

BS 8006-2:2011+A1:2017



BSI Standards Publication

Code of practice for strengthened/ reinforced soils

Part 2: Soil nail design

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Foreword

Publishing information

This part of BS 8006 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 December 2011. It was prepared by Subcommittee B/526/4, *Strengthened/reinforced soils and other fills*, under the authority of Technical Committee B/526, *Geotechnics*. A list of organizations represented on these committees can be obtained on request to their secretary.

Supersession

Together with BS 8006-1:2010, BS 8006-2:2011 superseded BS 8006:1995, which was withdrawn. BS 8006-2:2011+A1:2017 supersedes BS 8006-2:2011, which is withdrawn.

Relationship with other publications

This standard is published in two parts:

- *Code of practice for strengthened/reinforced soils and other fills*
- *Code of practice for strengthened/reinforced soils – Part 2: Soil nail design*

This part has been drafted following the principles of BS EN 1997-1:2004.

Information about this document

This part of BS 8006 was drafted to meet the specific needs of designers and installers of soil nails for strengthening and/or reinforcing soil slopes.

Text introduced by or altered by Amendment No. 1 is indicated in the text by tags  . Minor editorial corrections are not tagged.

Use of this document

As a code of practice, this part of BS 8006 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 8006 is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

The recommendations in this British Standard are based on typical UK practice and therefore might not be wholly valid in other territorial or regional environments. Design checks in accordance with other British or international Standards might be necessary.

This standard is likely to be used under a variety of contractual arrangements and forms of contract. In many cases multiple designers might be involved. Therefore, irrespective of the contract form it is essential that the design of the soil nailing element of a project is properly integrated into whole scheme and contractual interfaces are clearly and appropriately specified within contract documents.

Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Section 1: General

1.1 Scope

This part of BS 8006 gives recommendations and guidance for stabilizing soil slopes and faces using soil nails. Other methods of stabilization using reinforced soil methods are given in BS 8006-1:2010 and both parts might be needed for complex structures.

Additional considerations might be required for unusually loaded or high soil nailed slopes, or where they interface with other structures.

Whilst BS EN 1997-1:2004 specifically excludes soil nailing, this standard is intended to harmonize the design approach of soil nailing with other geotechnical structures designed using BS EN 1997-1:2004.

The principal purpose of this standard is to provide design guidance, however, where knowledge of construction methodology is required for design purposes then appropriate paragraphs have been included. Construction guidance is given in execution standard BS EN 14490:2010. At the time of preparation of this standard, CEN Technical Committee TC341 is drafting a standard covering the testing of soil nails.

Structures and processes that are similar to soil nailing but not addressed in the standard are described in [2.3.6](#).

1.2 Normative references

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

BS 8006-1:2010, *Code of practice for strengthened/reinforced soils and other fills*

BS 8081, *Code of practice for grouted anchors*¹⁾

BS EN 196 (all parts), *Methods of testing concrete*

BS EN 197-1:2000, *Cement — Part 1: Composition, specifications and conformity criteria for common cements*

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

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

BS EN 1990, *Eurocode — Basis of structural design*

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

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

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

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

BS EN 14487, *(both parts), Sprayed concrete*

BS EN 14490:2010, *Execution of special geotechnical works — Soil nailing*

¹⁾  This standard also gives an informative reference(s) to BS 8081:2015+A1:2017. 

BS EN ISO 14688, (both parts), *Geotechnical investigation and testing — Identification and classification of soil*

BS EN ISO 14689-1, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description*

BS EN ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution*

BS EN ISO 22476 (all parts), *Geotechnical investigation and testing — Field testing*

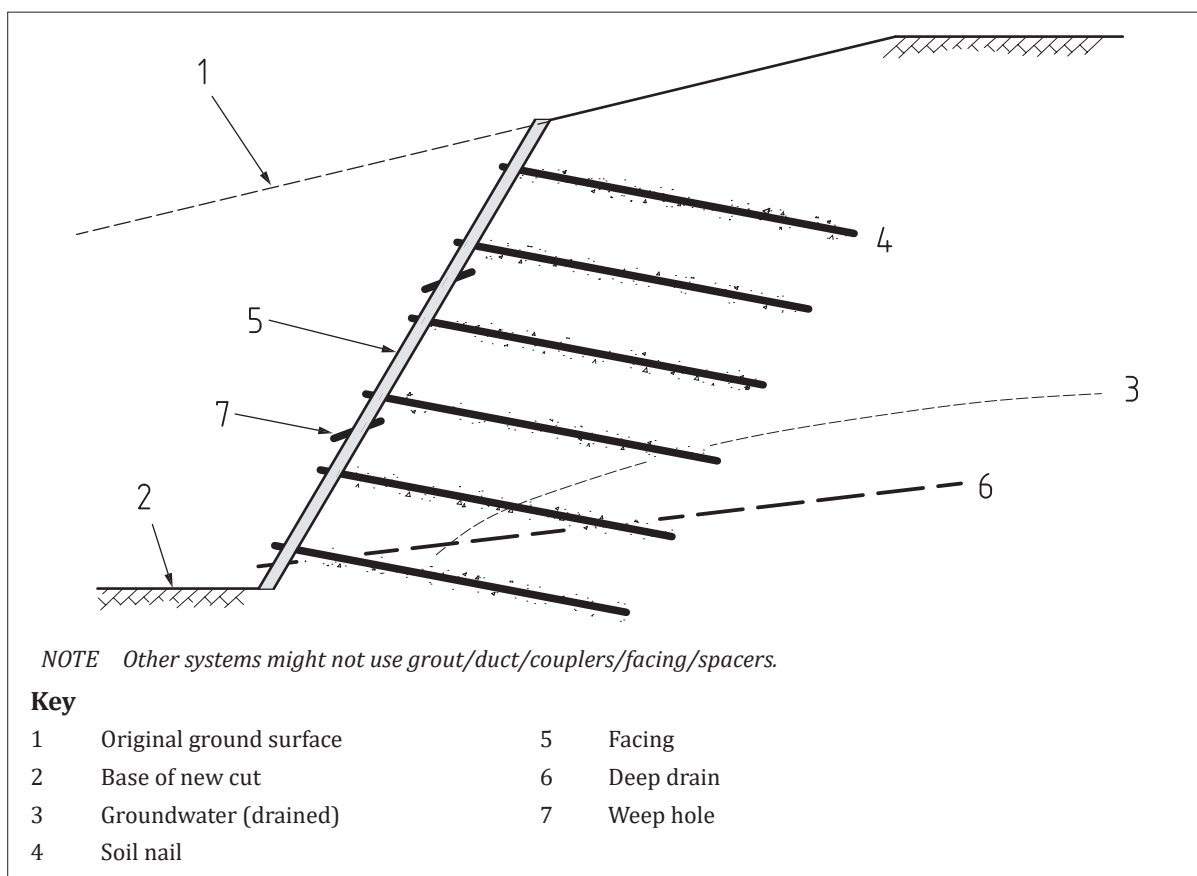
1.3 Terms, definitions and symbols

1.3.1 Terms and definitions

The following terms and definitions apply.

NOTE Some additional terms are illustrated in [Figure 1](#).

Figure 1 — Terms used in this standard



1.3.1.1 bearing plate

plate connected to the head of the soil nail to transfer a component of load from the facing or directly from the ground surface to the soil nail

[SOURCE: BS EN 14490:2010]

1.3.1.2 comparable experience

documented or other clearly established information related to the ground being considered in design, involving the same types of soil and rock and for which similar geotechnical behaviour

is expected, and involving similar structures; information gained locally is considered to be particularly relevant

[SOURCE: BS EN 1997-1:2004]

1.3.1.3 derived value

value of a geotechnical parameter obtained by theory, correlation or empiricism from test results

[SOURCE: BS EN 1997-1:2004]

1.3.1.4 design life

service life in years required by the design

[SOURCE: BS EN 14490:2010]

1.3.1.5 drainage system

series of drains, drainage layers or other means to control surface and ground water

[SOURCE: BS EN 14490:2010]

1.3.1.6 facing

covering to the exposed face of the reinforced ground that may provide a stabilizing function to retain the ground between soil nails, provide erosion protection and have an aesthetic function

NOTE See [Figure 1](#).

