimum of three spacers along the length of the nail. Such spacers shall be approved by the Engineer. Grouting of encapsulations shall be carried out using tremie pipes or directly through the base at a pressure not exceeding (200) kN/m².

Grout shall be injected at the lowest point to ensure that the sheath is filled without introducing air voids. Grout shall be injected slowly and progressively from the bottom to the top until the encapsulation is completely filled without separation and clean grout at the required consistency is seen to run from the top of the sheath. On completion excess grout shall be cleared away. The encapsulation shall be protected against shock or vibrations for a minimum period of 24 hours after grouting.

2.2.7 Protecting a fabricated nail

Soil nails projecting beyond the encapsulation shall be protected by a plastic sleeve until affixed to the nail head. The fabricated nail shall be handled, transported and stored to avoid corrosion or damage including that produced by bending or sagging of the encapsulation.

2.3 CONNECTIONS TO THE FACING

Connections to the facing shall be such as to transfer the axial tensile forces without forming a point of weakness. Their strength shall be not less than (90) percent of the parent material when considering the influence of combined stresses. No bolt, screw dowel or rod shall be less than 12 mm nominal diameter. Metallic components shall be mild steel conforming to BS 4449 or other equivalent European national standard. They shall be hot dip galvanized according to BS 729 or other equivalent European national standard. Connections between the facing and the soil nails shall be as given in the Particular Specification. As appropriate they shall consist of [metal/(*)] [dowel(s)/rod(s)/(*)] [casting in-situ].

2.4 FACING MATERIALS

2.4.1 Welded Steel Mesh

Shall comply with BS 4483 and shall have a nominal gauge of (6/4*).

2.4.2 Cast-in-place or precast concrete facing

Shown in the Working Drawings shall conform to the requirements for structural concrete given in the 1700 series clauses of the Specification for Highway Works.

2.4.3 Permanent structural sprayed concrete facing

Shall be constructed from mix proportions designed by the Contractor to satisfy the strength and other requirements of the Contract. The sprayed concrete shall be produced by the wet mix process achieving a minimum compressive strength of (30/40/50/4*) kN/m² in 28 days. To ensure that the 28 day strength requirement is complied with and so avoid excessive remedial works, the strengths of the concrete at 3 days and 7 days shall be determined in preliminary trials. During construction, cube strengths shall be determined at these intervals of time and shall confirm that the specified 28 day strength will be attained.

Admixtures shall be used only when approved in writing by the Engineer. Such admixtures shall be compatible with the cement used, be non-corrosive to steel and shall not promote other detrimental effects such as cracking and excessive shrinkage. They shall be used in accordance with manufacturers’ recommendations. Water used in the sprayed concrete mix shall be potable, clean and free from substances which may be harmful to concrete and steel. The water shall be free also of elements that would cause staining.

2.4.4 Geotextile and other forms of facing

Shall be constructed in accordance with the Particular Specification.

2.5 BEARING PLATES

Unless otherwise approved by the Engineer, the bearing plates shall be of carbon steel conforming to BS 4449 or other equivalent European national standard and be protected against corrosion according to the requirements of BS 5493 or other equivalent European national standard. The bearing plates in concrete facing shall be set in a seating formed of (concrete/cement/epoxy) or alternatively shall be seated directly on a cast-in steel plate.

2.6 SUPPLY TO SITE

Soil nails and other materials covered by this Specification shall be supplied to site at such times as not to hinder or delay the execution of the Works. Soil nails shall be delivered to site in an undamaged condition and shall not be damaged by site handling or storage. Any soil nails or other such materials covered by this Specification not conforming to these requirements shall be notified to the Engineer for acceptance or rejection. Rejected materials shall be removed promptly from the site.

