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THE WELSH OFFICE
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THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND

Geotechnical Considerations and Techniques for Widening Highway Earthworks

Summary: This Advice Note describes a number of methods of widening highway earthworks using reinforced soil, soil nailing and soil improvement.

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GEOTECHNICAL CONSIDERATIONS AND TECHNIQUES FOR WIDENING HIGHWAY EARTHWORKS

Contents

1. INTRODUCTION

1.1 The 1989 Government's White Paper 'Roads for Prosperity' (Ref 1) outlined plans for an Expanded Road Programme. As part of this Programme, it is envisaged that about 60 percent of the motorway network in England as well as some trunk roads will need to be widened by the provision of additional lanes. Many of these roads are in urban areas or adjacent to development which precludes the option of acquiring additional land without major public inquiries. Significant time delays would be incurred in such cases and new traffic lanes will therefore need to be provided within the existing highway boundary.

1.2 This presents particular problems where the existing carriageway is on embankment or in cutting. In this situation it may be necessary to consider steepening the side slopes of existing earthworks. Potential methods include:

a. steepening the side slopes of embankments by using granular materials or soil stabilisation;

b. steepening the side slopes using soil reinforcement or soil nailing:

c. using full or part height earth retaining walls, such as embedded, gravity, gabion or crib walls or using other structural solutions.

1.3 If the proposed design involves the use of any exposed concrete, steel or other materials, or if it is likely to be visually intrusive, then the advice of the Department's Regional Landscape Architect or Horticultural Officer should be sought at the earliest possible stage to advise on the environmental aspects of the proposed solution.

1.4 At the same time, consideration needs to be given to the fact that on slopes a significant incidence of shallow failures has been reported (Ref 2) in ageing motorway earthworks, particularly those constructed in over-consolidated materials. These are usually clays, which during their history have been subjected to greater vertical pressures than at present: common causes of overconsolidation are the erosion of overlying materials and the melting of ice masses. Slope steepening may well exacerbate these failures, if appropriate measures are not taken at the design stage.

1.5 This Advice Note describes a number of methods of widening existing earthworks using soil reinforcing, soil nailing and other forms of soil improvement: it also indicates other aspects which need to be considered.

1.6 For any particular scheme only some of the methods available may be appropriate. However, consideration should be given to as wide a range of solutions as possible in order to ensure that the most appropriate technical and economic solution is adopted for each particular case. Some information on the comparative costs of reinstatement techniques for embankment failures is given in Ref 3. Existing and proposed landscaping and land access will also need to be considered at an early stage.

2. SCOPE

2.1 This Advice Note is issued for the guidance of engineers responsible for the design of the geotechnical and associated aspects of widening highway earthworks, particularly motorway widening schemes. It describes some of the factors which may influence slope stability and gives information on some of the methods available. it is to be noted that it is not a design guide.

2.2 Sections 3, 4 and 5 of this Advice Note set out considerations which are generally applicable to the widening of highway earthworks. Techniques involving earthworks or soil strengthening are then described in Section 6. Methods based on the use of retaining walls or other structural solutions are generally more expensive, but in some cases will be unavoidable.
This Advice Note does not cover such methods, but guidance may be obtained elsewhere: in particular Technical Memorandum BE 3/78 (Revised 1987) deals with reinforced and anchored earth retaining walls (Ref 4) and Departmental Standard BD 30/87 deals with backfilled retaining walls (Ref 5). Other Departmental Standards and Advice Notes should be used where appropriate.

3. INITIAL CONSIDERATIONS

3.1 A number of sources of information exists on ground conditions and related geotechnical matters for the motorway and trunk road network. These may be of considerable benefit to designers undertaking widening schemes when they are preparing their 'Desk Study Report' and some details are given below.

3.2 Copies of the ground investigation reports for most of the motorway network and some trunk roads are held by the appropriate Regional Offices of the Department, by Highways Engineering Division, by Ground Engineering Division at the Transport and Road Research Laboratory (TRRL) and by the British Geological Survey. Further information can be obtained from Highways Engineering Division .

3.3 TRRL published a major survey of the condition of motorway side slopes in Research Report 199 (Ref 2). The computer database on which this report is based contains information on the condition of side slopes for over twenty per cent of the motorway network in England and Wales. The database contains details of geology, geometry, drainage, slope condition, vegetation and age when surveyed. Further information on the database can be obtained from Ground Engineering Division at TRRL. In addition, highway maintenance authorities are required to report earthworks failures to the Regional Offices (Ref 6): these reports should be consulted to highlight problems in a particular area.