[SOURCE: BS EN 14490:2010]

1.3.1.7 facing drainage

system of drains used to control water behind the facing

[SOURCE: BS EN 14490:2010]

1.3.1.8 facing system

assemblage of facing units used to produce a finished facing of reinforced ground

[SOURCE: BS EN 14490:2010]

1.3.1.9 facing unit

discrete element used to construct the facing

[SOURCE: BS EN 14490:2010]

1.3.1.10 flexible facing

flexible covering which assists in containing soil between the nails

[SOURCE: BS EN 14490:2010]

1.3.1.11 geotechnical action

action transmitted to the structure by the ground, fill, standing water or ground-water

[SOURCE: BS EN 1997-1:2004]

1.3.1.12 geotechnical category

category assigned to a structure in order to establish minimum requirements for the extent and content of geotechnical investigations, calculations and construction control checks of the design in relation to the associated risks

[SOURCE: BS EN 1997-1:2004]

1.3.1.13 ground

soil, rock and fill existing in place prior to the execution of the construction works

[SOURCE: BS EN 14490:2010]

1.3.1.14 hard facing

stiff covering, for example sprayed concrete, precast concrete section or cast in-situ concrete

[SOURCE: BS EN 14490:2010]

1.3.1.15 production nail

soil nail which forms part of the completed soil nail structure

[SOURCE: BS EN 14490:2010]

1.3.1.16 proof load

maximum load applied during testing

[SOURCE: BS EN 14490:2010]

1.3.1.17 raking drain

drain, normally drilled into the slope through the front face, α_1 angled α_1 above horizontal

1.3.1.18 reinforcing element

generic term for reinforcing inclusions inserted into ground

[SOURCE: BS EN 14490:2010]

1.3.1.19 reinforced ground

ground that is reinforced by the insertion of reinforcing elements

[SOURCE: BS EN 14490:2010]

1.3.1.20 resistance

capacity of a component, or cross-section of a component, of a structure to withstand actions without mechanical failure e.g. resistance of the ground, bending resistance, buckling resistance, tensile resistance

[SOURCE: BS EN 1997-1:2004]

1.3.1.21 sacrificial nail

soil nail installed in the same way as the production nails, solely to establish the pullout capacity and not forming part of the soil nail structure

[SOURCE: BS EN 14490:2010]

1.3.1.22 soft facing

soft facing has only a short-term function to provide topsoil stability while vegetation becomes established

[SOURCE: BS EN 14490:2010]

1.3.1.23 soil nail

reinforcing element installed into the ground, usually at a sub-horizontal angle, that mobilizes resistance with the soil along its entire length

NOTE See [Figure 1](#).

[SOURCE: BS EN 14490:2010]

1.3.1.24 soil nail construction

any works that incorporates soil nails, and can have a facing and/or a drainage system

[SOURCE: BS EN 14490:2010]

1.3.1.25 soil nail system

consists of a reinforcing tendon and may include joints and couplings, centralizers, spacers, grouts and corrosion protection

[SOURCE: BS EN 14490:2010]

1.3.1.26 stiffness

material resistance against deformation

[SOURCE: BS EN 1997-1:2004]

1.3.1.27 structure

organized combination of connected parts, including fill placed during execution of the construction works, designed to carry loads and provide adequate rigidity

[SOURCE: BS EN 1997-1:2004]

1.3.1.28 tendon

structural component of a soil nail, often in the form of a solid or hollow bar and running the full length of the soil nail

1.3.1.29 test nail

nail installed by the same method as the production nails for the purpose of verifying the pullout capacity and durability, and which could form part of the structure

[SOURCE: BS EN 14490:2010]

1.3.2 Symbols

The following variables are used in this standard.

Symbol	Definition	Units
a	Nail plate size	m
A_s	Cross-sectional area of nail tendon for structural design	m ²
$A_{s,nom}$	Nominal cross-sectional area at end of design life	m ²
B	Slice width	m
c'_d	Design value of the cohesion intercept in terms of effective stress (c'_k/γ_c)	kN/m ²
c_u	Undrained shear strength	kN/m ²
$C_{1,2}$	Cohesion force acting on base of wedges 1 or 2	kN/m
d_{hole}	Nail hole diameter	m
d_{bar}	Diameter of reinforcing element, tendon or bar	m
d_m	Diameter of the front face mesh element	m

Symbol	Definition	Units
E_d	Design value of the effect of actions	kN
E_m	Young's modulus for the mesh material	kN/m ²
f_y	Yield strength of nail tendon	kN/m ²
f_{yk}	Characteristic yield strength of nail tendon	kN/m ²
H	Slope height	m
K	Earth pressure coefficient in terms of total stress and factored soil strength (not equivalent to the active Rankine co-efficient, k_a)	—
k_a	Rankine active earth pressure co-efficient	—
k_L	Ratio of the in plane horizontal effective stress and the vertical effective stress	—
k_r	Ratio of the average radial effective stress σ'_r on a nail to the vertical effective stress σ'_v	—
L_n	Total length of nail ($L_n = L_a + L_e$)	m
L_a	Length of nail in active soil zone (front of nail)	m
L_b	Bonded length of test nail	m
L_e	Embedded length of nail in stable soil (back of nail)	m
$M_{driving}$	Driving moment	kNm/m
$M_{resisting}$	Resisting moment	kNm/m
$N_{12,21}$	Normal total force acting on inter-wedge boundary	kN/m
p_h	Average pressure acting behind hard facings (Figure 31)	kN/m ²
p_m	Average pressure acting on flexible facing (Figure 32)	kN/m ²
p_{np}	Average pressure acting on nail plate (Figure 34)	kN/m ²
P_{ult}	Ultimate pullout force achieved in test	kN
$Q_{1,2}$	Characteristic surcharge force acting on the surface of wedges 1 or 2	kN/m
q_p	Permanent unfactored surcharge pressure acting on the surface of a slice	kN/m ²
q_v	Variable unfactored surcharge pressure acting on the surface of a slice	kN/m ²
r	Radius of slip circle	m
$R_{1,2}$	Frictional force acting on base of wedges 1 or 2	kN/m
R_d	Design resistance	kN
R_{td}	Design nail tendon strength	kN
R_{tk}	Characteristic nail tendon strength	kN
S_h	Horizontal nail spacing	m
S_m	Horizontal spacing between elements within the mesh	m
S_v	Vertical nail spacing	m
$\tan \phi'_d$	Design value of the tangent of the angle of shearing resistance ($\tan \phi'_k / \gamma_{\tan \phi'}$)	—
T_d	Design nail force per nail, which is the lesser of the nail's factored pull-out capacity ($\tau_{bk} \pi d_{hole} L_e / \gamma_{\tau b}$) and its factored tendon strength ($(f_{yk} A_{s,nom} / \gamma_s)$ (see 4.3 and 4.5 and Figure 21))	kN
T_f	Axial force in nail head at facing	kN
T	Axial force in nail	kN
$U_{1,2}$	Pore water force acting on base of wedges 1 or 2	kN/m
u	Pore pressure acting on base of slice	kN/m ²
W	Self-weight of slice	kN/m
z	Depth of mid-point between layer of nails in question and the next layer below	m
α	Angle to the vertical from centre of rotation to base of slice	degrees
β_1	Principal slope angle	degrees

Symbol	Definition	Units
β_2	Upper slope angle	degrees
γ	Unit weight [or weight density in BS EN 1997 (both parts)]	kN/m ³
$\gamma_{c'}$	Partial factor on effective cohesion	—
γ_{cu}	Partial factor on undrained shear strength	—
γ_g	Partial factor on weight of soil	—
γ_k	Partial factor used to derive a characteristic parameter	—
γ_{qp}	Partial factor on permanent surcharge	—
γ_{qv}	Partial factor on variable surcharge	—
γ_s	Partial factor on strength (including strength of nail tendon)	—
γ_{Sd}	Model factor	—
γ_m	Partial factor on material (structural) strength	—
$\gamma_{\tan\phi'}$	Partial factor on tangent of soil friction angle	—
γ_u	Partial factor on pore pressure	—
γ_y	Partial factor on unit weight (weight density)	—
$\gamma_{\tau b}$	Partial factor on bond stress	—
ε	Nail declination angle and/or strain	degrees
η	Angle defined as $90^\circ - \alpha - \varepsilon$ (Figure 17 and Figure 18)	degrees
η_d	Design nail plate constant (Figure 30)	—
$\theta_{1,2}$	Base angle of wedge 1 or 2	degrees
λ_T	Interface factor relating mobilized friction angle to characteristic friction angle	—
ξ	Correlation factors on the minimum and mean pullout resistances or bond resistances measured in a soil nail pullout test	—
σ'_r	Radial effective stress acting normal to the surface of a nail	kN/m ²
σ'_v	Vertical effective stress	kN/m ²
τ_b	Bond stress	kN/m ²
ϕ'	Friction angle of soil	degrees
Subscript		
i	Relates to slice number i (from 1 to n)	
j	Relates to nail row number j (from 1 to m)	
d	Design value of parameter	
k	Characteristic value of parameter	
t	Test value of parameter	
u	Ultimate value of parameter (except as defined elsewhere, e.g. c_u and γ_u)	

Section 2: Soil nailing applications and construction considerations

2.1 General

COMMENTARY ON 2.1

Soil nailing is a ground stabilization method used to enhance the stability of slopes and faces. It is employed in "in-situ" ground, which may be natural or deposited by man, by the insertion of soil nails. Correctly orientated soil nails can improve the shear strength of soil, which is naturally weak in tension. Frictional forces are mobilized when surrounding soil shears against relatively inextensible soil nails. This results in:

- *an improvement of the slope's mass shear resistance; and*
- *development of tensile forces in the soil nails.*

Depending on the soil nailing application, the soil nails can rely on other elements such as bearing pads, facing systems and drainage to be most effective. The effectiveness and efficiency of a soil nailing application is highly dependent upon the ground conditions.

Soil nailing applications are described in 2.3.