* The mesh size and specified strength shall be established as a design requirement.
3. CONSTRUCTION METHODS

3.1 CONSTRUCTING SOIL NAILING SLOPES OR EMBANKMENTS

Where appropriate, soil slopes or embankments shall not be constructed with steeper side slopes or with greater widths and depths of excavation than those shown in the Contract, except to permit adequate compaction of the edges without affecting the stability of the slope. Any trimming back to the final profile shall be done according to the Contractor’s Method Statement and by means which do not damage or displace the soil nailing system.

3.2 CONSTRUCTING SOIL NAILING RETAINING STRUCTURES

Where appropriate a soil nailed retaining wall shall be constructed from the top down as the soil in front of the wall is removed and the nails are installed and grouted at each level. The exposed soil face shall be retained with a steel reinforcement mesh and sprayed concrete facing. Drainage systems as appropriate shall be installed prior to applying the sprayed concrete. If approved by the Engineer and shown on the drawings, a structural cast-in-place concrete, precast concrete or other facings may be subsequently constructed and suitably attached.

3.3 LIMITATIONS ON CONSTRUCTION PLANT

All vehicles and construction plant having a mass more than (1000) kg shall be kept at least (2) metre behind the facing or external boundaries. Where appropriate fill within (2) metre from facing shall be compacted with vibro-tamper, vibrating plate compactor, vibrating roller, having a total mass not more than (1000) kg.

3.4 INSTALLATION OF GROUTED SOIL NAILS

3.4.1 Drilling

Holes for soil nails shall be drilled to the depth, diameter, alignment and position shown on the Working Drawings. The holes shall have a maximum deviation from the positions shown in the Drawings or in the Particular Specification of +/- (100) mm. The maximum permitted deviation of the drill holes from the specified alignment shall be +/- (2.5) degrees. Unless otherwise approved by the Engineer, the holes shall be cased during drilling and the drilling shall not proceed more than 300 mm ahead of the casing.

If approval is given to exclude casing it shall be the Contractor’s responsibility to choose a drilling method that will maintain open drill holes. The method shall not promote mining and loosening of the soil at the perimeter of the drill hole or fracture soils with weak stratification planes by use of high pressures. Water flush shall not be used. The drilling method shall not increase the diameter of the hole by more than (10) percent of that shown on the Working Drawings. For the determination of grout quantities, allowance shall be made for any such overdrill.

Where the drilled holes are inclined downwards such that debris can fall into the hole, it shall be temporarily covered if the soil nail is not to be installed directly on completion of drilling operation.

3.4.2 Soil nail installation

The soil nails shall be installed in each drilled hole prior to grouting. The installation equipment and its operation shall be such as to minimize disturbance of the soil being treated. The maximum deviation of individual soil nails from the required angle of inclination shall be 1 in 30 unless otherwise specified. Each soil nail shall have a maximum departure from the positions shown in the Drawings or in the Particular Specification of +/- (75 mm). If a soil nail is damaged during installation or attachment to a facing panel, it shall be replaced unless otherwise instructed by the Engineer. The nails shall not extend beyond the limits shown on the Drawings without the approval of the Engineer.

3.5 GROUTING

3.5.1 Grouting equipment

Mixing equipment shall be used that produces a grout of homogeneous consistency and shall be capable of providing a continuous supply to the injection equipment. The injection equipment shall be capable of continuous operation at a constant delivery pressure. The injection equipment shall include a system for recirculating the grout during pauses in the grouting operation.

3.5.2 Grouting method for drilled holes

Grouting of drilled holes shall be carried out during the withdrawal of the casing using tremie pipes using hydrostatic, gravitational, or pressure grouting. Where pressure grouting is used the grout shall be injected at a pressure not exceeding (20) kN/m² per metre depth of ground above the hole. Grout shall be injected at the lowest point of the drill hole to ensure that the hole is filled without introducing air voids. Grout shall be injected slowly and progressively from the bottom to the top until the hole is completely filled without separation and clean grout at the required consistency is seen to run from the top of the hole.