3.4 The preliminary sources of information given above, together with additional information held by the Regional Offices, including 'as built' drawings and other information on the site, should be consulted to obtain as much geotechnical detail as possible. An assessment of the implications of this should then be made to determine the implications for the stability of existing earthworks and the consequences of widening them. The scope of any additional ground investigation should then be considered: this will need to be tailored to the methods likely to be used for widening. It may also be necessary to determine if the properties of the undisturbed soil and fill materials have changed with time and loading conditions from those given in the preliminary sources of information.

3.5 On earthworks where widening is likely to be carried out in the future, such widening should be borne in mind when planning current or future maintenance, cabling or similar activities.

3.6 A decision tree representing the process of earthworks widening is shown in Fig 1. Some of the potential problems likely to be encountered are listed below: however, the list is not exhaustive.

3.7 Existing Earthworks Wide Enough

Where the existing earthworks are sufficiently wide to accommodate the additional lanes required, the following points will need to be considered.

a. Moving the edge of the carriageway closer to the shoulder of the embankment or the toe of the cutting may reduce the stability of the earthwork. In this situation, consideration should be given to the following techniques:

i. the provision of a combined debris catcher unit and surface water channel (Ref 7) at the toe of cutting slopes;

ii. the provision of a large edge beam or verge wall at the back of the hardshoulder (Ref 8);

iii. the use of insitu soil reinforcing techniques such as soil nailing (See Section 6.4).

b. The condition of the earthwork may be such as to give rise to concern for its stability because of the presence of slip surfaces, cracking, seepage planes or excessive settlement. In this case, it may be necessary to carry out remedial works prior to or concurrent with the widening work. Possible techniques include the following:

i. soft spot replacement: the replacement of local soft spots with granular materials or lime stabilised material (Ref 6);

ii. the use of geotextile or geogrid reinforced soil repair techniques (Refs 3 and 9);

iii. rock ribs: the use of deep counterfort drains or geotextile reinforced granular buttresses (Ref 3, 7 and 10), or the use of slope drains (Section 6.5).

c. Particular attention to the problems in (b) will be required when the hardshoulder is to be used as a running lane during construction work.

3.8 Existing Earthworks Not Wide Enough

Where the existing earthworks are not sufficiently wide to accommodate the additional lanes required, the following points will need to be considered.

a. If the condition of the earthwork gives rise to concern for its stability, it is unlikely that widening will help stability unless repair or strengthening of the existing embankment or cutting is incorporated into the widening process. Adding additional material to the top of an embankment or removing material from the toe of a cutting which is already in poor condition will only exacerbate the situation.

b. Potential problems identified in the original site investigation such as faults, deep seated slips, natural or man-made cavities, made ground etc need to be overcome using similar technique to those used in the original construction.

c. The presence of organic layers, soft ground or other difficult ground conditions in the foundation of the existing embankment or in the base of the existing cutting will need assessment. Any special engineering measures taken in the original design to overcome these problems need to be incorporated in the widening process. These might include soil improvement or reinforcement, additional drainage to improve consolidation and stability, or other methods of reducing settlement and increasing stability.

3.9 When assessing the methods of widening existing embankments, consideration should also be given to the following aspects.

a. The need to bench in the new works to the existing embankment in such a manner that the contact between them does not generate a plane of weakness.

b. The effects of construction and compaction of new works on the stability of the existing embankment.

c. The methods of dealing with the likely differential settlements and associated shear forces which may occur as the new works consolidate at a higher rate than any residual consolidation in the original embankment. The effects of differential settlement will also need to be carefully considered in the design of the transition between the existing and the new pavement.

d. Earthworks incorporating some types of reinforcement and soil nailing may undergo significant lateral expansion during and immediately after construction. This should be allowed for before constructing the pavement and drainage system.

3.10 When assessing the methods of widening existing cuttings, important aspects will include the following.

a. The influence of rock discontinuities and their properties on the stability of steepened slopes. Further information is contained in Refs 11 and 12.

b. The possible need to incorporate current requirements for sight lines when widening older motorways and trunk roads (Ref 13).

