THE HIGHWAYS AGENCY

HA 48/93

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

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THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

Maintenance of Highway Earthworks and Drainage

Summary: This Advice Note gives guidance to highway engineers responsible for maintaining earthworks slopes and drainage on trunk roads including motorways.

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VOLUME 4 GEOTECHNICS AND DRAINAGE

SECTION 1 EARTHWORKS

PART 3

HA 48/93

MAINTENANCE OF HIGHWAY EARTHWORKS AND DRAINAGE

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1. INTRODUCTION

General

1.1 Failures of earthwork slopes are an increasingly common occurrence on some lengths of highways (1). Cutting and embankment slopes are susceptible to failure as a result of reduction in strength due to weathering and water ingress. The failed material may then move down onto the carriageway in the case of cuttings, or undermine or remove the road structure in the case of embankments. Structures at the top of cutting slopes may also be threatened. Slope failures in the early stages of development can often be identified and stabilized provided that the maintenance engineer is aware of the causes of failure and recognizes those slopes most likely to be at risk. Appropriate inspections are therefore required as a matter of routine. In order to maintain the stability of slopes, drainage systems must be inspected and maintained regularly. In order to prevent failures, additional slope drainage may also be required on slopes not showing signs of failure but which are in areas of known instability.

1.2 Road drainage systems are also required to be inspected and maintained regularly in order to prevent instability of the earthworks and provide adequate drainage of the road surface, pavement and foundation. Faulty drainage can lead to softening of the subgrade and subsequent failure of the pavement. In areas of domestic and toxic wastes, maintenance is important in order for the drains to operate in the manner envisaged in the design. Dangerous gases can build up in enclosed spaces, and pollutants may be present on the road surface; both require properly designed and functioning drainage systems to function correctly.

1.3 Departmental Advice Note HA 26/83, "Maintenance of Highway Earthworks", is superseded by this Advice Note.

Scope

1.4 This Advice Note is issued for the guidance of engineers responsible for the inspection and maintenance of trunk roads. It describes how the common causes of slope instability develop, those slopes at risk of failure, what to look for as early signs of earth slips and how remedial or preventive treatments should be carried out. It also covers the maintenance of slope drainage on general earthworks and more specifically, the maintenance of earthworks and drainage for roads constructed through sites of domestic and toxic wastes. Spillages of hazardous liquids on the road surface are also considered.

1.5 This Advice Note does not cover either the design of new earthworks, which is dealt with in HA 44 (DMRB 4.1.1), or widening of existing earthworks which is described in HA 43 (DMRB 4.1). It is not intended to cover complex geotechnical problems (see Paragraphs 3.3 and 3.4) for which specialist geotechnical advice should be obtained. In addition, the routine maintenance of pavement and road surface drainage is not considered here and reference should be made to the Overseeing Department's Code of Practice for Routine Maintenance (4). This Advice Note covers technical aspects and procedures. The Overseeing Department's Code of Practice for Routine Maintenance contains information on inspection regimes and repair timescales.

Use in Northern Ireland

1.6 For use of this Advice Note in Northern Ireland the Maintenance Agent shall be considered to be the appropriate Division of Roads Service.

Implementation

1.7 This Advice Note should be used forthwith in the inspection and maintenance of trunk road earthworks and drainage, in the assessment of slope failures, and in the design of remedial or preventative works provided that, in the opinion of the Overseeing Department, this would not result in unacceptable additional expense or delay. Maintenance Agents, and others involved in trunk road maintenance, should confirm its application with the Overseeing Department.

2. SLOPE FAILURES ON EARTHWORKS

2.1 Slips are most frequently associated with cohesive soils although failures in other types of material do occur. Whilst some failures, often deep-seated, occur either during or just after construction, the most frequent type of failure is at a shallow depth and occurs a number of years after construction. These latter slips are usually 1.0-1.5m deep and, in some areas, constitute a considerable maintenance problem. In cuttings of rock, the failure mechanism depends on the stability of blocks of rock in the slope and the orientation and strength of discontinuities or interbedded weaker materials.

2.2 Many earthworks are now of an age at which instability may occur. The materials most susceptible to failure are listed in Table 2/1 taken from TRRL Research Report RR199. The frequency of failure of these materials appears to increase significantly at between 10 and 15 years after construction. It was estimated in 1989 that three times as many slopes were likely to fail in the future. This prediction is an estimate based on earthworks up to 25 years old and probably under-estimates the frequency of failure in the longer term. Many highway earthworks, although at less severe geometries than the geometries of slopes that have failed so far, are still likely to fail in the future as water ingress and weathering continue to weaken the materials in the slopes. TRRL Research Report RR199 indicates that slope failures are rare in slopes with heights less than 2.5m.

2.3 On embankment and cutting slopes, failure of the topsoil layer can occur if vegetation has not yet become established. Failure is usually associated with steep slopes and large thicknesses of topsoil. The use of pins and geotextiles on the surface of the topsoil may provide enough stability until the vegetation becomes established.

2.4 Embankment slope failures are often detected later than failures in cuttings as the slope is below the level of the carriageway and hence less visible.

TABLE 2/1

GEOLOGIES WITH HIGH PERCENTAGES OF FAILURE

GEOLOGY	PERCENTAGE OF FAILURE	PREDOMINANT SLOPE ANGLE
EMBANKMENTS		
Gault Clay	8.2	1:2.5
Reading Beds	7.6	1:2
Kimmeridge Clay	6.1	1:2
Oxford Clay	5.7	1:2
Lower Keuper Sandstone	4.9	1:1.5
London Clay	4.4	1:2
CUTTINGS		
Gault Clay	9.6	1:2.5
Enville Beds	5.8	1:2.5
Oxford Clay	3.2	1:2
Reading Beds	2.9	1:3
Bunter Pebble Beds	2.3	1:2
Lower Old Red Sandstone -St Maughan's Group	1.7	1:2

3. FAILURES IN CUTTINGS

Soil and Soft Rock Slopes

3.1 In cohesive soils and other low plasticity soils (eg with high silt contents, such as glacial tills), the excavation of a cutting, and associated stress relief, leads to an immediate reduction of pore water pressure often to a negative value ie suction. This reduction is followed by a slow gradual increase in pore water pressure (equilibration) and an associated reduction in shear strength. Thus, a stable slope becomes less safe with time and slips may occur in increasing numbers.

3.2 Shallow slips in clay cuttings can be expected within 25 years of construction where cutting slopes exceed the recommended maximum angles for particular geologies as given in TRRL Report RR 199. The survey reported in RR 199 is extensive and all the known common factors leading to slope failures were included. Most slips are only 1.0-1.5 metres deep, but deeper failures do sometimes occur. Slopes less steep than 1:3 (vertical:horizontal), without pre-existing failure planes and with the necessary drainage, have so far been free from all but these shallow failures. It may, however, be more economic to accept regular maintenance of steep slopes than to flatten slopes as the required land-take may be considerable. Alternatively, one of the improvement measures in Chapter 6 may be used. As well as economic considerations, consideration should also be given to the environmental impact of the repair on a site specific basis.

3.3 Potential failure mechanisms for typical soil and rock types are given in Table 3/1. For soils, the Table includes rotational slips (Figure 3/1) and slab or block slides (Figure 3/2), both of which can occur at a range of depths. Slab slides on man-made slopes are usually not extensive but more extensive failures can occur on natural slopes when an old slide is reactivated along a pre-existing shear plane. Reactivation can be caused by either removal of toe restraint when a cutting is excavated, by loading the natural slope with an embankment or by other disturbing factors such as erosion. Failure is likely to be progressive. The slope design may require adequate drainage of the slope: in such cases maintenance of the drainage system will be critical.