2.2 Description of typical soil nail element components

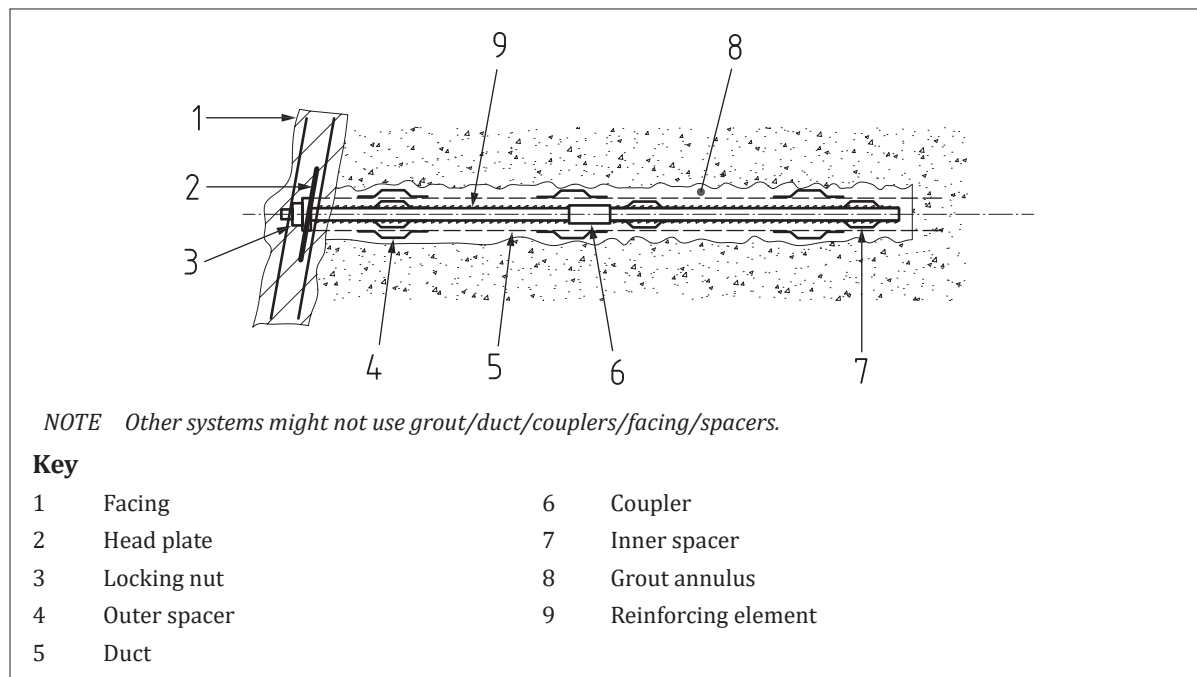
A typical soil nail element comprises a number of components, some of which are required for structural load carrying capacity and others to ensure durability over the design life. The material requirements of the components are detailed in BS EN 14490:2010, but a brief description is given below, with reference to [Figure 2](#).

The key components can be described as:

- Tendon:** This is the main component for transferring axial load along the length of the soil nail. It is typically a steel bar or rod, with diameters in the range 10 mm to 32 mm. Tendons with other diameters or made from other materials may be used provided they exhibit the necessary mechanical properties. Tendons may be constructed from several sections joined by couplers. The structural capacity of the couplers, or reduced section area at the coupler, may dictate the design strength of the tendon.
- Head plate and locking nut:** A head plate and locking nut are used to transfer load between the tendon and facing. A tapered washer, or similar arrangement, is often inserted between the head plate and locking nut to ensure even load distribution; particularly where the tendon and facing are not arranged orthogonally. The head plate may be embedded within the facing or bedded onto it or a concrete pad. Concrete pads can be recessed into the slope so they are less visible.
- Protective ducts, sheaths and coatings:** Protective ducts, sheaths and coatings may be used to improve durability of the soil nail. Where required they should be detailed to ensure continuity along the entire length of the nail element. Coatings may be applied directly to the reinforcing element.
- Grout annulus:** The grout annulus is designed to provide intimate contact between the soil nail and the ground. It should also be designed to protect the tendon from chemical attack in aggressive soil. Spacers around the tendon may be used to ensure adequate grout cover. Separate inner and outer annuli may be formed if ducts or sheaths are included in the design.

Inner and outer spacers would normally be required in such cases and different grout specifications may be applied to each annulus.

Figure 2 — Possible components of soil nail system, pre-bored and grouted, shown with rigid facing



2.3 Typical applications

2.3.1 Stabilizing new cut slopes

Where ground is excavated at an angle steeper than that at which it can stand safely then soil nails may be used to improve the stability. Soil nailing may be used to stabilize slope angles up to the vertical.

NOTE 1 Early examples of new cut slopes were cited by Bruce and Jewell [16] and more recently, a number of UK examples were presented in CIRIA C637 [1].

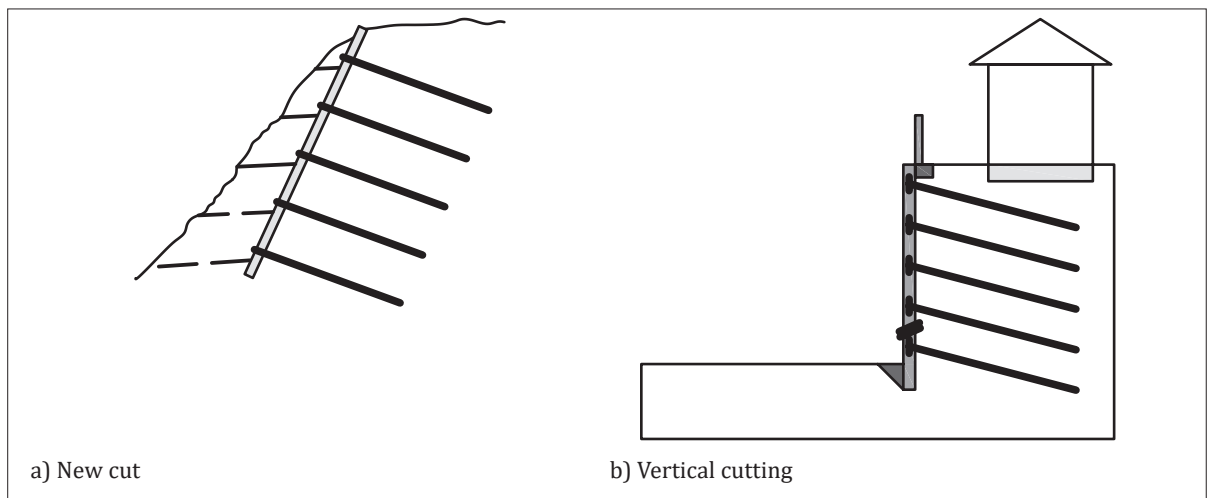
New cut slopes should normally be constructed incrementally. Each increment should consist of a phase of excavation to a stable level, followed by a phase in which soil nails and facing are placed in the newly cut face. This sequence should continue until the full depth of the excavation is achieved [Figure 3a)].

NOTE 2 In this way, the soil nails become progressively loaded as excavation induced movements occur.

New cuttings may be formed in natural ground or in existing earthworks; the latter occur typically when an existing cutting is widened without increasing land take at the crest or when the toe of an embankment is cut away to facilitate later construction without narrowing the crest.

Recommendations for the design for the soil nails and facing become more onerous as the slope angle increases. The case of vertical or near vertical soil nailed structures should be considered further as often the crest of such slopes are close to existing structures, foundations, infrastructure or services where ground movement might be critical [Figure 3b)]. Furthermore, as the near surface ground is often poor and sensitive to surcharging the control of groundwater, excavation, stability of the cut face and nail installation should be critical design considerations.

Reference to BS 8002 may be considered appropriate for some elements of the design of steep soil nailed slopes that are relevant to retaining structures.

Figure 3 — Typical soil nailing applications (new cut and vertical cutting)

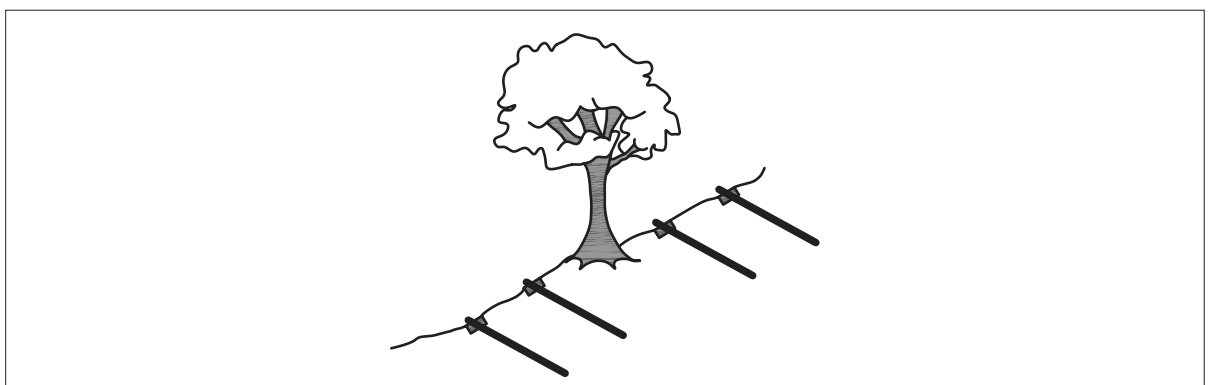
2.3.2 Existing slopes

Soil nailing may be used to improve the stability of both natural and man-made slopes with a range of slope angles. It should normally be used in such applications where the slope is deemed to have an unacceptably low factor of safety and presents a hazard to adjacent land usage or places a restriction on its development. There are many examples of where it may be used on coastal slopes (above the tidal zone) where its purpose would also include reducing the effects of weathering.

NOTE Soil nailing is likely to be more effective in reducing the risk of a first time failure than the remediation of existing failed slopes. Unlike the case for new cut slopes, it might be necessary to back analyse the **A1** slope to determine the relevant parameters required to just generate theoretical failure and use these parameters to inform the characteristic values for the remedial design **A1**. Unless or until further movement of the slope occurs the soil nails will remain unloaded.

The arrangement of soil nailing used in a remedial situation may be very different to that in a preventative one as a specific failure mode will most likely need to be addressed.