3.11 For both cuttings and embankments, the following aspects should not be overlooked.

a. The potential effects of construction on sensitive adjacent structures and on other adjacent features such as canals, railways, rivers etc.

b. The relative volumes of cut and fill likely to be generated by the widening methods adopted, although this may be difficult to balance in on-line widening schemes and may require costly double handling of material.

c. The cost of traffic delays during road widening will usually be substantial and will be a major factor in the choice of method. Further details are given in Ref 14.

d. Where geotextiles or related products, or soil nails qre used to strengthen the earthwork, care should be taken to ensure that they are not damaged by the subsequent installation of safety fence posts, sign and lighting columns, cables and trenches, or by subsequent planting or
maintenance work. The potential conflict between edge of pavement drains, which extend below the underside of capping, and the upper layers of reinforcement or nails will also need to be considered.

e. The need to achieve adequate foundation support for verge safety fences to ensure their fitness for purpose.

4. TECHNICAL APPROVAL (STRUCTURES) AND GEOTECHNICAL CERTIFICATION

4.1 Although not covered by this Advice Note, retaining walls with a design retained height in excess of 1.5m require technical approval in accordance with Departmental Standard BD 2/89 Part 1 (Ref 15). Reinforced earth structures having a hard facing, such as those defined in Technical Memorandum BE 3/78 (Ref 4), will require technical approval.

4.2 Reinforced soil has a soft facing of soil or granular material which may, or may not, be contained by a surface layer of geotextile, geogrid or related product. As earthworks, they will normally be topsoiled and sown or planted. This will also normally be the case for slopes where soil nailing is used.

4.3 Gabion and crib walls are earth retaining structures and technical approval is required if they have a design retained height in excess of 1.5m. If they are less than this height, they will require geotechnical certification.

4.4 Technical approval procedures shall be followed for strengthened embankments when the angle of the slope face to the horizontal is 70 degrees or greater and the design retained height is greater than 1.5m. Where the angle of the slope face to the horizontal is 45 degrees or less, geotechnical certification will be required. For strengthened embankments between these limits, the advice of the Overseeing Department should be sought.

4.5 In such cases, the decision on whether technical approval or geotechnical certification is the most appropriate course of action will depend on the consequences of failure of the strengthened e embankment and the difficulty of repairing it.

4.6 Earthworks incorporating reinforced soil or soil nailing require a design life to be ascribed to them so that the creep and durability properties of polymeric[1] materials and the corrosion properties of metallic materials can be assessed. For reinforced earth retaining walls designed in accordance with BE 3/78 (Ref 4), the design life is 120 years: where geotechnical certification is used, the design life shall be not less than 60 years.

4.7 Until such time as detailed design methods and performance criteria are issued by the Department, the Contractor will need to supply evidence to show that proprietary materials to be used to strengthen earthworks have properties which ensure that they are fit for the purpose intended and that they will retain these properties for the prescribed design life. This information will also need to cover site damage to the materials during installation.

4.8 In the longer term, it is the intention of the Department that proprietary materials for use in reinforced soil and soil nailing will require a Roads and Bridges Certificate issued by the British Board of Agrement or an equivalent body.

[1]'Polymeric' is used here as a generic term to describe geotextiles, geogrids and related products made from polyethylene, polypropylene, polyester or other polymers.

5. DRAINAGE

5.1 It may be possible in some circumstances to incorporate the existing drainage of the sub-base and existing drains at the toe of the embankment, or at the top of cuttings, into the new design.

5.2 In many cases, however, it is likely that the existing drainage will need to be replaced. This is particularly true at the edge of the pavement, where the use of combined filter and surface water drains is now considered to be fundamentally undesirable. Advice on edge of pavement details is given in a Departmental Advice Note (Ref 16) and standard details are shown in Highway Construction Details (Ref 17).

5.3 When the edge of pavement drain is to be replaced, it is important to ensure that the existing drain does not act as a reservoir for water to subsequently enter the sub-base or the subgrade. This can be achieved by either removing the original drain completely or introducing positive drainage from the bottom of the original drain to the new drainage system. It will also be necessary to ensure that the types and thicknesses of materials used for capping and sub-base construction are such that they do not impede the drainage of the existing sub-base and/or capping and vice versa.