3.4 Fissured clays (eg London Clay, Oxford Clay, Gault Clay, Lias Clay and certain glacial tills) present a particular problem. In their natural state these clays are over-consolidated with fissures which reduce their bulk strength. Fissures may open due to stress relief and shrinkage cracks may develop in periods of dry weather, both providing channels for ingress of water which then softens the surface of the fissures and cracks. Available information (6) indicates that pore water pressure equilibration can be a slow process, sometimes taking 120 years to complete; this leads to a gradual reduction in the apparent cohesion (part of the available effective shear strength) to near zero. In these materials a flatter slope angle is needed than for non-fissured clays to ensure as long a period of stability as possible.

3.5 Granular soils present fewer problems in cuttings. Flow type failures can, however, occur in finer grained granular deposits (eg fine sands) if either pore water pressures become sufficiently high after prolonged wet periods, excavation of a new slope intersects a water table or if the groundwater regime is changed so that water enters the slope.

3.6 Cuttings in mixed cohesive and granular soils, as occur in glacial tills and Bracklesham Beds, can be troublesome if water bearing layers are present. Seasonal seepage from such layers indicates the occurrence of local softening of the clay layers and can lead to piping and undercutting of the strata above.

Rock Slopes

3.7 Failure mechanisms involving rock discontinuities in cuttings are of three types (7) (8) (9); plane (Figure 3/3), wedge (Figure 3/4) and toppling (Figure 3/5). These failure types normally occur in full or partial conjunction with each other. Highly fractured and weak rocks can, however, exhibit failures in a similar way to soils. Plane failure occurs where bedding planes or other planes of weakness intersect the cut face or slope at an angle of dip, into the cutting, less than that of the slope. Also the dip of the discontinuity must be sufficient to overcome the friction between block and the rest of the rock mass. Toppling failures (Figure 3/5) are a lot more common than is generally recognised. The toppling mechanism is characterised by a rotatory movement of blocks into a cutting or excavation. The blocks are formed within the rock mass from near vertical discontinuities, which dip into the cutting face at a steep angle, and near horizontal discontinuities which dip out of the cutting face. This situation can lead to major failures even in shallow cuttings and can involve very large volumes of rock. If the horizontal discontinuities are too steep the blocks will tend to slide rather than topple.

3.8 Weathering of steep sided cuttings may lead to undercutting at the base of the slope and collapse of the overlying rocks. Frost action causes rock debris to form and fall down the slope, collecting at the toe. Debris of this sort should be prevented from reaching the carriageway by either an open ditch or catch fence or both.

3.9 Failures of soil infilling voids in rock can occur as a result of steep faces being constructed which, although stable for the rock which makes up the majority of the face, is too steep for the soil infill. Drift material infilling solution features in limestone is a good example of a situation where this type of failure occurs.

TABLE 3/1

POTENTIAL FAILURE MECHANISMS IN CUTTINGS

SLIP TYPE	ALLUVIAL WEATHERED & SOLIFLUCTED CLAYS	FISSURED CLAY	BOULDER CLAY	GRANULAR SOILS	SOFT ROCK (INCLUDING CHALK)	HARD ROCK
ROTATIONAL	●	●	●	—	●	—
SLIDE (TRANSLATIONAL) (a) SLAB SLIDE (includes reactivation of old slides)	●	●	●	—	●	●
SLIDE (TRANSLATIONAL) (b) (MUD) FLOW	●	●	—	●	—	—
WEDGE	—	●	—	—	●	●
EROSIONAL	●	●	—	●	●	●
TOPPLING	—	●	—	—	●	●
VALLEY BULGING	—	Creep ● Movements	—	—	● Cambering, joints open	●

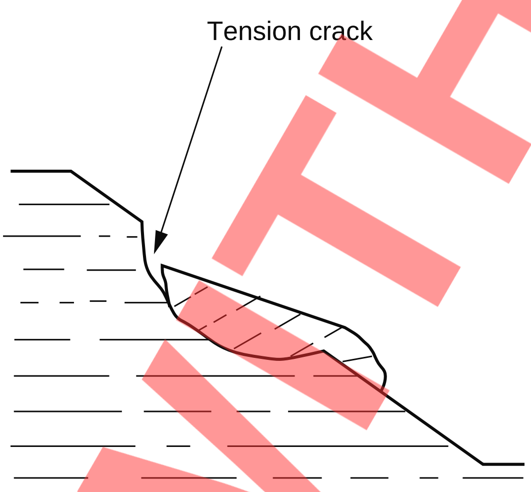

Fig 3/1. ROTATIONAL SLIP

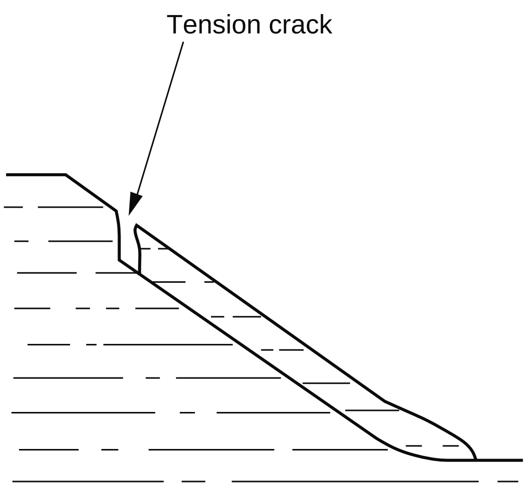

Fig 3/2. SLAB SLIDE

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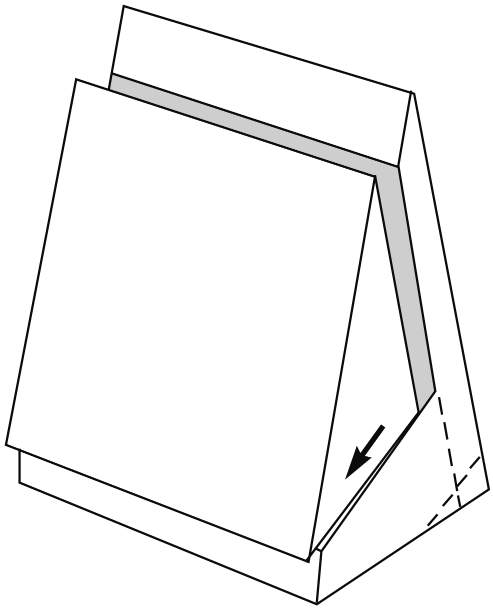