For natural slopes ([Figure 4](#)) the design should take cognisance and be sensitive to existing vegetation and wildlife and often soft or flexible facing systems may be preferred, in association with landscaping.

Figure 4 — Soil nail placement to preserve existing vegetation

2.3.3 Existing retaining structures

NOTE Some of the first uses of soil nailing in the UK were for the upgrading and remediation of existing retaining walls (see Barley [\[17\]](#)).

Soil nailing may be used for many retaining wall types including: stone, brick or concrete walls and abutments that are suffering distress, or likely to do so due to a change of usage, i.e. remedial or

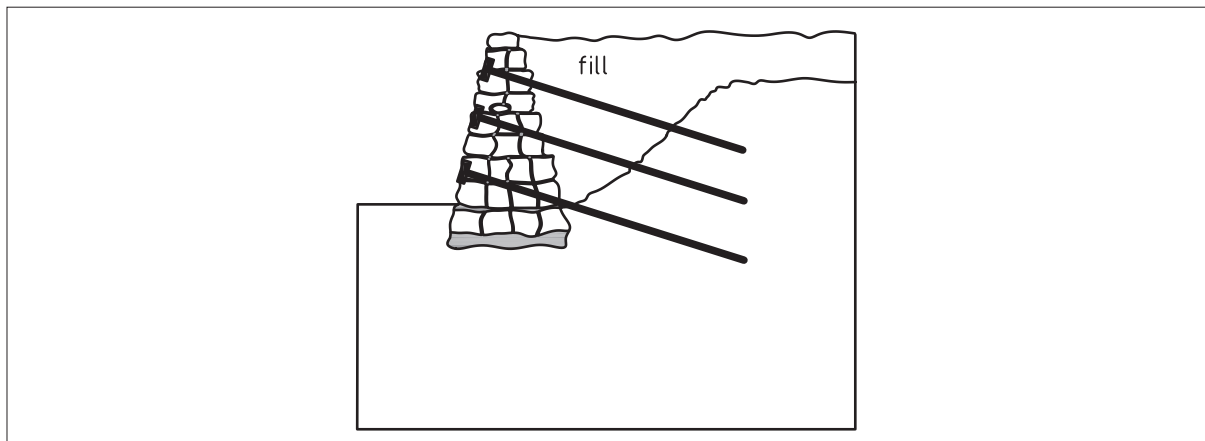
preventative works (see [Figure 5](#)). The soil nailing solution may be significantly different for the case of remedial works relative to that required for preventative works as a specific failure mechanism might have to be targeted.

The key element that should be considered in the design of works to existing retaining structures is the connection of the nails to the existing structure and the load transfer at this point to prevent pullout or damage to the structure. In these applications special measures may be required to stabilize the ground immediately behind the structure and permit nail installation, as often this comprises poor quality fill material.

Where drainage exists it is important to review the impact of the upgrading works in terms of construction process and long-term effectiveness. Where necessary, existing drainage should be protected.

As with existing slopes, it may be necessary for further movement of the structure to occur before the nails can be effective. Safe access for nail construction should be considered as this can have a significant impact on feasible solutions.

Figure 5 — Example of soil nailing of an existing retaining structure

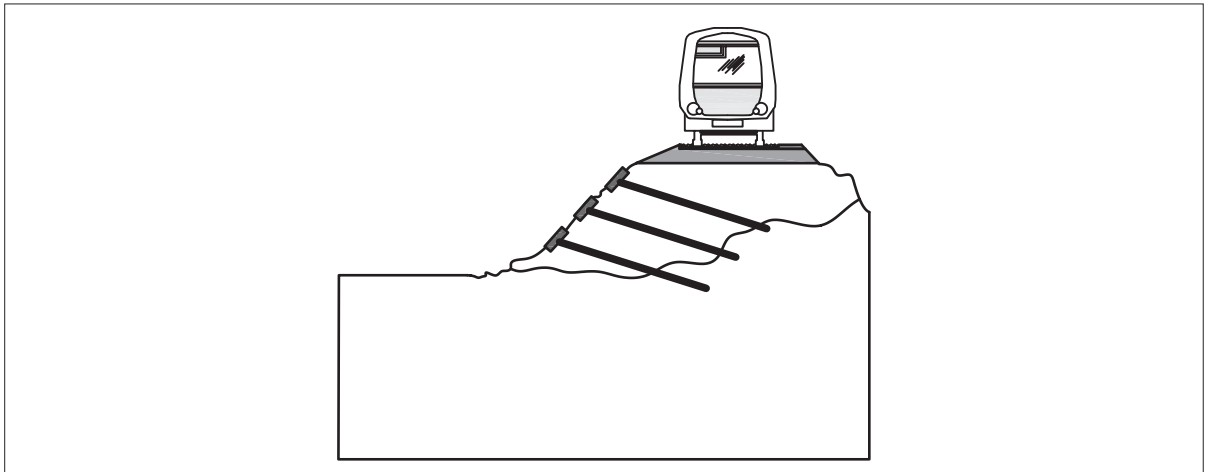


2.3.4 Embankment stabilization

NOTE 1 Embankment stabilization is one of the most common forms of soil nailing being used, especially by the rail industry ([Figure 6](#)), where increased trafficking requires a greater reliability of embankment performance. It has also been used on highway and dam embankments.

Many older embankments were constructed with variable and often uncontrolled fills and can often suffer from shrinkage and swelling due to seasonal moisture content and porewater pressure changes; in such cases soil nails may be used to stiffen the embankment and reduce the requirement for reballasting. They may also be used to provide enhanced stability to the slopes and prevent deep slips that could undermine the track or carriageway. The utilization of soil nails on embankments should be challenged at an early stage of the design as to whether their primary purpose is to improve serviceability or stability and how they will achieve this [\[A1\]](#) (see also [3.4.3](#)) [\[A1\]](#).

NOTE 2 Many of the issues relating the use of soil nailing for embankments are covered in CIRIA C591 [\[8\]](#).

Figure 6 — Example of soil nailing of an embankment

2.3.5 Hybrid applications

There are a number of applications where soil nails may be used in combination with other forms of construction such as providing an anchorage for reinforced fills, or where they may be used in combination with rock bolts and ground anchors to stabilize a variably weathered slope. Ground improvement techniques such as grouting or electro-osmosis may be used to treat the ground into which the soil nails are inserted. In such cases it may be appropriate to use certain elements of this standard for the soil nails or facing materials. However, many of the mechanisms discussed for design may not be wholly appropriate and reference to other standards should be considered.

2.3.6 Applications of a similar nature but not relevant to this standard

This standard is not applicable to the design of ground anchors or rock bolts despite their similarities with soil nails; this is because the fundamental mechanisms by which they stabilize the ground are different and often geological features, such as jointing or bedding planes, dictate the failure mechanisms used for design; reference should be made to BS 8081.

Other applications that involve similar construction processes such as reticulated minipiles, or where the soil nails work predominantly as shear dowels, should not be designed using this standard.

2.4 Construction design considerations

COMMENTARY ON 2.4

Soil nailing execution is covered by BS EN 14490:2010. Further detail on construction considerations and examples are given in CIRIA C637 [1], Clouterre [19] and FHWA [20]. Recommendations and guidance in this standard relating to construction are provided where the construction operation might have a direct influence on the design model, method or parameters chosen.

2.4.1 Preliminary works

Any preliminary works requiring design such as an intrusive site investigation, drainage to control surface runoff, temporary dewatering, edge protection, underpinning of adjacent footings, working platforms or access scaffolds, should be designed by a competent person, prior to commencement on site. The location, identification, assessment and if appropriate protection of any adjacent services or utilities should be carried out. The requirement for easements to install soil nails should be established before a design is finalized.

Where monitoring is required as a part of the design then baseline readings and background influences should be recorded prior to commencement to permit the necessary control during

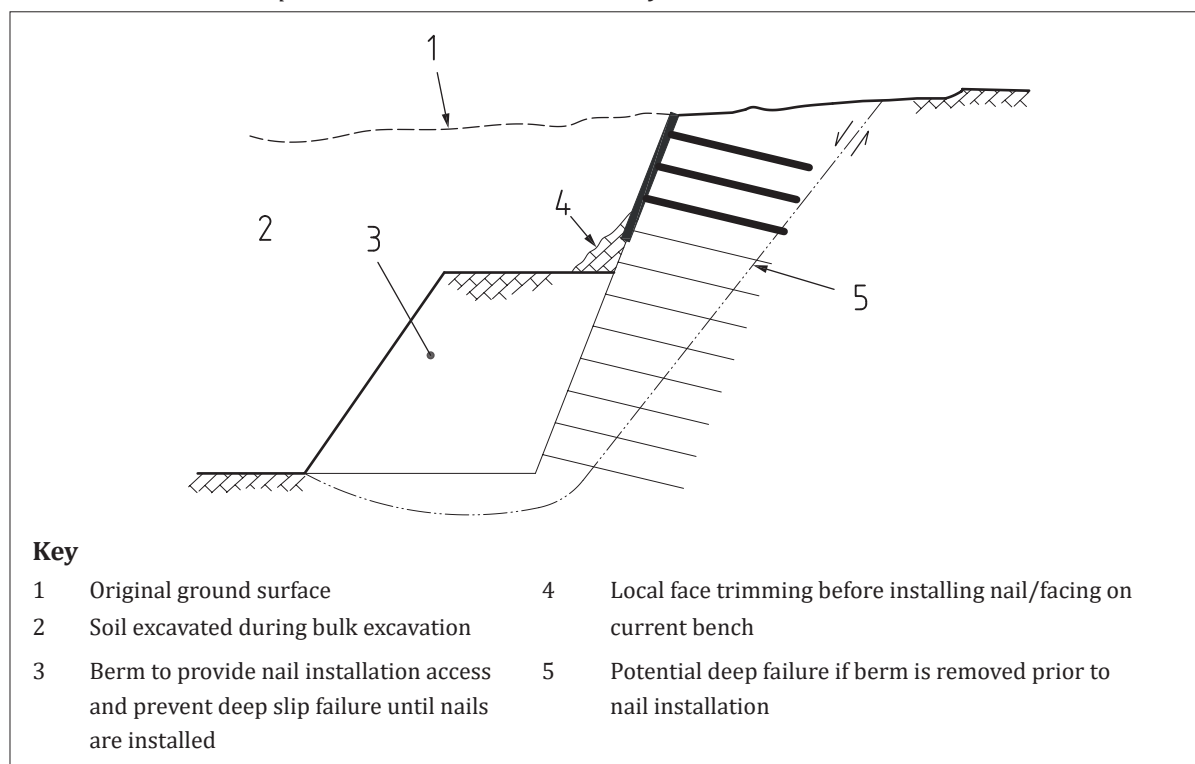
construction. The designer should also provide alarm and intervention trigger levels and the appropriate actions to be taken in event of them being exceeded.