The grout shall fill the hole flush with the wall or slope face as appropriate. Grouting shall be discontinued if the ambient temperature falls below 5 degrees Centigrade or if the grouting temperature falls below 5 degrees C. When the grout has developed a strength not less than (90) percent of that specified for the 28 day strength, the nail bearing plate shall be installed on the bedding specified in sub-clause 2.6. The bearing plate shall be bedded down on a mortar pad and the nail tensioned by applying a torque that induces a grout-nail bond strength of (30) percent of existing ultimate bond strength. The ultimate bond strength shall have been determined from

Note that drains may be installed during or after construction provided stability is not at risk.
preliminary trials that relate compressive strength of grout to bond strength.

3.6 INSTALLATION OF DRIVEN SOIL NAILS

Driven nails shall be installed without pre-drilling to the depth, diameter, alignment and position shown on the Working Drawings. The nails shall have a maximum departure from the positions shown in the Drawings or in the Particular Specification of +/- (75) mm.

3.6.1 Installation equipment

The installation equipment and its operation shall be such as to minimize disturbance of the soil being treated. The installation equipment shall be capable of gradually imposing the total required force to drive the nail to the required depth by a jacking system or other method approved by the Engineer. Alternatively the installation equipment shall provide a vibro-percussive (pneumatic / hydraulic) force capable of driving the nail to the required depth. The equipment shall support the nail over the length by means of a suitable frame that provides a reaction, prevents buckling or permanent distortion of the nail, and ensures its correct alignment. The design of the equipment shall permit the applied force to be recorded to an accuracy of +/- (1.5) kN and the length of nail installed to an accuracy of (75) mm.

The nail bearing plate shall be installed on the bedding specified in sub-clause 2.6. The soil nail shall be bedded down on the bearing plate by applying a torque that induces a bond strength between the nail and soil not exceeding (30) percent and not less than (15) percent of ultimate bond strength. The ultimate bond strength shall have been determined from preliminary pullout trials.

3.6.2 Splices/Couplers

These shall be according to the Particular Specification and in addition shall not involve any method which requires removal or damage to the protective coating. Only nails greater than 9 metre in length may be spliced/ coupled using a mechanical splicer or coupler. The tensile, bearing and shear strength of a splice/coupler shall be not less than (90) percent of the soil nail when considering the influence of the combination of stresses.

3.6.3 Protective coating

The Contractor shall ensure that the protective layer against corrosion is not damaged by driving or that adequate sacrificial thickness of material has been provided to allow for superficial damage. The required additional sacrificial allowance shall be established from pre-construction trials carried out in the same soil and using the same equipment and soil nails as used in the Works. The method of assessing damage to the protecting coating shall be as approved in the Method Statement.

3.6.4 Damage to soil nails

If a soil nail is damaged during installation or attachment to a facing panel, it shall be replaced unless otherwise instructed by the Engineer. The nails shall not extend beyond the limits shown on the Drawings without the approval of the Engineer.

3.6.5 Unforeseen obstructions

Where an unforeseen obstruction prevents installation of a driven soil nail to the required depth, the Contractor shall inform the Engineer without delay. Where practicable an alternative nail shall be installed at (500) mm to one side, if approved by the Engineer the obstruction may be avoided by realigning the nail direction by not more than (5) degrees. If this alternative nail fails the Contractor shall continue with other nails provided stability is not endangered.

3.7 FACING

3.7.1 Preparation of the soil face

Where appropriate, the face of the wall or slope shall be excavated over the required width and depth as approved in the Method Statement for a particular stage. The excavated face shall not be exposed for a period in excess of (24) hours or as specified in the Method Statement without the prior approval of the Engineer. Excavation shall proceed in stages exposing the minimum amount of soil or rock face which will allow the practical and expeditious application of the sprayed concrete and the installation of soil nails while assuring stability of the excavated face and minimising ground movements.