Fig 3/3. PLANE FAILURE IN ROCK

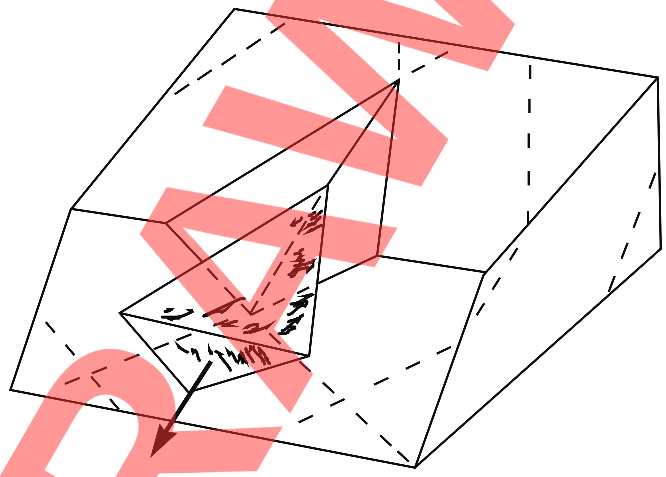

Fig 3/4. WEDGE FAILURE IN ROCK

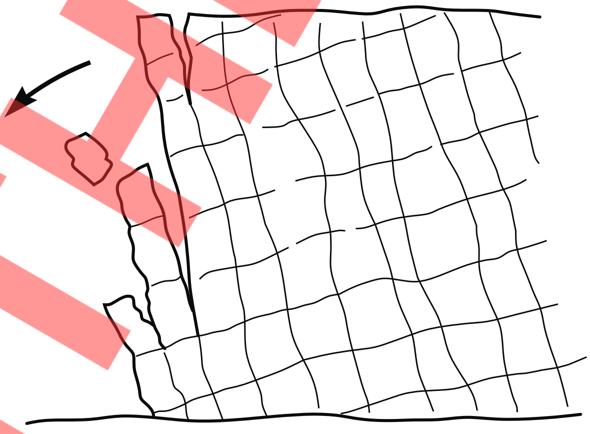

Fig 3/5. TOPPLING FAILURE IN ROCK

4. FAILURES IN EMBANKMENTS

Soil and Soft Rock Fills

4.1 The majority of slips which develop in clay embankments in the longer term are shallow first-time failures. Maximum recommended slope angles to prevent this type of failure occurring within 25 years of construction are given in TRRL Report RR 199 (1). It may, however, be more economic to accept regular maintenance, rather than flatten slopes to this extent, or use one of the improvement methods in Chapter 6. The excavation of soils can cause negative pore water pressures to develop in fragments of firm or stiff clay and positive pore water pressures may not be generated by the compaction process (10). Ingress of water then causes pore water pressures to increase gradually (equilibration) and the clay swells and softens. This may be accentuated in over-consolidated clays when they are taken from deep excavations and are not sufficiently remoulded during excavation, deposition and compaction.

4.2 Shallow slips in the surface slopes of embankments are recorded as being most prevalent after periods of wet weather. Water infiltration into the slope as a result of rainfall is exacerbated by the following.

i. Shrinkage cracking which provides passages for water to penetrate into the embankment (11).

ii. Water entering the slope from the road structure through sub-bases extended out onto the slope, a construction detail now considered to be undesirable (12).

iii. Poor compaction at the outer edges of embankments.

iv. Unsatisfactory reinstatement of slopes after tree planting (see Paragraph 6.8).

v. Trenching or excavation across the top or at the bottom of slopes eg for drainage or communication trenches or for minor construction projects.

4.3 The laying and compaction of fills may result in the formation of horizontal shear planes and provide paths for the ingress of water (13). At present, it is uncertain whether this has caused or will cause deep seated failures. Where sandy and clayey soils form alternating layers, this can lead to the development of perched water tables. Water tables can also form near to the top of embankments due to the entry of water through the central reserve and verges. Water can also infiltrate into the embankment through the pavement structure and from faulty drains in the central reserve and verge.

4.4 Embankments fail catastrophically when the foundation does not provide sufficient support. This type of failure usually occurs during or shortly after construction but it can also occur in the longer term where embankments are built across areas of ancient landslips (14).

4.5 Roads constructed or widened on side long ground may be subject to long-term failures because pore water pressures can increase within the embankment, particularly where spring water issuing from the foundation has not been adequately dealt with. The presence of spring water may not have been evident at the time of construction due to seasonal fluctuations.

Rock Fill

4.6 The slopes of earthworks constructed of rock fill can exhibit loss of topsoil. Although a steep slope angle may be suitable for the rock fill, topsoil may become unstable at such angles and no longer adhere to the rock beneath. A number of topsoil failures of this sort have occurred with rock fills of Keuper Sandstone and Chalk. Where topsoil cannot be retained, it will be necessary to use geosynthetic sheets or jute to provide a stable environment for the propagation of grass. If topsoil can be retained on a rock fill, the slopes should not require much maintenance.

5. INSPECTION OF EARTHWORKS SLOPES

5.1 The routine inspection of earthworks should be carried out by trained personnel, whether or not slips have previously occurred. Procedures are outlined in the Overseeing Department's Code of Practice for Routine Maintenance (4). Inspections should follow periods of heavy rain, severe frosts, or prolonged dry weather.

5.2 Slopes at an early stage of instability can often be identified by bulging of the slope profile at the bottom of the slope and very narrow tension cracks at the top. Inspectors should be aware that high earthworks failures on slopes can occur on part of the slope, hence tension cracks may occur further down a slope and bulging may occur higher up the slope. Shrinkage cracking, as a result of dry weather, will in cohesive soils provide access for water and may indicate slopes at risk of failure. Incipient movements may be recognised by the presence of tension cracks at the back of the slip and from changes in ground profile. The cracks can be curved or straight in plan. Where rotational failure is developing, the profile will be depressed in the upper part of the slip and bulge at the toe. Toe bulging may also occur with slab slides but the tension crack will usually be wider and the slope angle of the surface of the slipped material will tend to remain similar to that of the surrounding stable slope. A checklist for recording information on earthworks failures is given in Appendix A.

5.3 Drainage systems must be inspected regularly to ensure that they are working effectively. Opportunities should be taken to inspect the systems during heavy rainfall to check if the drains are surcharging or are carrying eroded soil. Specifically in cuttings where permeable materials overlay impermeable materials, cut-off filter drains are used as shown in Figure 5/1. These drains at the top of cuttings are intended to intercept groundwater flows. When placed too near the edge of the cutting, they have been responsible for accelerating slip failures, and so correct positioning away from the crest of the cutting slope is important. Slope drains should be installed on slopes showing signs of seepage where the material is likely to become unstable or suffer from erosion. Seepage can be identified on a slope by the presence of wet ground plants, boggy ground, spring lines or erosion due to water issuing from the slope. The frequency of inspections is given in the Overseeing Department's Code of Practice for Routine Maintenance (4).

5.4 If surface water flows from higher ground are increased as a result of some changed condition (eg after felling timber) to the extent that the system is overloaded, the flows must be intercepted by separate shallow ditches and the top of the existing filter drains may then require to be sealed (see Figure 5/1). All sealed filter drains and open ditches must be inspected regularly for leakage as water may be finding its way into the slope where it will cause rapid deterioration. Indications of leakage, apart from the presence of water issuing onto the slope, include boggy ground and wet ground plants on the adjacent slope. The longitudinal profile of open ditches should be checked regularly and any localized ponding dealt with as soon as it occurs.

5.5 Any signs of surface movement or slope deformation should be monitored by inserting rows of poles or pegs into the slope. Displacements and shallow slide movements can be determined by subsequent measurement and observation of the distortion to the rows of poles or pegs. Movements at greater depths can be found by installing slip indicators (see Appendix B). Knowledge of the depth of the slip surface is essential for the correct design of remedial works. It is important however that the indicators go well below what is judged to be the deepest position of the slip plane and are put in before secondary slip surfaces have developed within the slipped mass. Failure to do this may result in the slip being considered to be shallower than it really is.