2.4.2 Excavation and face preparation

Where the soil nailing process includes excavation, the designer should consider placing limits on the maximum depths, lengths and slope angles that can be excavated and specifying these to the constructor. The maximum height of cut slope that can safely stand unsupported until nail installation and facing construction should be taken into account when specifying the nail spacing.

The design of an excavated slope needs to address both the local (internal) stability of the soil nailed face and the global (external) stability of the whole slope ([Figure 7](#)). The criteria for internal and external stability are addressed in [Section 4](#).

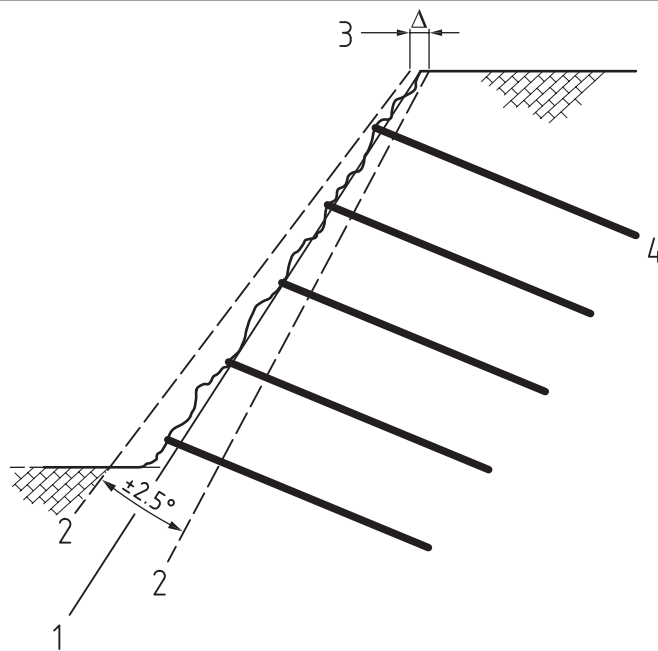
Figure 7 — Bulk excavation and requirement to check overall stability



BS EN 14490:2010 gives details of face stability assessment tests that should be considered in the assessment of temporary stability and excavation bench heights. The maximum bench height needs to be considered when determining the vertical nail spacing.

The risk of undercutting increases with the steepness of the cut face. For very steep faces this could lead to dramatic reductions in stability. In such cases greater control of face trimming is required. The designer should specify the tolerances upon which the design is based, taking into account the structure and fabric of the ground and the likely excavation methods to be used. As a general rule slope excavation should start within 50 mm of the design crest. The excavation should be cut to within 2.5° of the design slope angle (β) [[Figure 8a](#)]. Deviation from the design slope between nails should not exceed the lesser of either the nail spacing divided by 20 mm or 50 mm [[Figure 8b](#)]. Local bumps and indentations are permitted, provided they do not affect the integrity of the facing.

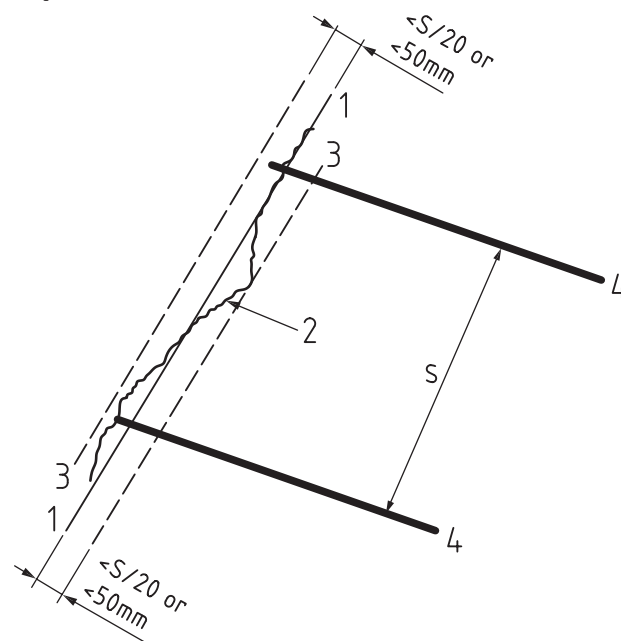
NOTE Control of face trimming is important as an uneven face can affect the performance of, or ability to, correctly construct the facing. The positioning of nail heads can become problematic and wastage of materials increases.

Figure 8 — Excavation tolerances

a) Excavation tolerance relative to crest

Key

- | | | | |
|---|---|----------|-----------------------------------|
| 1 | Design excavation line | 3 | Slope crest |
| 2 | Excavation tolerance limits $\pm 2.5^\circ$ from design excavation line relative to slope crest | Δ | Crest tolerance (set by designer) |



b) Suggested local trimming tolerance between nail rows

Key

- | | | | |
|---|-----------------------------------|---|---|
| 1 | Design excavation line | 4 | Soil nails |
| 2 | Actual excavated face | S | Spacing between nail rows measured parallel to the face |
| 3 | Tolerance limit between nail rows | | |

If a design is sensitive to the changes in ground conditions, the design should clearly state the expected conditions and acceptable variations in strength or location of individual strata, with instructions on reporting back to the designer.

2.4.3 Nail installation

2.4.3.1 General

The method of nail installation chosen will have a direct impact on the pullout resistance that may be used in the design. Some methods of nail installation may be deemed inappropriate because of the specified nail length and diameter, ground conditions, required durability or equipment required for installation when taking into account the safe access or manual handling requirements.

2.4.3.2 Soil nail installation tolerance

The designer should take into account the requirements of the facing when specifying nail installation tolerances. The nail location on the face should generally not be specified as less than ± 100 mm and the nail orientation to less than $\pm 5^\circ$. Potential clashing of soil nails should be considered.

2.4.3.3 Direct installation methods

Direct installation methods include driven (percussive and vibratory), jacked and fired soil nails. When selecting these methods the designer should consider the implications of refusal of the nail before the design penetration has been reached and the potential for damage during installation that could affect durability. Compared to other installation methods, direct installation tends to utilise relatively short, small diameter, soil nails. The relatively small surface area of each nail generally results in a higher density of nails than for an equivalent drilled soil nail design.

2.4.3.4 Drilled installation methods

Drilled methods may be used in all soil types, for a wide range of nail diameters, lengths and durability systems. They should nearly always include grouting.

The drilling method and flushing medium (if used) can affect the friction between the nail and the ground and consideration of potential effects should be made.

NOTE Potential adverse effects of drilling methods include softening of cohesive soils by water flush, scour of granular soils by air flush and smearing of the bore walls through augering.

A requirement for casing to be used should be assessed and the ability to install the nail element whilst keeping it clean prior to grouting should be considered carefully and where appropriate taken into account in the design.

In general, keeping the cycle time between nail drilling and grouting to a minimum is beneficial with respect to the frictional resistance available; test nails should be constructed to be representative of the production nails.

The nail design should ensure that the method of installation addresses continuity of the corrosion protection system over its entire length and into any facing system or head plates/bearing pads.

2.4.4 Grouting

NOTE 1 Effective grouting is important in achieving the design frictional resistance and required durability. Most soil nails involve grouting under gravity, but in some soils grouting as a part of the drilling process or grouting at an elevated pressure can enhance the friction available between the nail and the ground (see 4.3).

Where the design is based upon the benefit of elevated grout pressures then the designer should consider the use of design investigation tests or suitability tests to confirm the enhancement achieved.

NOTE 2 Grout take is the volume of grout that has to be injected to completely fill the annulus around a drilled soil nail. Grout loss can be defined as the volume of grout take exceeding the design or expected volume. It occurs when injected grout escapes into the interstitial voids of the soil in greater quantities than predicted. It is a particular risk in clean, coarse granular soils. Possible mitigation measures include increasing grout viscosity (e.g. using sanded

grout mixes or gelling agents) or applying multiple injections of grout. The soil nail designer needs to be alert to the increased risk of grout loss in granular soils and make adequate provision to deal with the consequences.