5.4 Drainage must be maintained at all times and the possible consequences of prolonged heavy rainfall or rapid thaw during reconstruction must be allowed for. The specification for sub-base and capping materials will also need to take account of this requirement.

5.5 Temporary drainage measures may therefore be required during the works as well as temporary connections to ensure that the adjacent permanent drainage continues to function.

5.6 In view of the particular susceptibility to chloride attack of metallic elements such as reinforcements or nails, every effort should be made to ensure that chloride contaminated surface run-off water and groundwater are not allowed to percolate into areas where these are used. Further information is given in Section 13.2 of Departmental Standard BD 12/88 (Ref 18).

6. WIDENING METHODS

6.1 Design Considerations

6.1.1 When considering the adoption of any of the techniques described in this Advice Note, the problems of short term as well as long term stability will need to be addressed. In most cases, it will therefore be necessary to consider the undrained situation as well as the fully drained condition.

6.1.2 In order to obtain the most economic solution and efficient construction sequence, the number of widening options finally adopted should be kept to a minimum within any one contract.

6.2 Conventional Solutions

6.2.1 The simplest solution to widening an earthwork is to use the original slope angle and construct within the existing highway boundary: this does, of course, require sufficient space to be available. However, there is a number of caveats to be placed on such a method.

a. If the existing earthwork is showing signs of instability or if weathering or softening of the slopes is occurring already or is likely to occur in the future, it may be prudent to include a strengthening technique in the new construction.

b. Benching into the existing embankment is required, and it is important to ensure that potential planes of weakness are removed by excavating back into sound material. A stability analysis must be carried out to check that there is an acceptable factor of safety against deep seated as well as shallower failures.

6.2.2 An alternative solution is to construct the new shoulders of an embankment using granular materials or chemically stabilised cohesive materials, eg lime stabilisation, possibly using a steeper slope angle. In addition to the provisos in Section 6.2.1, the following should also be taken into account.

a. Using granular materials, which are relatively permeable, may allow surface water to percolate down to cohesive materials in the existing embankment and cause long-term softening to occur at depth.

b. It must be demonstrated that chemically stabilised materials are likely to retain sufficient strength in the long-term. Further information is given in Ref 19, which deals with the strength of lime stabilised clays.

6.2.3 In some cases, it may be possible to reconstruct embankments with steeper side slopes using on-site materials and to steepen existing cutting slopes, in both instances without compromising stability. In these cases, the factors discussed in Section 6.2.1 are likely to be even more important.

6.3 Reinforced Soil

6.3.1 In this method, horizontal layers of reinforcing elements are incorporated between layers of compacted fill material to improve the stability of the resulting soil mass. Many types of reinforcing materials have been used including metallic strips, geotextiles and geogrids. Reinforcements have been incorporated successfully in a range of soils from granular through to heavily over-consolidated clays, by adopting an appropriate combination of reinforcement and soil types for a particular application.

6.3.2 Because the technique involves incremental construction from the bottom upwards it is more appropriate to the construction and repair of embankments (Ref 3). However, the technique may be used for the repair of cutting failures when appropriate (Ref 9).

6.3.3 In embankments where the soils may have a wide range of mechanical and chemical properties, the use of geotextiles, geogrids and related products is more common than the use of metallic reinforcements. Two common arrangements of geotextile reinforcements have been used. The first involves wrapping the reinforcement around the slope face and embedding the upper end as shown in Fig 2: this technique is appropriate in steeper slopes or where the soil has relatively poor long-term strength. The second method, shown in Fig 3 is to truncate the reinforcement at the slope face: although this method is easier to construct, it may allow material to slough from the slope face in the longer term.

6.3.4 All polymeric materials are susceptible to creep and to the associated problems of load relaxation, stress rupture and damage. These phenomena need to be carefully evaluated in design. Methods of achieving this have been reviewed in the literature (Refs 20, 21 and 22).

6.3.5 In a reinforced soil structure, consideration needs to be given to both external and internal stability. Analyses for external stability cover translational, rotational and bearing failure of the reinforced soil mass, whereas internal stability covers the soil-reinforcement bond, pull-out of the reinforcement and rupture.

6.3.6 The design of reinforced slopes is normally based on limit equilibrium analysis. This form of analysis does not take into account directly the stress-strain behaviour of the soil or of the reinforcement: however, limit equilibrium methods have been used extensively and offer a fairly straightforward method of design. Analyses are usually based on a two-part wedge mechanism (Refs 23 and 24), but circular methods have also been used (Ref 25).