5.6 Grass, trees and shrubs should not be removed from slopes unless absolutely necessary. Grass prevents erosion of the slope by binding the soil together and reducing the speed of run-off water. Trees and shrubs draw water out of the slope: they also bind and reinforce the soil. Where changes in vegetation are necessary, the advice of the Overseeing Department's Regional Landscape Architect or Horticultural Officer should be sought at the earliest possible stage.

5.7 Maintenance of rock cuttings should include the following:

i. Routine inspections of slopes for signs of instability, including the development of new tension cracks and widening of existing cracks as measured by regular reading of monitoring devices. Hoek and Bray (7) describe suitable monitoring devices. Observations should also be made in areas away from tension cracks so that the extent of the distress may be deduced. By careful monitoring of the slope, assessments can be made of whether the movements are large or small, increasing or decreasing. Whether stabilization is feasible and what type of measures are needed will depend on the results of the monitoring, characteristics of the slope, the size of failure, ease and expense of stabilization. A specialist may need to be used for complex situations or where techniques, such as the use of climbing equipment, is required.

In exceptional circumstances where there is no economic solution for stabilising a slope, consideration may need to be given to re-routeing the highway.

ii. Inspection of catch fencing, in case of damage or incorrect design, and immediate repair or improvement.

iii. Removal of weathered or spalled rock debris at the base of cutting slopes where encroachment of material onto the carriageway could occur, but under controlled conditions. Remove only the minimum of material so as to retain stability of the slope.

iv. Inspection of the effectiveness of drains at the top and bottom of the slope, of drains on benches and of horizontal drains drilled into the slope face. Vertical drainage wells, whether pumped, connected to horizontal drains or connected to drainage galleries should be checked for effectiveness.

5.8 Guidelines on the design and inspection of slopes in quarries have been produced (15), (16). Although written for the quarrying industry, the principles and the guidelines are equally applicable to any excavated slope or embankment. The main points for highway earthworks have been covered in the previous paragraphs.

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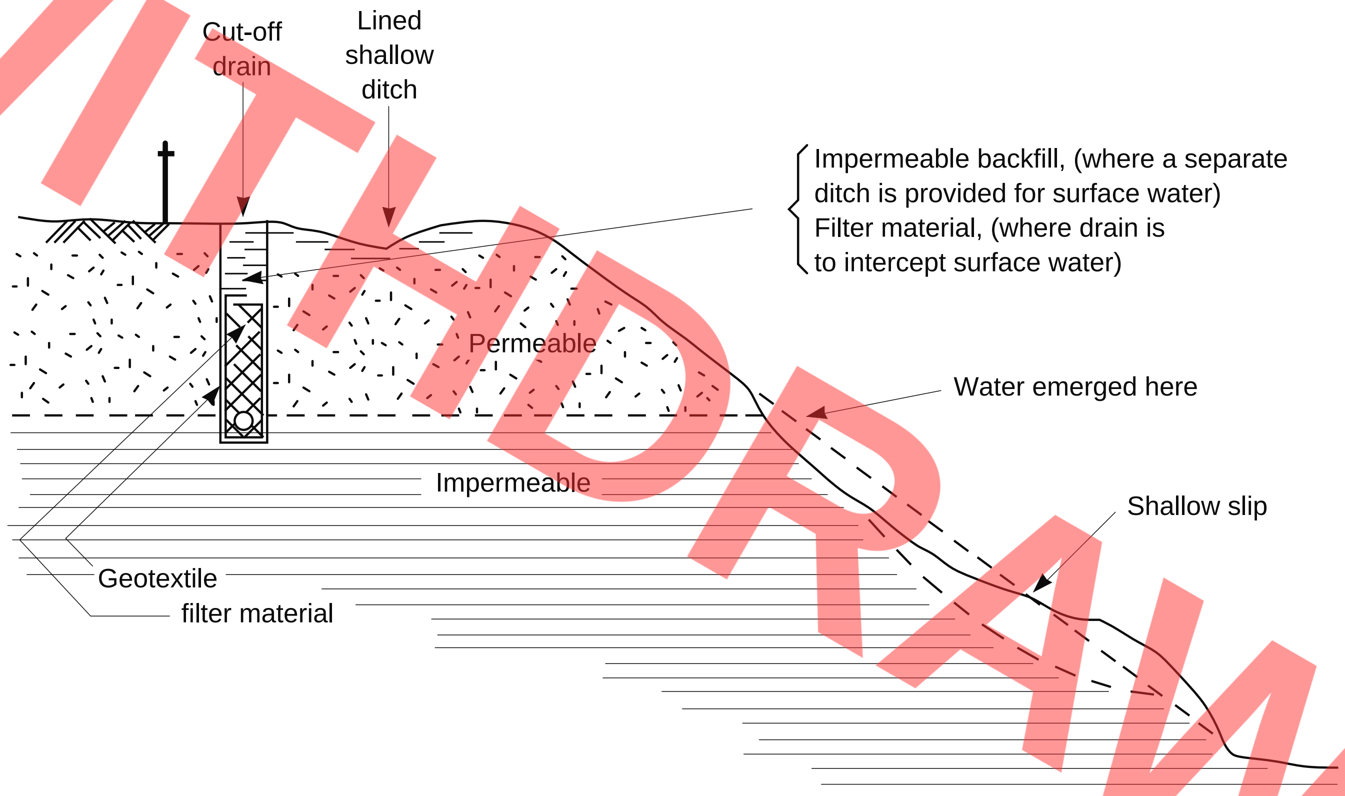

Fig 5/1. INSTALLATION OF INTERCEPTING DRAIN FOR CUTTINGS

6. METHODS OF IMPROVING THE STABILITY OF POTENTIALLY UNSTABLE SLOPES

General

6.1 There are five rules for maintaining the stability of earthwork slopes:

Do not:

i. remove material from the toe of the slope except under controlled conditions which maintain stability;

ii. stock pile material at the top of the slope;

iii. allow surface or sub-surface water to enter the slope;

iv. remove trees, shrubs or grass unless absolutely necessary as they may be helping to maintain slope stability and resistance to erosion;

v. regrade the slope to a steeper angle.

Although common sense, these rules may sometimes be ignored because of the confines of the site and can lead to serious repercussions by creating new slips or exacerbating existing ones.

6.2 When a slip occurs beneath a carriageway, traffic may need to be diverted, particularly when the carriageway is cracked and tell-tales indicate that the cracks are progressively widening.

Soil and Soft Rock Slopes

6.3 The length of time a slope remains stable can often be extended by diverting sub-surface water away from the slope. Interlayered soils are particularly susceptible to failure as a result of ingress of sub-surface water. Where significant surface movements eg 100mm, or any subsurface movements have been found in either cuttings or embankments, counterfort drains can be installed (Figure 6/1) which may stabilize the slope and prevent further movements and failure. Counterfort drains (17) provide both deep drainage
and buttressing action in reinforcing the slope. Geotechnical advice should be sought when considering counterfort drains as the excavations are deep and installation must be completed without exacerbating the situation. Advice will be required on the spacing, width and depth of the counterfort drains. They must always be backfilled with drainage material and be provided with a positive outlet for removing water. In order to investigate any movements, inspection trenches should be excavated down the slope, (see Paragraph 8.3 below for advice on safety), the material profile recorded, samples taken, and water seepages should be noted. If a slip plane is found in the trench, it, and any softened material, must be removed and replaced with drainage material even if no water is observed at that time. Drainage measures of this kind may not be sufficient for large potential slips.