The designer should specify the characteristic grout strength to be achieved in samples before loading of the nails to prevent damage and to achieve the durability required. Minimum characteristic strengths of 5 N/mm² and 25 N/mm² prior to loading and at 28 days respectively should be specified, as required by BS EN 14490:2010.

NOTE 3 BS EN 14490:2010 requires a minimum cube strength of 5 N/mm² to be achieved prior to excavation below a nail.

Typically grout should comprise water mixed with a BS EN 197-1:2000, CEM I or CEM II cement in the ratio in the range 0.40 to 0.45. Sand filler and admixtures may be used in the grout in some instances.

NOTE 4 The high cement content of cementitious grouts generally makes them durable. At the time of writing, however, there is limited information on grout durability in contact with ground and groundwater. Guidance developed for concrete (e.g. BRE SD1 [3]) is not directly applicable.

Time should be allowed for the grout to develop sufficient strength before planned loading of the soil nails. This requirement is particularly applicable to situations where soil nails are installed to support a planned excavation. In such cases the designer should clearly state the requirements for time to elapse between installation of the soil nails and start of excavation.

2.4.5 Drainage installation

General slope drainage and that required to control runoff are not considered in this standard but should be considered as a part of the overall scheme design. However, it is essential that the soil nail designer considers the nature of any drainage required to ensure design assumptions on groundwater or pore-pressures can be met during the design life of the structure. Where membrane type drains are positioned behind facings then the risk of damage and the hydraulic continuity of joints should be considered. If deep-drilled drains are to be installed there may be restrictions on the angle and head elevation of these imposed by the installation equipment. Access for maintenance should be considered, especially where new structures are located in front of the soil nailed slope. Maintenance requirements for drainage should be clearly specified by the designer and safe access considered as a part of the design.

2.4.6 Facing installation

There are too many facing types to outline the key construction features that interface with design (as described in 4.7), however, attention to detail in the design is critical for the facing to achieve its aesthetic, serviceability and durability requirements. Specific construction issues that should be raised at an early stage of the design process include:

- a) relative tolerances on the prepared ground face, soil nails and facing connections;
- b) how joints between facing sections can be achieved;
- c) connections between head plates and facings;
- d) continuity of nail durability system/corrosion protection through the facing;
- e) drainage and facing interfaces;
- f) the sequencing of facing construction and access;
- g) interfaces between safety barriers, etc., and the facing and whether relative movement during construction needs to be considered.

Soil nail facings should be constructed to prevent loosening of the ground immediately behind.

Section 3: Suitability of ground and groundwater conditions

3.1 General

NOTE 1 Not all soils are suitable for nailing. Some soils present problems either during construction or in the long term, which make soil nailing impractical, uneconomical or unsafe as a solution. Recognition of such conditions at an early stage is vital to prevent selection of an inappropriate scheme.

Designers should obtain site-specific information on the geological and hydrogeological conditions and use this information to determine the specific risks and suitability of soil nailing.

Recommendations on the suitability of different ground conditions for soil nailing are discussed in this standard, based on the following principal material types and their characteristic properties.

- a) Cohesive soils.
- b) Granular soils.
- c) Soft/weak rocks.

NOTE 2 Soil nailing has been used in a wide variety of the ground conditions that exist in the UK. A range of soil nailing equipment and construction techniques has been developed by specialist contractors to accommodate different ground conditions. Selecting the right technique requires knowledge of the prevailing conditions at the site.

3.2 Understanding the site geology

By its very nature, the successful application of soil nailing is highly dependent on the suitability of the ground conditions; a thorough understanding of the geological and hydrogeological setting of the site is imperative to assess the suitability of the technique for a given project. This understanding should include not only the material within which the soil nails would be installed but also the underlying strata, which may affect the global stability or deformation of the soil-nailed system.

The designer should consider a number of key questions about the geology of the site to determine its suitability for soil nailing including the following.

- a) Does the site comprise natural or made ground?
- b) What are the characteristic properties of the soil to be nailed? Is it cohesive or granular (or something in between) in its behaviour? Is it stiff/dense or soft/loose? Can the ground conditions be considered as homogeneous?
- c) What is the nature of the underlying soil/rock?
- d) What is the structure of the deposits: bedding, fissures, joints, fractures and/or laminations?
- e) What chemical and mechanical processes are occurring or have occurred at the site?
- f) What has the site previously been used for? Could there be any sources of contamination on the site? How might they affect construction workers and end users of the site? How might they affect durability of materials used in the proposed scheme and the need for special measures?
- g) Does the site have a history of stability problems (pre-existing slope failures)?
- h) What are the groundwater conditions?
- i) What are the potential deformation mechanisms (including groundwater and/or vegetation induced mechanisms and collapse potential)?

Many of these questions should and can only be adequately addressed by a comprehensive site investigation following a desk study and scrutiny by a geotechnical specialist. However, to make a preliminary assessment of the suitability of the ground for soil nailing, sufficient knowledge of the site conditions may usually be obtained from published geological information combined with a walkover survey of the site.

3.3 General requirements for suitability of soils and rocks for soil nailing

The success of a soil nailing scheme relies on the ability to form an adequate bond between the nail and the soil into which it is installed; for soil nailing to be economical, the soil should have sufficient shear strength to develop such a bond.

Steepening of existing slopes is often achieved through a cyclic sequence of benching and nailing. The faces to be nailed are typically between 1 m and 3 m high and need to stand unsupported pending installation of the soil nails. It is essential that the soil has sufficient shear strength to allow the bench faces to be formed and remain adequately stable in the temporary condition.

NOTE The suitability of typical UK soils and rocks for soil nailing is summarized in [Table 1](#).

3.4 Suitability of cohesive soils for soil nailing

3.4.1 Soft clays and silts

Soft clays and silts are generally unsuitable for soil nailing.

3.4.2 Firm and stiff clays

Soil nailing is generally well suited to firm and stiff clays (i.e. clays with an undrained shear strength of 50 kN/m² or greater). Such clays are usually overconsolidated. They generally provide sufficient stand-up time during excavation of benches to permit progress without immediate support of the cut face. They may also be assumed to provide good bore stability for drilled and grouted nails without the need for casing. Sufficient bond strength may usually be achieved, particularly in slopes where tension forces in the nails are relatively low.

3.4.3 Potential problems associated with soil nailing in cohesive soils

3.4.3.1 Shrinking and swelling

High plasticity clays have the potential to develop significant shrink/swell behaviour due to changes in moisture content. This might be due to cyclic changes in moisture content through precipitation and/or the effects of vegetation. Soil nailing may only be appropriate in these soils if it can be demonstrated that the design will cater for such potential deformations.

NOTE High plasticity, overconsolidated clays are very prone to volume change on wetting and drying. This is due to the presence of clay minerals of the smectite group, such as montmorillonite, which have “shrink/swell” properties. Soil-nailed slopes in such materials can suffer from deterioration, particularly at the crest and the face, due to repeated seasonal wetting and drying causing cyclic swelling and shrinking of the clay. This can result in corresponding fluctuations in the nail loading as well as localized slumping at the face. Clays having lower plasticity, due to a lower proportion of clay particles or lower proportions of smectite minerals are less inclined to shrink and swell.

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Table 1 — Summary of ground conditions best suited and less well suited to soil nailing

Developed from FHWA, 1998 [19] [This is Table 4.1 from CIRIA C637 [1].]

	Ground conditions best suited to soil nailing	Ground conditions less suitable for soil nailing	Possible measures to improve suitability of ground conditions
Material to be nailed	firm to stiff, low plasticity clays	soft cohesive and organic soils prone to creep deformation	none will improve these soils sufficiently for soil nailing
		high plasticity or highly frost susceptible soils and rocks	provide adequate protection against wetting and drying
	well graded soils having a cohesive matrix such as some glacial tills, provided that cobbles and boulders do not obstruct nail installation	loose, clean sands and gravels with little or no apparent cohesion	pre-grouting or ground freezing to improve temporary stability
	fine to medium sands and silty sands with some apparent cohesion		limit excavation heights/lengths
Groundwater conditions	medium dense to dense sands and gravels with some apparent cohesion.		
	weathered rock without adverse joint orientation	weathered rock with adverse joint orientation or voids	
	engineered fills comprising selected natural or uniform, non-aggressive materials that have been carefully placed and well compacted to achieve characteristics similar to those of the natural soils described above	non-engineered fills, particularly those containing variable, aggressive and/or degradable constituents that are prone to collapse and differential settlement (and obstructions)	excavate, sort re-usable material and replace (unlikely to be cost effective) if fill constituents are suitable, ground improvement methods may be used to reduce the risk of collapse settlement, such as grouting, vibro-stone columns and dynamic compaction
	above the groundwater table with a dry excavated face	below the water table artesian groundwater at depth	temporary and permanent dewatering should be accommodated within the design, both in terms of internal and external stability
		perched water or groundwater seepage through granular soils or pockets	temporary dewatering and permanent drainage measures to ensure long term stability of the slope or wall.