6.3.7 in using this technique to widen existing embankments or to repair existing cuttings, particular attention must be given to both overall settlements and differential settlements within the reinforced soil mass. The effect of these settlements on the loads and strains induced in the reinforcements will need to be considered carefully in design. This subject has been covered in a review of the use of reinforced soil in areas of mining subsidence (Ref 26).

6.3.8 In addition, many of the potential problems discussed in Sections 3 and 6.2 will also be relevant to the design of reinforced soil for this application. In practice, it is likely that for most applications, the length of reinforcement will need to be such that it extends well beyond the slope face of the existing embankment, which will need to be cut back. This may result in an excavation of such depth that a lane closure is required, but it does have the following advantages:

a. it will reduce the change of a failure occurring in the zone of contact between the existing slope face and the new construction;

b. it will also help to smooth out differential settlements between the old and the new construction.

6.3.9 In simple applications, such as low height and relatively shallow slopes, the design of reinforced soil structures will normally be relatively straightforward. However, the complexity of design and the likely consequences of failure will increase with increasing height and slope angle. Reinforced soil is still being developed andt in all but the simplest applications, it may be prudent to obtain specialist geotechnical advice before this solution is adopted. In the first instance, enquiries should be directed to the appropriate Regional Office.

6.4 Soil Nailing

6.4.1 The technique of reinforced soil is generally accepted as applying to the improvement of soil by incorporating reinforcement into the fill as construction takes place. In contrast, soil nailing is usually applied to natural or man-made slopes and enhances stability by the installation of reinforcements directly into the ground after the slope has been formed. It is therefore more likely to be used to prevent the failure of cutting slopes or to increase the stability of such slopes when they need to be steepened. However, it can also be used to improve the stability of existing embankment slopes, but in general would not be appropriate for use in the construction of new embankments.

6.4.2 The other major differences between soil nailing and soil reinforcing are as follows.

a. In soil reinforcing, backfill materials with appropriate strength and corrosion properties can be used, whereas soil nailing has to cope with what already exists.

b. In reinforced soil, tensions generally develop as construction progresses, thus allowing the reinforcing elements to participate in increasing stability. In soil nailing, some general ground movements will be necessary after installation of the system and before tensions develop in the elements.

c. Reinforced soil is constructed from the bottom upwards whereas soil nailing is normally constructed from the top downwards.

6.4.3 Two typical schematic layouts of steepened slopes incorporating soil nailing are shown in Figs 4 and 5. The reinforcements most commonly used are round metal bars or tubes with typical diameters of 20 to 50mm which are installed either by driving or inserting into pre-formed or pre-drilled holes of 80-120mm diameter. Cement grout may then be pumped into the hole at relatively low pressures to form a bond between the reinforcement and the surrounding ground. The nail is then connected by a threaded arrangement to a bearing plate at the surface. The size of this plate will depend on the load in the nail and the soil properties. For slope angles greater than about 60 degrees, the whole of the slope face may subsequently need to be covered by some form of hard facing. In all cases, the Department's Regional Landscape Architect or Horticultural Officer should be consulted at the earliest possible stage to advise on the suitability, from an environmental aspect, of the proposed facing.

6.4.4 In addition to metal rods and tubes, a number of other reinforcements have been suggested. These include expanded anchors in which the buried end of the anchor is expanded mechanically, pneumatically, hydraulically, or by controlled explosion. Wedge pile anchors which are expanded along their entire length have also been used, as have anchor shoes attached to lengths of wire rope. In this latter type, a pivot arrangement compels the anchor shoe to rotate into a fully resistant position under load (Ref 3), but because of the pivot arrangement and wire rope, the anchor cannot develop resistance through shear. In addition, significant relative movement is required to develop the full pull-out resistance of the anchor.

6.4.5 Soil nailing has been very little used in the United Kingdom. However, it has had considerable use in West Germany and France, where it is highly regarded as a convenient and cost-effective technique. A review of its use is given in Ref 27, and a review of the subject for typical road applications in the United Kingdom is given in Ref 28.