6.4 Slope drains (1) (Figure 6/2) or rock ribs (18) have been successful in delaying shallow failures on cuttings and embankments. Trenches should be cut from the top to the bottom of the slope. The base of each trench should be sloped towards the toe to ensure water does not collect in the drain. The trenches should then be filled with filter material. Positive drainage should be provided at the base of the slope to remove the water collected by the slope drains.

6.5 Surface water from adjacent land should be removed using drains at the top of cuttings, if the landfall is toward the highway, and drains at the base of embankments to keep water away from the toe of the slope. This will prevent water entering the slope.

6.6 Where space allows, embankments and cuttings can often be stabilized by the provision of toe loading berms. The slope covered by a berm must be benched and any soft material at the toe removed, working in short sections to maintain stability. A drainage layer must always be provided at the back of and below the berm: the drainage layer underneath the berm must be sloped eg 1 in 15 to allow water to drain away from the slope towards the drain at the toe of the slope. The berm must, of course, have a slope angle appropriate to the stability of the material used.

6.7 Soil nailing can be used to improve the stability of existing slopes and is described in HA 43 (DMRB 4.1).

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6.8 Once vegetation has become fully established, it is likely that deep-rooted trees and shrubs can help to prevent the occurrence of some shallow failures (19). However, vegetation on its own may not provide sufficient support for some materials at steep slope angles especially in the early days of growth. Great care must be taken to prevent ingress of water into the slope through the pits used for planting vegetation. In order to prevent water ingress along distinct lines at which failure may be initiated, the planting of trees and shrubs should be staggered. The selection of trees and shrubs, including considerations of species and size, will need to take into account their beneficial and detrimental effects, including environmental aspects and their effects on the stability of the earthwork. Also, the planting of trees and shrubs requires careful consideration in relation to drains. The disruptive nature of the rooting system and possible blocking of drains can be counter productive. In deep cuttings, drainage is usually present on berms and the planting of trees which could affect the drains should be avoided. Trees may also inhibit access where required on berms. In all cases, the advice of the Overseeing Department's Regional Horticultural Officer or Landscape Architect should be sought at the earliest possible stage.

Rock Slopes

6.9 In cuttings, individual blocks of rock, which show signs of distress and which were not treated at the construction stage, can be stabilized using active rock reinforcement. This covers mechanically anchored rockbolts, grouted or friction - anchored dowels and grouted cables. Passive rock support, which includes shear dowels, straps, mesh and shotcrete, can also be used (20).

6.10 With time, seepage areas may become more obvious and further drainage may be necessary. The type of drainage will depend on the amount of seepage and whether it requires draining at the face or some distance behind the face.

6.11 Erosion of soft rocks layered between hard rocks may be prevented using 'rock dentition'. With this technique, the weathered rock is removed and the remaining material buttressed with more durable blocks of rock (1). Rock dentition can also be used to prevent failure of soils infilling voids in steep rock faces. Drainage should be provided behind rock dentition, using drainage material and weepholes for removing any water.

6.12 Erosion of extensive areas of steep soft rock slopes, where vegetation has not become established and topsoil cannot be laid, may be reduced by laying and pinning geotextiles, including jute, on the slope to provide a stable mat on which vegetation can become established (19).

6.13 Smooth-wall blasting is sometimes used for reducing the danger of rockfalls from a rock face which has been heavily blasted or where jointing has created loose blocky conditions on the face (7). The technique involves firing two sets of explosives down boreholes in the rock. One set provide the main blast while a second set of closely spaced holes, which are in line parallel to the face and further into the rock mass, provide the final design slope. Unlike pre-split blasting, the main blast is fired before the firing of the line of holes.

6.14 Preventing topsoil failures on rock fill in the long term (see Paragraph 4.6) may be achieved by providing shrubs whose roots help the soil to adhere to the rock.