In anticipation of applying the sprayed concrete, surfaces shall be cleaned of all loose material, rebound from previously placed sprayed concrete, and other foreign matter that prevents bond. If necessary, the surface shall be dampened prior to applying the sprayed concrete. Permanent drainage measures shall be incorporated as specified in the Working Drawings and connected to the existing system. During placement of sprayed concrete the drainage system shall be protected against contamination to ensure proper functioning.

Thickness measuring pins shall be installed on a 1.5 m square grid. These shall be durable, non-corrosive and of sufficient length to provide adequate fixing during application of the sprayed concrete. Alternative methods for ensuring that the required minimum thickness of sprayed concrete is being applied shall be approved by the Engineer. The steel mesh reinforcement shall be firmly positioned to prevent movement and vibration while the sprayed concrete is being applied. Construction joints shall be as approved in the Particular Specification. The surface of such joints shall be thoroughly wetted before any adjacent section is placed.

3.7.2 Equipment

Pumping and delivery equipment shall be capable of providing a continuous uniform supply at a constant delivery pressure and shall have been specifically designed and constructed for the purpose of spraying concrete. The equipment shall be inspected and cleaned...
twice daily when in use. During working operations the
delivery hoses shall be arranged to avoid sharp bends or
kinks at all times.

3.7.3 Application of sprayed concrete

The sprayed concrete shall be applied from the bottom
twice daily when in use. During working operations the
delivery hoses shall be arranged to avoid sharp bends or
kinks at all times.

3.7.3 Application of sprayed concrete

The sprayed concrete shall be applied from the bottom
to prevent accumulation of rebound on the surface still
to be covered. The nozzle shall be held at between 600
mm and 1500 mm and such angle as to place material
behind reinforcement before it is allowed to accumulate
on its face. Sprayed concrete shall not be placed through
more than one layer of reinforcing mesh in one applica-
tion unless approved by the Engineer. The material shall
emerge from the nozzle in a steady uninterrupted flow.
Water content, air pressure and thickness shall be
carefully controlled to prevent sagging or sloughing.

The minimum cover to the reinforcement shall be (40)
mm. On completion, the sprayed concrete shall be cured
in accordance with the recommendations of BS 1881,
Part 108. On attaining its initial set, the sprayed concrete
shall be finished as shown on the Contract Drawings.

When any layer of sprayed concrete is to be covered by a
succeeding layer, it shall be first allowed to develop its
initial set. Prior to applying a further layer, all loose
material and rebound must be removed by brooming or
scraping. Particular attention shall be given to cleaning
the area at the base of each lift to insure good joints
between lifts. Surface protrusions in material that has
attained its final set shall be removed by sandblasting
and thorough cleaning.

Layer thickness shall be determined from pre-construc-
tion trials to ensure compliance with the requirement that
the material shall not slump or sag to induce a failure of
bond. The horizontal leading edge of thick layers shall be
maintained at a slope.

3.7.4 Interruptions to sprayed concrete

operations

Sprayed concreting shall be discontinued if wind or air
currents cause separation of the nozzle stream during
placement. Alternatively a means of screening the nozzle
stream shall be provided as detailed in the Method
Statement. Sprayed concreting shall be discontinued if
the ambient temperature falls below 5 degrees Centi-
grade or if the sprayed concrete cannot be adequately
maintained in excess of 5 degrees C. Sprayed concreting
shall be discontinued during heavy rain or if runoff is
anticipated.

3.7.5 Construction joints

Construction joints shall be formed by providing a taper of
approximately 30 degrees that is cut back square to the
reinforcement. An overlap of the existing mesh and new
reinforcement of (300) mm shall be formed at adjacent
sections of sprayed concrete where the facing shall be
continued. Prior to applying sprayed concrete to this
tapered section it shall be thoroughly cleaned and wetted.