6.4.6 Design methods for soil nailing are similar in concept to those used for reinforced soil and include the same checks for external and internal stability. Details of a limit equilibrium analysis using a two-part wedge are given in Ref 28, and an analysis using a parabolic failure surface is described in Ref 29. A method of analysis which considers the influence of bending and deformation has been described in Ref 30. However, full-scale tests (Ref 31) have indicated that the shearing resistance generated by the nails is small: this is at variance with the design method given in Ref 30. Further research is currently underway to resolve this point.

6.4.7 Although most of the applications of soil nailing are likely to be concerned with the steepening of existing slope angles or with increasing the stability of slopes considered to be at risk, another potential application is to enhance the load carrying capacity of existing earthworks. This could be particularly useful where the influence of surface loads applied close to the edge of an embankment might cause a large scale bearing failure of the shoulder. This application has been considered in Ref 28.

6.4.8 Many of the potential problems to be considered in the design of soil nailing are similar to those already described in Sections 3 and 6.2. In addition, the durability of the nails will need to be carefully assessed, as will the potential benefits of any protective coating envisaged. Soil corrosivity assessment (Ref 32) and the use of protective coatings in soil structures (Ref 33) have both been reviewed by TRRL.

6.4.9 Although soil nailing has had little application in the United Kingdom, it appears to offer the potential for significant savings over other techniques. The design methods are still in the development stage, as are the construction techniques. However, experience in Europe suggests that the design and construction techniques are adequate to allow soil nailing to be implemented safely. In view of the limited experience with this technique, it is important that specialist geotechnical advice should be obtained before the solution is adopted. In the first instance, enquiries should be directed to the appropriate Regional Office.

6.5 Slope Drainage

6.5.1 Slope drainage is widely used in highway works to reduce pore water pressures and thereby improve stability, both in new construction and in existing cutting slopes. Counterfort drainage, in which strength is also provided by the use of rock fill, is less widely used. As with all forms of sub-surface drainage, care must be taken to ensure that the granular or geotextile filter is correctly designed for the soil in contact with it. Consideration must also be given to the ease of subsequent inspection and maintenance.

6.5.2 When considering slope drainage, an adequate ground investigation is required to ensure the following.

a. The actual or potential failure mechanisms are correctly identified and that the stability will be adequately improved by drainage.

b. The soil is reasonably isotropic with respect to permeability, in which case design charts of the type given in Ref 34 may be used. If the soil is markedly anisotropic (eg some alluvial deposits), or contains seepage planes, appropriate charts are not available and the dimensions of the drainage system must be calculated (Ref 34).

6.5.3 Possible applications of slope drainage are:

a. deep drains to improve the short or long term stability of cutting slopes against deep-seated failure;

b. shallow, closely spaced drains to reduce the incidence of the type of shallow, planar slips identified in Section 3.3;

c. bored horizontal drains are little used in the UK, but may be an appropriate solution in large cuttings with well defined seepage zones.

6.5.4 In principle, slope drainage is also applicable to embankments. However, as mentioned in Section 6.2.2(a), there is a risk that this will allow water to percolate into the drier materials at depth within the embankment. In addition, compacted clay fills are not fissured like natural clays and are therefore likely to be less permeable. It may therefore take many years for them to reach equilibrium with the installed drainage.

7. CONSTRUCTION

7.1 Some details of construction have been given in earlier Sections of this Advice Note and further details are given in the References cited. However, particular emphasis should be placed on the following aspects.

7.2 There are three important rules for working on earthwork slopes.

a. DO NOT remove material from the toe of the slope except under controlled conditions which maintain stability.

b. DO NOT stockpile material at the top of the slope.

c. DO NOT allow water to enter the slope and check that the existing drainage system is functioning correctly.

7.3 In many situations involving excavation into an existing slope, it will be necessary to work in short sections such that the material left in place on either side of the excavation provides arching support. It is also important to keep the time for which the excavation is unsupported to a minimum, especially with cohesive soils where the dissipation of negative pore water pressures may cause instability.

7.4 Many side slopes on motorway and trunk road earthworks are already showing signs of distress, on others a heavily vegetated and desiccated crust may be disguising softened material at a lower level. All construction techniques cause some disturbance, which will need to be kept to a minimum by using appropriate types of plant located in the appropriate place.

7.5 Where trees or shrubs exist on the embankment or cutting slope, the Department's Regional Landscape Architect or Horticultural Officer should be consulted to establish if any of the vegetation can be retained for environmental reasons, and if so what protection measures need to be adopted to safeguard such retention.