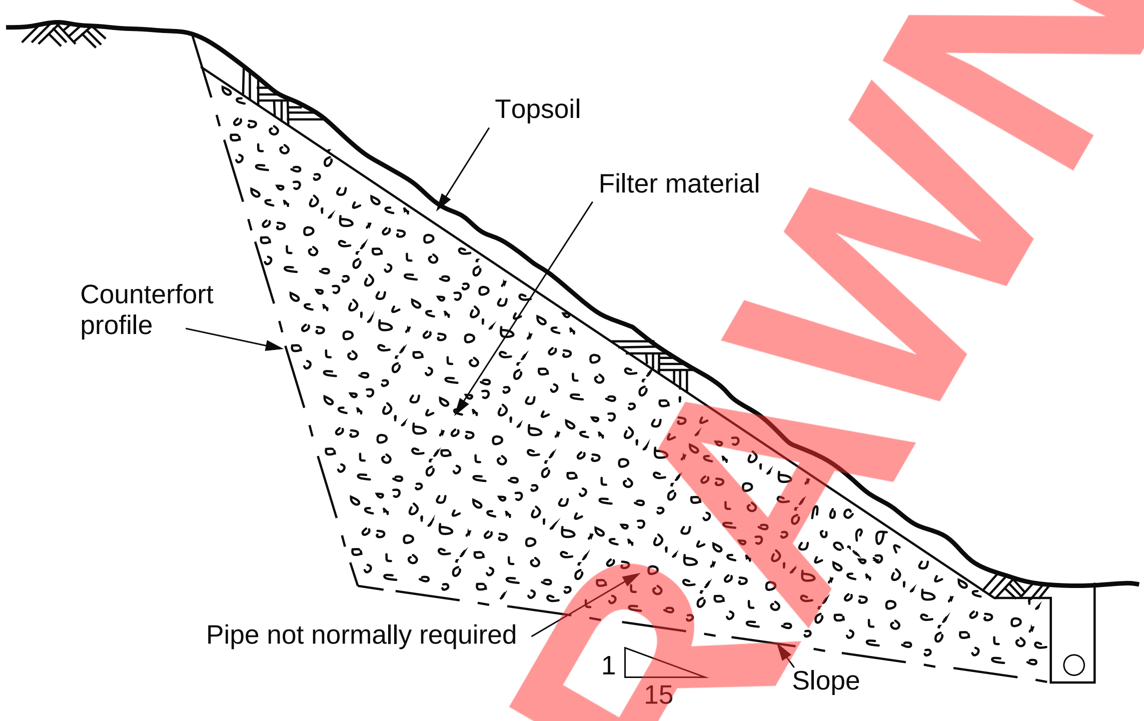

Fig 6/1. TYPICAL ARRANGEMENT OF COUNTERFORT DRAINS

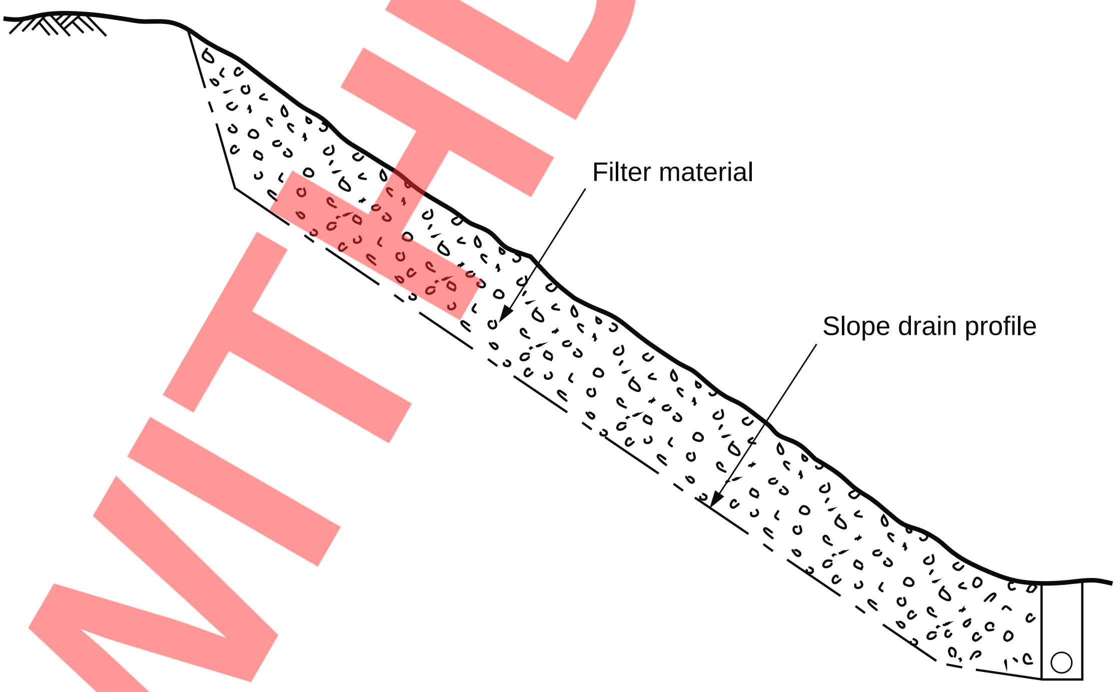

Fig 6/2. TYPICAL ARRANGEMENT OF SLOPE DRAINS

7. FEEDBACK, ANALYSIS AND DESIGN OF SLOPE REPAIRS

Reporting Failures

7.1 All embankment and cutting slope failures, or potential failures, on trunk roads should be reported without delay using Form A (Appendix A) to the Overseeing Department. The same failures should also be recorded in the Quality Control Reporting System (QCRS) in an abbreviated version. In these situations, the use of a geotechnical specialist should be considered, particularly where the stability of the road or adjacent properties are involved. This specialist will determine the scope of any investigation, the need for monitoring and prepare a report with recommendations for remedial treatment.

Analysis

7.2 Slips which involve large volumes of slipped material, and present a threat to the stability of the road or adjacent property, require a fully reported geotechnical investigation and stability analysis. The soil and rock type, ground profile, pore water pressure, ground properties and failure mode must be established before designs for repairing the slip and improving the future stability can be prepared. If, however, stability is required as an emergency measure, toe loading or toe restraint may be the only immediate solutions.

Design of Slope Repairs

7.3 Designs are assessed by calculation of a factor of safety from stability analyses (21). The choice of minimum factor of safety that will be required to be met by the design will have some influence on the type of reinstatement and vice versa. A higher factor of safety may be needed for some designs involving mechanical stabilization (eg gabion wall or reinforced soil) than for slope flattening, as the number and extent of uncertainties in the former case can be greater. Solutions involving mechanical stabilization do, however, have the advantage of requiring less landtake. Depending on the type of reinstatement chosen, either technical approval or geotechnical certification procedures may need to be followed. Further advice on this is given in Advice Note HA 43 (DMRB 4.1).

7.4 Form B (Appendix A) should be used when proposing the remedial works to the Overseeing Department. Some repair methods are described in Chapter 8. These may be used to reinstate the more common, and usually less critical, shallow failures described in Paragraph 2.1.

8. REINSTATEMENT OF SLOPE FAILURES

Categories of Reinstatement

8.1 Slips can be categorized for reinstatement purposes as follows:-

Category (i) Those which require prompt action because of imminent danger of large movements affecting the carriageway and associated works, nearby structures, including those belonging to others, or statutory undertakers services.

Category (ii.1) Likely to develop into Category (i) within a few weeks if weather conditions are adverse.

Category (ii.2) Likely to be stable for a few weeks but may become unstable within a few months if weather conditions continue to be adverse.

Category (ii.3) Tolerable for a year; unlikely to affect third parties.

Category (iii) Most unlikely to affect areas outside the slope; will not affect carriageway, services or any property for many years.

8.2 Categories (i) and (ii) are similar to those given in the Overseeing Department's Code of Practice for Routine Maintenance. Category (ii) has, however, been sub-divided to cover more specific time-scales of failure. An additional category, Category (iii), has been included in order to cover long-term observations, outside the yearly cycle of routine maintenance. These categories should be used when completing Form A (Appendix A) to aid maintenance programmes.

General

8.3 Slipped material resting at the toe of the slip will help to stabilize the slope and therefore must not be removed until the repair of the slope is in hand, unless other temporary support, such as sheet piling, can be substituted. Essential matters to be considered as part of the reinstatement, include the sequence of site operations, the handling of materials and the location of plant accesses. To overlook these in design may reactivate the instability and create dangerous hazards. Risks may be minimized by reconstruction in alternating bays across the width of the slip.

8.4 A number of different repair techniques are described in References (18) (22) and (23). The engineer should select the most appropriate taking account of cost, additional landtake, availability of materials, construction plant, supervising personnel, access to the site and available space on the site. All the techniques are regarded as options to regrading the slope to a flatter profile, which can be costly and often time consuming in obtaining additional land.

8.5 It is important that the site is properly prepared by excavating below the softened debris and benching into the remaining stable material. Failure to do this may result in subsequent slips behind the reinstatement. Drainage measures also require careful consideration at each location.

8.6 The use of over-consolidated clays should be avoided where possible in slopes with an angle of 1 in 3 or steeper. Where they are used at steeper slope angles, the maintenance requirements must be recognised or measures included, such as soil reinforcement, to maintain stability as softening occurs. Attention to details such as the selection of more stable soils for the slope batters, adequate compaction of the slope and control of seepage water will help to reduce the incidence of instability.

8.7 During reinstatement work, requirements for working spaces and safety zones must be observed. Some of these are contained in the Traffic Signs Manual Chapter 8 (24) and in the Note for Guidance on Safe Working on Trunk Roads and Motorways (25).

Granular Replacement

8.8 A cross-section through a typical repair is given in Figure 8/1, the sequence of operations being:

i. excavate to below the slip surface, remove all soft material and form benches at a slope of 1:15 say;

ii. place and compact free draining fill material;

iii. form the finished profile of the compacted fill making allowance for topsoiling;

iv. restore construction plant access ramps where used;

v. spread topsoil and seed.

8.9 The use of coarse gravel or broken bricks or stone without topsoil may not be aesthetically pleasing and has been criticized by the Landscape Advisory Committee (26). It will be necessary to ensure that water entering the granular fill is not allowed to collect on the underlying surfaces of cohesive soil (see Figure 8/1).

8.10 Consideration must be given to the stability of the topsoil placed on completion of a slope repair. Where the topsoil exceeds approximately 150mm thickness it may be necessary to provide a method of retention to maintain the topsoil on the slope. The means of such retention should ideally be biodegradable and will be a short term measure until the vegetation is established.