3.7.6 Checking integrity of sprayed concrete

Daily quality control shall be based on test cubes, taken
in accordance with BS 1881, Part 108, when sprayed
concrete operations are in progress. The integrity of the
sprayed concrete shall be checked for hollow areas by
sounding with a hammer not more than (24) hours after
placement. Alternative methods may be used with the
prior approval of the Engineer. Defective areas shall be
rectified in accordance with the Particular Specification.
Sprayed concrete which lacks uniformity, exhibits
segregation, honeycombing, or lamination, or shows
evidence of other defects shall be removed and replaced
with fresh sprayed concrete.

3.7.7 Finish to sprayed concrete

Unless otherwise specified the finish to sprayed concrete
shall be undisturbed gun finish as applied from nozzle
without hand finishing.

3.8 RECORDS

The Contractor shall keep daily records of the soil nails
installed. Copies of these shall be submitted to the
Engineer within two days following the installation. The
records shall show:

(a) Date
(b) grid and area reference of each soil nail
(c) position, length and inclination of each soil nail
(d) obstructions and delays
(e) torque force applied to soil nail
(f) number and type of tests carried out
(g) readings from relevant instrumentation.

Any unforeseen conditions encountered and reported
shall be noted in the records.

4. TESTING AND MONITORING

OF SOIL NAILING SYSTEM

The specified sequence of operations for the soil nailing
installation and instrumentation shall be followed. Where
instruments are placed before nails are installed, the
position of the instruments shall be adequately marked
and maintained by the Contractor.

4.1 PRE-CONSTRUCTION TESTING OF

PANELS

Prior to the start of the soil nailing operations, test panels
shall be made using the proposed equipment, materials
and mix proportions intended for the Works. A test panel
of at least 1m x 1m shall be made for each mixture being
considered. The test panels shall be fabricated to the same thickness as in the structure, but not less than 100 mm. At least five 75 mm diameter cores shall be removed from each panel for testing in accordance with BS 1881 or other equivalent European national standard.

4.2 CONSTRUCTION TESTING OF FACING

Cores shall be taken at the positions and intervals specified in the Particular Specification and in accordance with BS 1881 or other equivalent European national standard. A minimum of three cores shall be taken from each 100 square metres of completed facing. Alternatively, one test panel shall be constructed to represent each 100 square metres of completed facing under the same environmental conditions as the represented section of facing. The minimum dimensions of the panel shall be 0.5m x 0.5m x 100mm. The test panels shall be cured as the facing, except that the test specimens shall be soaked in water for a minimum of 40 hours prior to testing. The Contractor shall remove a minimum of three cores from each panel for testing according to BS 1881 or other equivalent European national standard. The average compressive strength of each core of a set of three cores must be not less than (95) percent of the specified compressive strength.

4.2.1 Reinstatement of core holes

Holes created by removal of cores shall be thoroughly cleaned and dampened and reinstated with mortar as approved in the Particular Specification.

4.3 TESTING OF SOIL NAILS

4.3.1 Equipment

Displacement measuring gauges that can measure to 0.1 mm or better and mounted on an independent reference frame shall be used to measure movement. Hydraulic equipment capable of inducing pullout failure of any selected nail, together with a pressure gauge, calibrated as a unit shall be used to apply the test load. Alternatively the applied load may be monitored utilizing a suitably calibrated load cell. The load measuring system shall be capable of measuring the load increments to an accuracy of one percent of the design load or better. The test loads shall be applied incrementally over a minimum of 10 increments of loading to reliably establish the load-displacement curve.

4.3.2 Characteristics of pullout testing

One soil test-nail per horizontal row shall be installed and load tested to pullout failure and the maximum number of test nails shall not exceed 3 per cent of the total number of nails. Pullout failure is defined as movement in excess of (1) mm during the period between one minute and 10 minute, or (2) mm per log cycle of time over a maximum sustained load period of 60 minutes. The test nails at each level shall be installed and tested at a rate consistent with the construction operations. The length of test-nail shall be chosen to induce pullout failure prior to steel yield, but it shall not be less than 2.5 metre. A minimum ungrouted or unbonded length from the face of 1 metre shall be provided. The method of installation and nominal diameter of the drill hole shall be the same as for production nails.