7.6 There is some evidence to suggest (Ref 2) that good compaction of fill materials in embankment side slopes increases the stability of the slope in the longer term. Good compaction control is therefore of primary importance: Table 6/4 of the Specification for Highway Works (Ref 35) shows that it is possible to achieve as high a level of compaction using a larger number of passes and smaller compacted layer thicknesses with lightweight compaction plant as it is with heavy equipment. The former is to be preferred where stability is critical or space is at a premium.

7.7 The sequence of site operations, the handling of materials and the location of plant accesses are essential matters which must be catered for as part of the design: to overlook them may lead to instability, create dangerous hazards and increase costs, particularly on long narrow worksites.

7.8 DTp requirements for working spaces and safety zones must be observed: safety zones are covered in the Traffic Signs Manual, Chapter 8 (Ref 36). The Note for Guidance on Safe Working on Trunk Roads and Motorways (Ref 37) should also be consulted.

7.9 When using any of the techniques described in Section 6, the finished side slopes should, wherever possible, be topsoiled, grassed and seeded in accordance with SHW Clause 618. On steeper slopes, it may be necessary to incorporate measures to reduce the incidence of soil erosion. Geotextiles and related products, except those used specifically to reduce soil erosion, must not be left exposed to sunlight. Further information is also contained in a CIRIA publication on the use of vegetation in civil engineering (Ref 38).

8. ACKNOWLEDGEMENT

8.1 Much of the work on which this Advice Note is based was carried out by the Ground Engineering Division and Structural Analysis Unit of the Transport and Road Research Laboratory for the Highways Engineering Division of the Department of Transport.