Geogrid Containment

8.11 Reinstatement by geogrid containment (Figure 8/2) strengthens the slope by wrapping about 1m thick recompacted layers of slipped material in geogrid envelopes (3). Initially, the bottom bench is cut and the material stockpiled nearby; a drainage blanket is then placed. The geogrid roll is laid over the drainage blanket, with the end pinned at the back by pegs and then unrolled over the filter drain. A layer of clay from the next higher bench is then placed on top of the geogrid and compacted. Successive layers are placed and compacted until the recompacted clay is level with the base of the second bench. The geogrid is then unrolled up the face and over the recompacted clay onto the second bench. It is then cut off at the rear of the bench, pulled tight and pinned down at the back. The procedure is repeated for all benches and the complete envelopes topsoiled. A wedge of granular material is used to complete the repair and the remaining surface topsoiled. In some cases when the slope is not high and only a few benches are to be used, all the benches may be cut in one operation.

8.12 The geogrid return at the face of the slope may, for ease of construction, be omitted and replaced by intermediate layers of geogrid (23). However, this is only recommended for slopes that, although reinforced, can retain topsoil and resist erosion.

8.13 If material is too wet to be compacted, it may be possible to dry it if the weather conditions are suitable. It may sometimes be possible to replace the wet material with borrow material from within the highway boundary. Where borrow material has to be imported from a distance, suitable cohesive material may be more readily available at a lower cost than granular material, but the latter will be easier to handle, particularly in difficult locations. Alternatively, some wet unworkable soils can be modified by mixing them with lime. Lime modification, where short-term improvement in workability, placing and compaction is achieved primarily by an increase in plastic limit, is the prime improvement mechanism in this application. Lime stabilization, where cementitious products are produced in the long-term, will also add to the strength of the soil in the reinstatement. For lime modification, ambient temperatures are not critical; for lime stabilization, however, ambient temperatures are a very important consideration as the strength developed due to the long-term pozzolanic reactions increases with temperature. HA 44 (DMRB 4.1.1) gives more details on lime modification and lime stabilization. It is essential that tests for total sulphate content be conducted as the reaction between sulphates and lime can lead to the formation of expansive minerals. HA 44 (DMRB 4.1.1) has details on limits of total sulphate content. There have been no reported problems with heave of slope reinstatements, although problems have occurred with lime stabilized capping (27).

Gabion Wall

8.14 Reinstatement using a gabion wall (Figure 8/3) is another possible method of repair (3). A foundation bench is cut with a slope of 1:15 (vertical:horizontal) towards a filter drain to reduce the possibility of water build up behind the wall. A layer of gravel is placed and compacted on the bench tapering down from the front edge to the back. This ensures that the gabion wall is inclined slightly into the embankment or cutting to give greater stability.

8.15 The gabions are then filled with stone which has been selected and broken where necessary to give good packing. The gabion should be slightly overfilled to allow for settlement, the top levelled by hand and the lid pulled down tightly and tied together. A filter fabric at the back of the gabions may be required for fine granular backfills in order to prevent fines migrating into the granular fill of the gabions. To produce a flat surface for the next layer of gabions, pea gravel may be spread over the completed gabions. Once the repair is complete the slope above the wall should be topsoiled.

Crib Wall

8.16 Crib walls may be used to retain the base of a repair and allow the slope above to be made less steep (Figure 8/4). Granular materials must always be used within the crib wall and behind it. A foundation wall is cut at the base of the slope with a slope of 1:15 towards a filter drain to drain the material from within the crib units and the granular backfill. A layer of gravel is placed on the foundation and tapered from the edge to the back. This will control the angle of the face of the completed wall and so must be considered in the design of the wall. A layer of crib wall units and granular backfill is then placed on the gravel and the wall built up layer by layer until the wall reaches its full height. The slope above the wall is then completed at a shallower slope angle than the original using imported clay and granular backfill and finally topsoiled.

8.17 The crib wall units are interlocked as the wall is built. The crib wall, with infilling granular material, functions as a gravity structure to resist the soil pressures from the backfill.

Treatment With Lime

8.18 Reinstatement of slipped clay material by lime treatment is achieved by mixing in about 3% by weight of quicklime (18). This will usually convert weak wet cohesive materials into soil suitable for replacement and compaction and give acceptable long-term stability (ie lime modification and lime stabilization; see Paragraph 8.13). The lime can be mixed into the soil by the action of the plant used for excavation and reinstatement. It is suggested that 50% of the lime is placed directly on the slipped soil before excavation and the remainder added when the material is redeposited, but before compaction, without any special mixing. The degree of mixing required will be achieved by the plant replacing and compacting the soil.

8.19 Appropriate precautions will be needed to minimize the spread of dust. Experience has shown that there is less dust hazard using quicklime in bags than in bulk. Quicklime is generally preferred for this application since it has a greater drying action than hydrated lime. However, quicklime in bags is more expensive than in bulk.

8.20 The Moisture Condition Test (28) can be used to assess the compactibility of the lime/soil mixture, moisture condition values in the range 10 to 12 are normally suitable. Because of the long-term pozzolanic reactions which may take place between the lime and the soil, a gradual increase in strength may occur, allowing the reinstated material to provide some buttressing effect. Using only lime to reinstate slope failures is a relatively new technique and the long-term performance has not been fully assessed. It is possible, for example, that the clay may not have been sufficiently mixed with the lime so that sufficient additional softening of the intact clay can still occur to cause a further failure. Also lime might leach out from the mixed material in the long-term.

8.21 Cement can be used as an alternative to lime. It is more easily mixed with granular soils than cohesive soils and is therefore less likely to be an appropriate repair for the slope as less failures occur in granular materials.

Anchored Tyre Wall

8.22 Anchored tyre walls have only recently been used in the UK. The few that have been constructed include an experimental anchored tyre wall on the A45 in Cambridgeshire (18) and a larger wall at a motorway junction on the M62 near Bradford (29). Reinstatement using an anchored tyre wall (Figure 8/5) involves constructing a wall at the toe of a slope using old car tyres. The side walls of the car tyres are cut away and then they are tied together in layers, and connected at intervals to anchor tyres buried in the embankment or cutting. A filter drain should be constructed at the toe of the slope to collect water from a drainage layer beneath the wall, thus reducing the possibility of water build-up behind the wall.

8.23 The bottom row of tyres is laced together with corrosion resistant flexible straps which are also looped over the anchor tyres at the back of the trenches and tightened. The second layer is then placed with each tyre being staggered longitudinally by half a diameter. Fine granular material is placed in and behind the tyres and in the trenches and levelled and compacted. This procedure is repeated with alternating layers being laced together and tied to anchors: the number of anchors required will depend on the resistance required to ensure stability of the wall. Loose topsoil is allowed to trickle down the front face of the wall to encourage the growth of vegetation. The area above the wall is then backfilled with general fill and formed to a less steep slope angle. The ends of the wall are contoured into the existing slope and the whole repair above the wall is topsoiled.