Table 1 (*continued*)

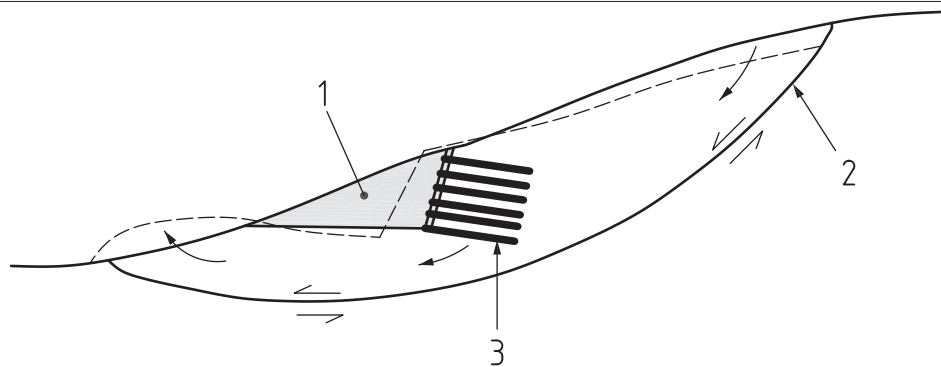
	Ground conditions best suited to soil nailing	Ground conditions less suitable for soil nailing	Possible measures to improve suitability of ground conditions
Underlying ground conditions and geological features	underlying conditions and geological features that do not compromise the stability and performance of the soil nailed structure	adverse underlying ground conditions and geological features such as: pre-existing slip surfaces or adverse jointing soft, compressible layers unless strengthened before soil nailing voids such as solution features or mining cavities liquefiable silty soils	possible measures will depend on nature of the adverse conditions/features and has to be assessed on a site specific basis

3.4.3.2 Previous disturbance and slope instability

Shear strength parameters for design of soil nailing in clays should be selected to reflect the degree of disturbance caused to the clay by previous activity and by the proposed works. For example, if a slope has suffered from previous slip failures, pre-existing shear planes might exist over which lower strengths apply and allowance should be made for the existence of such planes in design, both within the soil-nailed block and beneath it (Figure 9).

NOTE For high plasticity clays, the residual strength of the clay when it is sheared is much lower than the peak strength of the intact material.

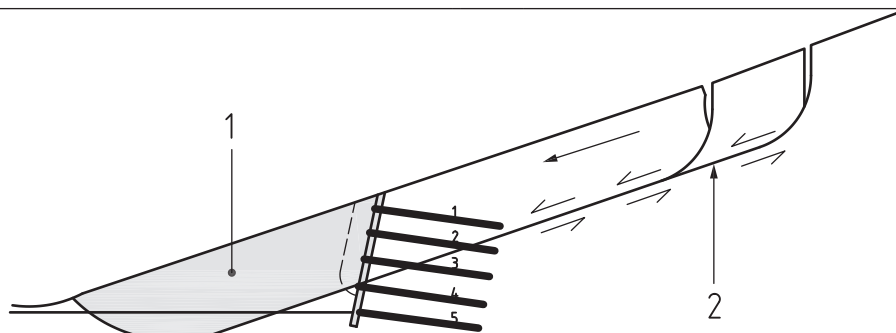
Figure 9 — Examples of the effect of pre-existing shear surfaces on soil-nailed structures



a) Pre-existing shear surface below a soil-nailed structure

Key

- | | | | |
|---|--|---|--|
| 1 | Toe weight is reduced during excavation of soil nailed structure | 3 | Soil nails do not extend below the shear surface and offer no resistance to slip |
| 2 | Reactivation of pre-existing shear surface | | |



b) Pre-existing shear surface through a soil-nailed structure

Key

- | | | | |
|---|--|---|--|
| 1 | Toe weight is reduced during excavation of soil nailed structure | 2 | Reactivation of pre-existing shear surface |
|---|--|---|--|

NOTE 1 Soil nails 1, 4 and 5 are above or below shear surface and offer no resistance to slip.

NOTE 2 Soil nail 2 has little anchorage below the shear surface and is likely to pull out.

NOTE 3 The wall facing may offer nominal shear resistance but the majority of the driving force from the slip is transferred to nail 3, which is likely to fail by pullout or rupture.

From CIRIA C637 [1].

3.4.3.3 Effect of grading

COMMENTARY ON 3.4.3.3

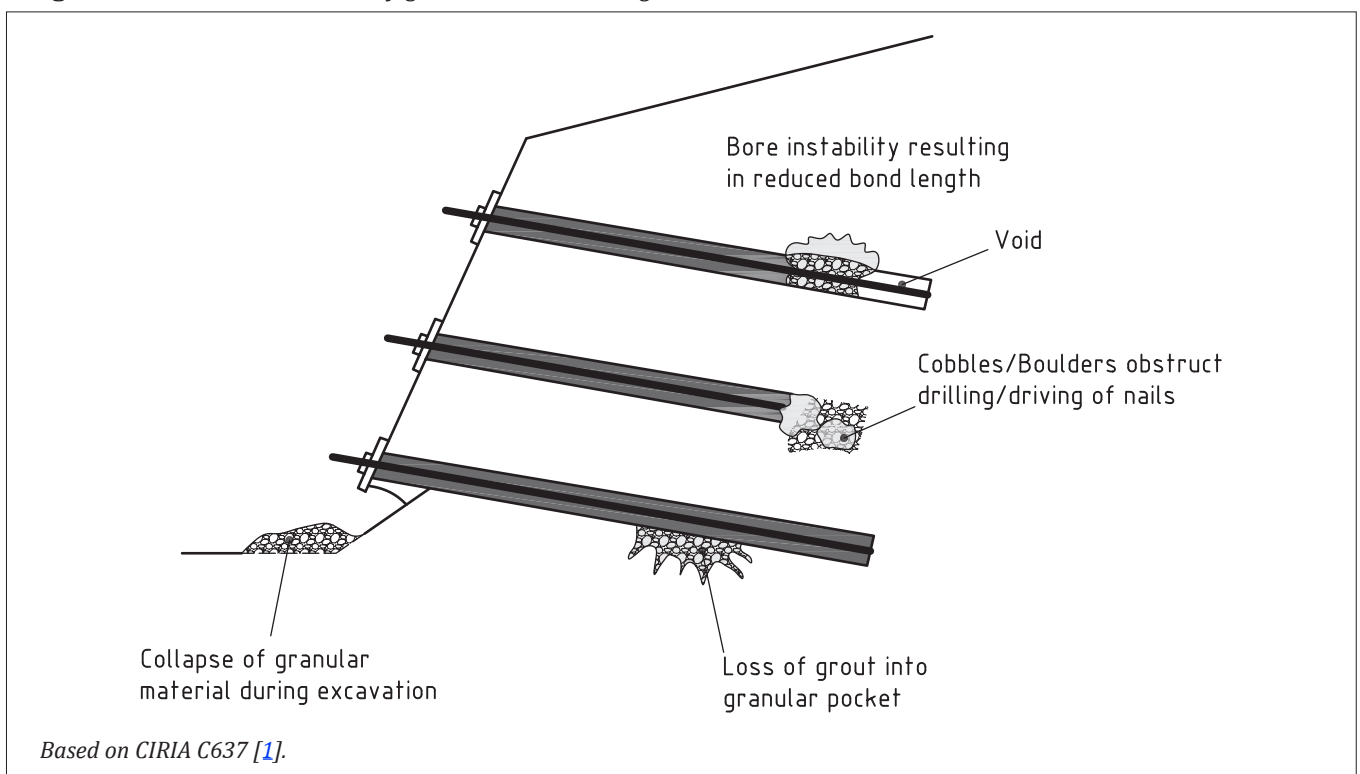
The presence of coarse material in a predominantly cohesive soil can cause problems during construction and in the long term performance of the soil-nailed structure. Interbedded clays have a

more rapid response to pore water pressure change, particularly where layers are relatively thin, and drained conditions can be achieved in the short-term. This can affect temporary excavation stability.

The engineering properties of glacial tills are discussed in detail in CIRIA Report C504 [2]. The variability of grading of some of these materials makes them worthy of particular consideration. Glacial tills occur over much of the UK. Due to the nature of their deposition, the grading of glacial tills is highly variable, ranging from clay-sized particles to cobbles and boulders. The characteristic behaviour of the till depends on the proportion of fine material.

Glacial and periglacial deposits where the clay fraction dominates, might still contain a significant proportion of coarse material, variably distributed within the finer matrix. Soil nailing is well suited to such mixed soils although larger particles and localized granular pockets can present some difficulties (Figure 10). Boulders and cobbles can obstruct drilling or driving or cause deflection. Localized problems can occur with stand-up time of temporary excavations and with stability of bores where zones of more granular material occur, particularly where seepage of groundwater occurs, with resulting wash-out of fines and loss of cohesion. Softening of the clay matrix occurs around seepage pathways (see 3.8). Loss or washout of grout can occur into the granular material, although this rarely takes place in large volumes since granular material generally occurs in discrete, discontinuous pockets. Problems can also occur with the loss of air flush during drilling in glacial till of variable grading.

Figure 10 — Problems caused by granular material in glacial till



3.4.3.4 Aggressive ground conditions

NOTE Compared with other solid geology, the weathered zones of the sedimentary clays are the most likely soils to contain high concentrations of sulfates (BRE SD1 [3]). This presents a risk of sulfate attack on soil-nail grout and concrete facings. Minerals such as pyrite and gypsum in an unweathered state can rapidly deteriorate if exposed to air and water during construction. Weathering of these minerals will release water soluble sulfates.

3.4.3.5 Drilling/driving problems

NOTE Very stiff clays are likely to be too resistant for successful construction of directly installed soil nails; drilled soil nail systems might be more appropriate. Ground consisting of interbedded clays, granular layers of rock can produce difficult conditions for augering and direct soil nail installation.