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10. ENQUIRIES

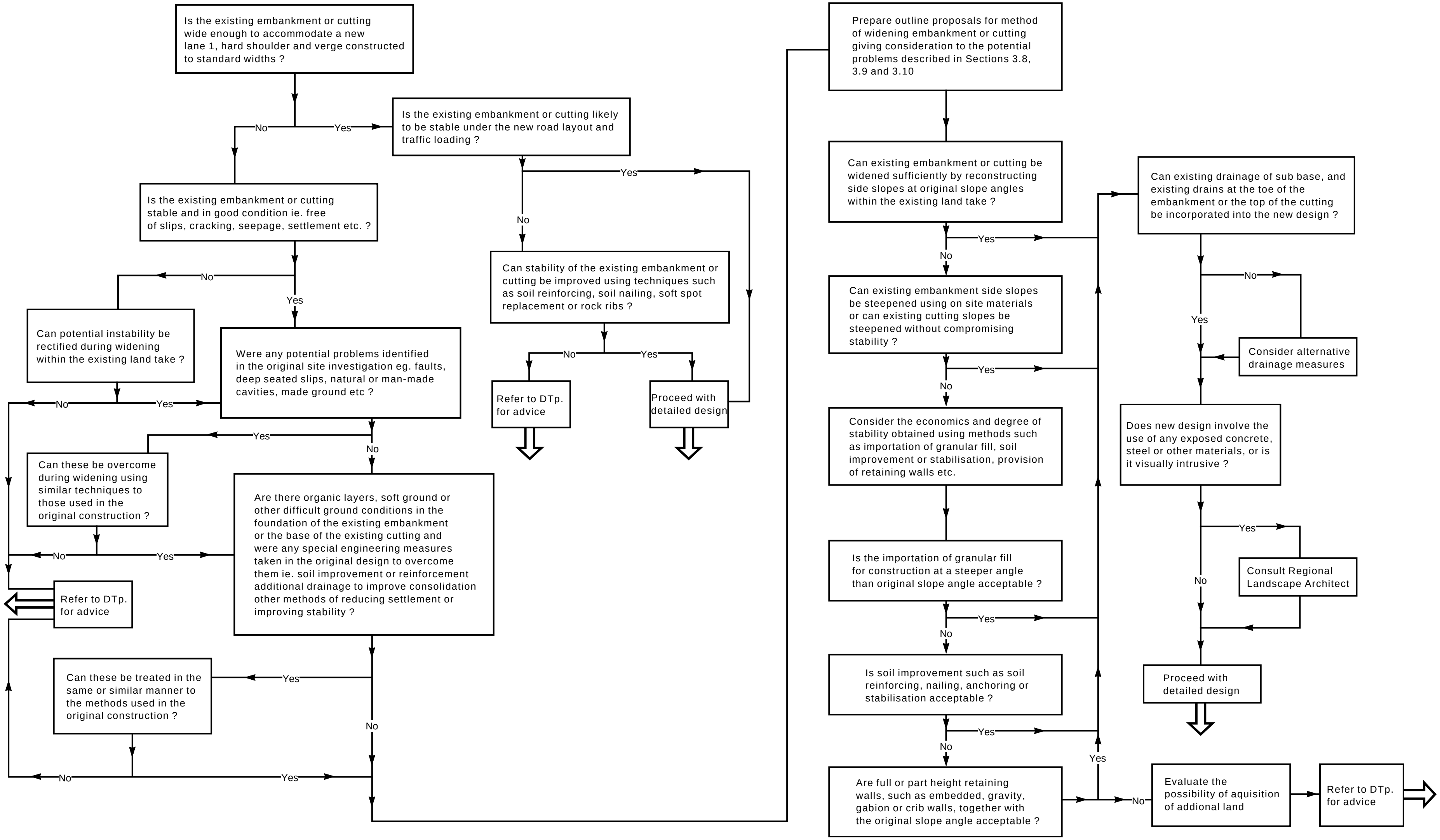

Fig. 1 Decision tree for widening highway earthworks

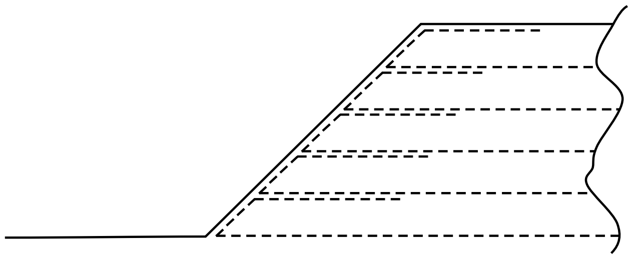

Fig. 2 Reinforced soil with wrap round face detail

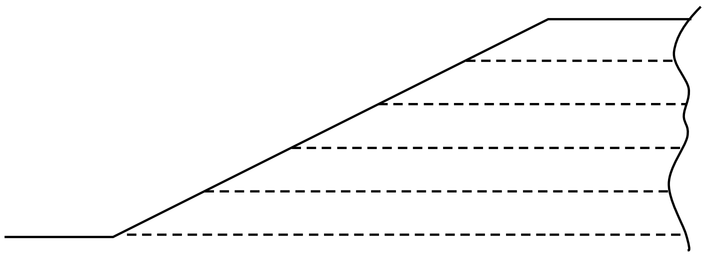

Fig. 3 Reinforced soil with reinforcement truncated at slope face

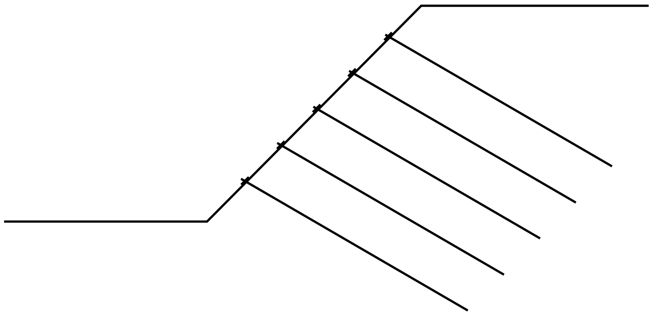

Fig. 4 Soil nailing with a uniform slope angle

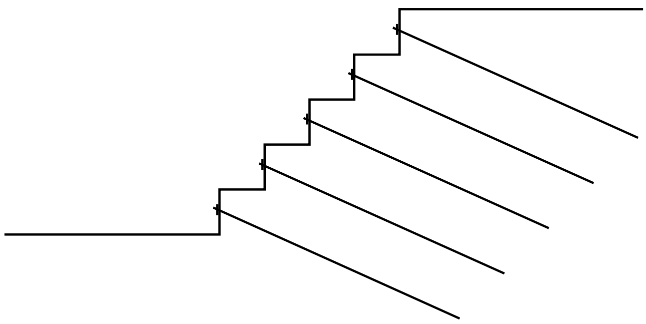

Fig. 5 Soil nailing with a terraced face