4.3.3 Pullout test procedure

For drilled and grouted nails, each test nail shall be grouted in place as part of a regular production grouting process. After grouting, the nail shall not be loaded for a minimum of (3) days. For driven nails, each test nail shall not be loaded for (24) hours after installation. An exception to this time delay could apply to installation in purely frictional soils when delays to permit pore pressure dissipation are unnecessary. Reaction frames shall not be permitted to bear on the sprayed concrete face within a one metre radius of the centre of the drilled hole.

The pullout test shall be made by incrementally loading and unloading the nail over a minimum of two cycles. During the first loading cycle the maximum load shall correspond to (50) percent of design ultimate unit bond stress for the particular depth of nail. The second load cycle shall attain a maximum load of (100) percent of the design ultimate unit bond stress or until pullout failure is attained. The unloading stage for both cycles shall be attained in a minimum of three decrements to the fully unloaded state. During and after the application of each increment or decrement of load the nail movement shall be measured and recorded to the nearest 0.1 mm with respect to an independent fixed reference point. The load applied through the hydraulic equipment shall be monitored with a pressure gauge or other approved measuring device.

The sustained load period shall start as soon as the load increment has been attained. Movement shall be recorded at 1 minute, 2, 3, 4, 5, 6 and 10 minutes. If the period of sustained loading is extended, the nail movement shall be recorded at 15, 25, 30, 45 and 60 minutes. Each increment of load shall be no greater than 20 per cent of the maximum load to be applied.

4.3.4 Pullout test acceptance criteria.

The nail performance shall be deemed acceptable if the stress mobilized at failure in adherence per unit area of the nail perimeter, equals or exceeds the design ultimate value. Unacceptable test results shall result in modifications to the construction procedures. Such modifications shall be approved by the Engineer and shall require the verification testing procedures to be repeated. Graphs shall be plotted during the test of deflection against load.

4.3.5 Failure to meet acceptance criteria.

If a soil nail fails to meet the acceptance criteria established from the pre-construction test programme, the Engineer must be informed without delay. Unless otherwise agreed by the Engineer, all nails installed subsequent to the last successful proof test shall be proof
tested. Nails not meeting the acceptance criteria shall require remedial action as directed by the Engineer.

4.3.6 Records of tests

The Contractor shall keep records of the tests carried out and copies of these shall be submitted to the Engineer on the working day after each test is completed. The records shall describe:

(a) date
(b) area and location of test
(c) number of tests carried out
(d) any variations from the specified procedure
(e) details of the test results
(f) any unforeseen conditions encountered

The form of the test records shall be agreed with the Engineer in the Method Statement.

5. PARTICULAR SPECIFICATION

The following matters are, where appropriate, described in the Particular Specification:

(a) Ground water conditions
(b) Facing to retaining structure
(c) Drainage measures
(d) Construction procedure
(e) Treatment of defective areas
(f) Curing of sprayed concrete
(g) Construction testing

6. HEALTH AND SAFETY

All work shall be carried out safely and according to current statutory requirements. Special attention shall be given to eye and dust protection hazards when applying sprayed concrete.
MORE INFORMATION FROM TRL

TRL has published the following other reports on this area of research:

CR214 Examples of the use of nailing for unstable slopes, G Cartier, Price Code B
CR239 Soil nailing - experimental laboratory study of soil-nail interaction, J Marchal, Price Code B
CR255 Mobilisation of stresses in nailed structures, J P Gigan and P Delmas, Price Code C
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If you are planning a project where we may be able to help, contact TRL at Crowthorne, Berkshire RG11 6AU, telephone 0344 770004, fax 0344 770356.