3.5 Suitability of granular soils for soil nailing

3.5.1 General

COMMENTARY ON 3.5.1

Many naturally occurring granular soils are well suited to soil nail applications. They offer high angles of shearing resistance, resulting in a strong bond. However, granular soils are only suitable provided they offer adequate short term cutting stability to allow application of a temporary facing. Sufficient temporary stability might be given by the presence of fine material to provide a small amount of cohesion between the grains. An apparent cohesion might also be given to sands by capillary tensions in the moisture between the grains.

In coarse granular soils with no appreciable fine matrix, capillary tensions are generally not sufficient to provide the apparent cohesion required for temporary stability.

Loose, clean granular soils, having a standard penetration test (SPT) N value of less than about 10 or relative density of less than about 30% are not well suited to and should not be used for soil nailing with steep cut slopes, due to poor stand-up times, poor bond and sensitivity to the vibrations caused by construction plant (FHWA [19]).

3.5.2 Potential problems associated with soil nailing in granular soils

3.5.2.1 Temporary stability problems

Where little or no cohesion or apparent cohesion exists, temporary drill casing is usually required, or drilling is carried out using a drilling fluid, such as a cement grout.

Short term stability of cut faces in granular soil is limited by the shear strength of the soil. Where the design requires a cut slope to stand at an angle greater than the angle of shearing resistance of the soil and places reliance on effective cohesion or soil suction, then close control is required and the designer should consider how the slope face is to be supported in the temporary condition. The use of controlled excavation, in short bays for limited periods of time, or temporary support, such as sprayed concrete, may be considered.

NOTE Apparent cohesion can be readily destroyed by the presence of groundwater and can only be relied upon for limited periods of time. Maintaining this apparent cohesion is vital to stability – ravelling can occur if the exposed face is allowed to dry out or if the saturation of the sand increases significantly due to infiltration of rainwater in the soil, for example. Observation under controlled condition trials can aid the understanding of the ability of a cut slope to remain stable during the period between excavation and completing face stabilization.

3.5.2.2 Grout loss

The use of grouted nails in clean coarse granular materials (coarse gravels, cobbles, rockfill) having little or no fine matrix might be problematic due to the risk of grout loss in voids; sanded grout mixes or grouts with gelling agents to increase viscosity and reduce flow may be considered as options in such situations. Failure to ensure a complete annulus of grout around the grout tendon might compromise pullout capacity or long-term durability.

3.5.2.3 Driving/drilling problems

The designer should take care in selecting a soil nail installation method appropriate for the grading of the soil. The presence of cobbles and boulders in a derived soil or unweathered layers in a residual soil may preclude the use of certain techniques.

3.6 Suitability of weak rocks for soil nailing

3.6.1 General

Steep slopes in weak or highly weathered rocks may be amenable to stabilization using soil nails. An appropriate method of nail installation, capable of penetrating inter-bedded strata of contrasting hardness, should be selected by the designer. Drilling to produce a rough bore surface generally provides an excellent bond. Provided the geological structure is favourably oriented (see [Figure 11](#)), weathered and weak rocks may be relied upon to offer good stand-up times for excavated faces. Particular guidance on the properties of specific rock types should be sought – examples of published guidance include CIRIA C570 [4], which provides detailed guidance on the behaviour of Mercia Mudstone, and CIRIA C574 [5], which gives advice on engineering in chalk.

3.6.2 Potential problems associated with soil nailing in weak rocks

3.6.2.1 Adverse bedding and jointing

NOTE Adverse jointing can result in stability problems in both the short and long term, particularly if joints contain low strength fine material on which blocks of intact rock can slide ([Figure 11](#)).

3.6.2.2 Effects of weathering/disturbance

NOTE Weathered rocks which are prone to degradation result in materials which exhibit the same advantages and disadvantages as the equivalent soil type.

3.6.2.3 Dissolution

NOTE Calcareous rocks (chalk, limestone) are prone to dissolution. The risk of dissolution features in chalk is significant. Voids form by gradual dissolution of the chalk, particularly along joints and fissures where water flows readily. These features are generally infilled with material that has infiltrated from overlying recent deposits. Dissolution features are often relatively small (up to a few cubic metres in volume) so their presence might not be identified during routine site investigations (see [3.10](#)).

3.6.2.4 Other voids

NOTE Shallow voids resulting from mining operations such as bell-pits and adits are common where the coal measures outcrop in the Midlands and North of England (particularly in Lancashire and Yorkshire) and in Wales and Scotland. Localized quarry pits used to obtain rocks and minerals for construction and industrial processes can also result in hollow or infilled voids in the ground.

3.6.2.5 Aggressive ground conditions

NOTE Sulfates are commonly found in the weathered zone of most mudstones and shales where sulfurous minerals such as pyrite and gypsum (in relatively high concentrations) have oxidized in the presence of air and water. Sulfates attack cementitious materials and can result in degradation of grouted nails and concrete facings (see [3.14](#) and [3.15](#)).

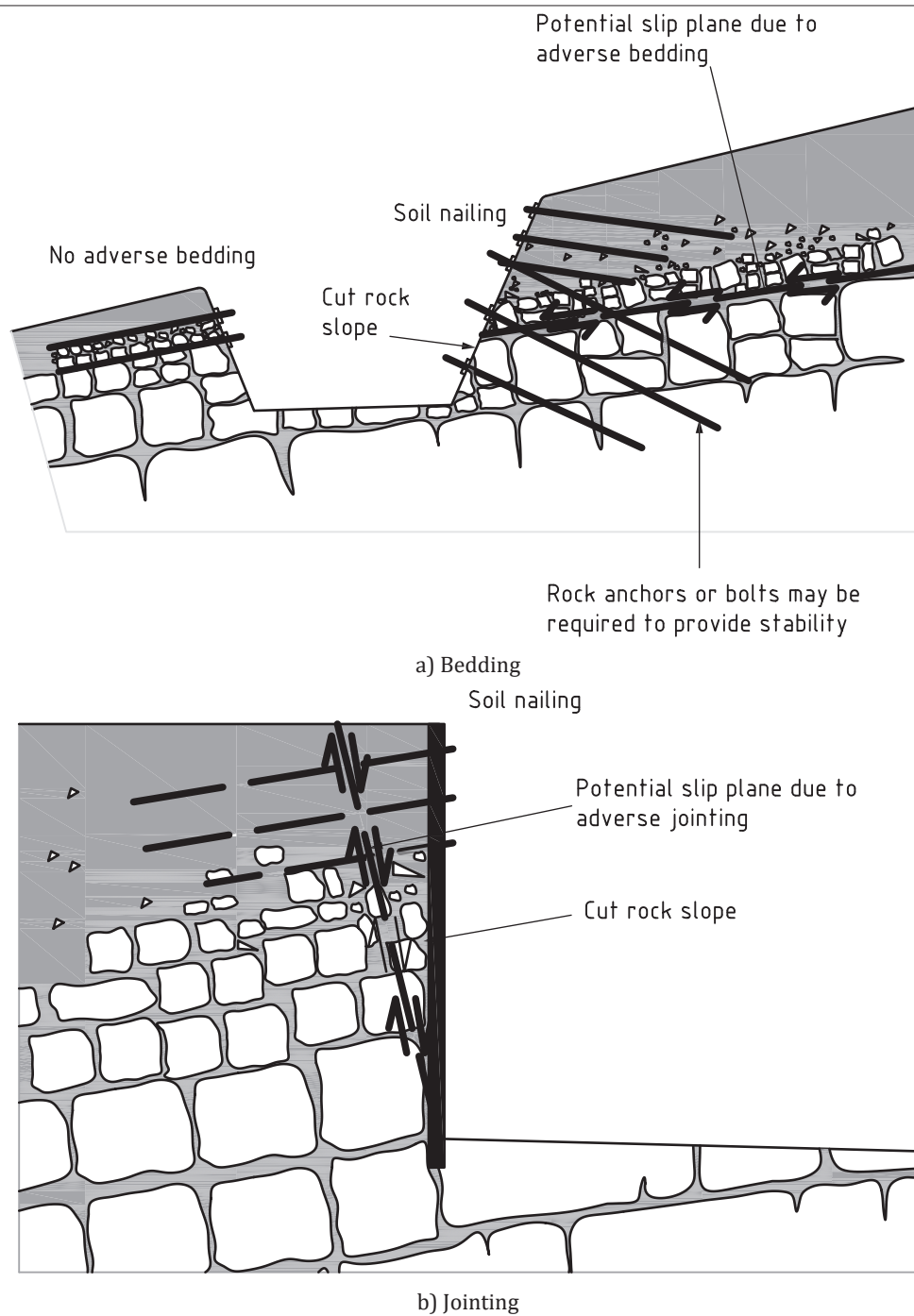
3.7 Suitability of fill for soil nailing

3.7.1 General

Fill material that has been graded, selected, placed and compacted in a controlled manner to give an essentially homogeneous material may be used to provide an ideal environment to install soil nails.

COMMENTARY ON 3.7.1

This is commonly referred to as engineered fill. Fills placed in more recent developments, such as reclamation works, highway and rail embankments tend to be engineered fills.

Figure 11 — Adverse effects of jointing and bedding on cut slopes in weak or weathered rock

Based on CIRIA C637 [1].

However, the majority of existing fill materials encountered in the UK do not fall into this category. More commonly, fills have historically been produced and placed without careful consideration of their properties and behaviour. They can have adverse characteristics including some or all of being:

- a) variable in terms of nature and distribution of its constituents (heterogeneous);
- b) soft or weak;
- c) degradable;
- d) loose due to poor placing and compaction;
- e) poorly graded;