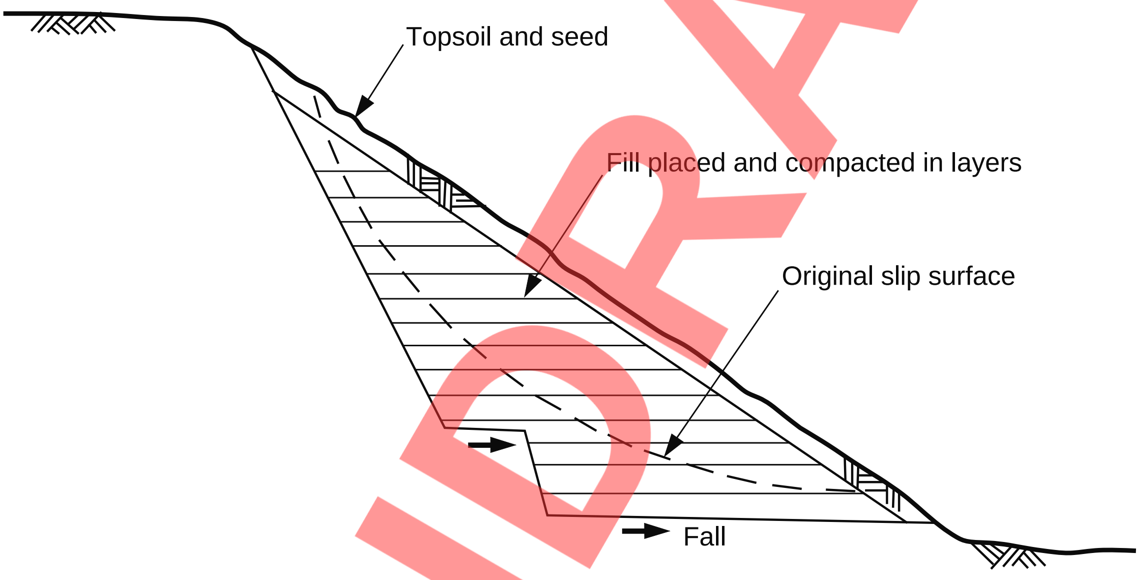

Fig 8/1. TYPICAL GRANULAR REPLACEMENT REPAIR

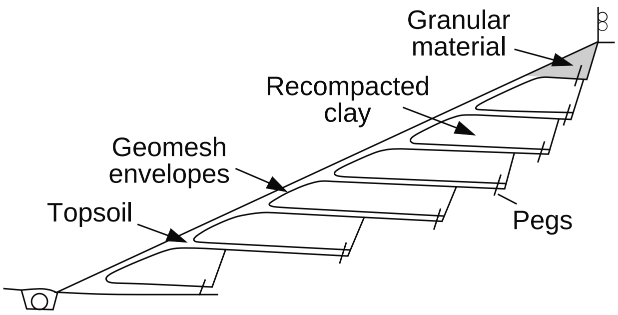

Fig 8/2. GEOGRID CONTAINMENT

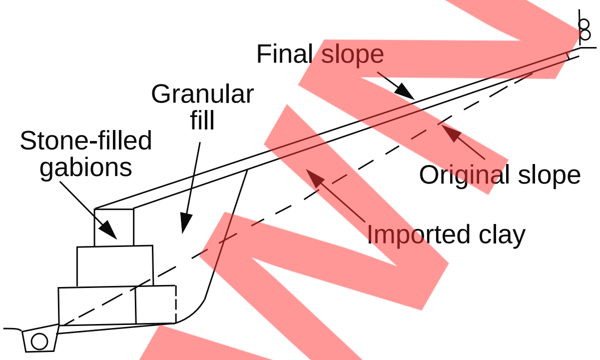

Fig 8/3. GABION WALL

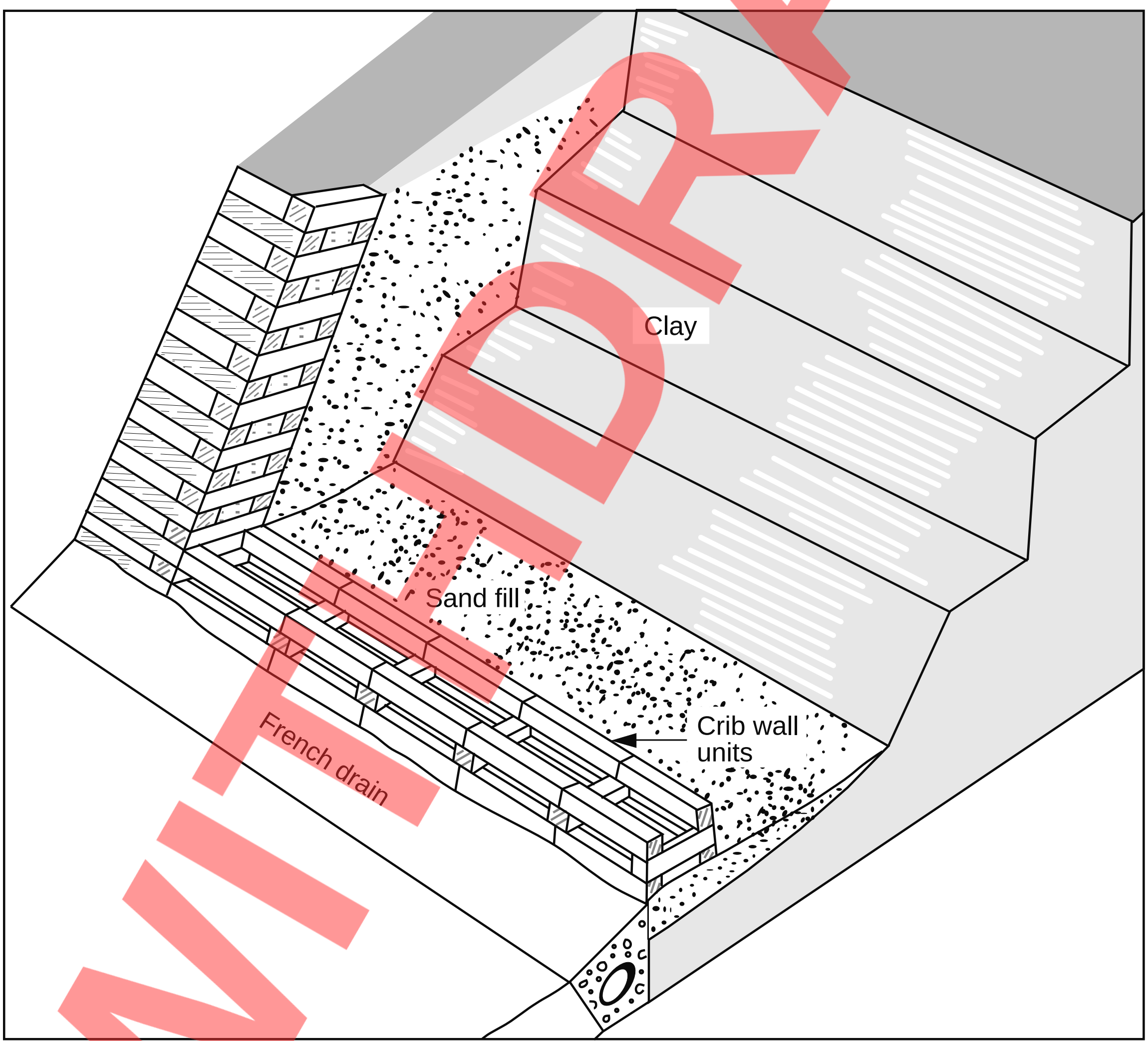

Fig 8/5. SECTIONED VIEW OF CRIB WALL

Fig 8/5. SECTIONED VIEW OF ANCHORED TYRE WALL SHOWING LACING LAYOUT

9. POTENTIAL PROBLEMS AND HAZARDS WITH DOMESTIC AND TOXIC WASTES

Settlement

9.1 Some long-term settlement of earthworks which cross landfill sites, such as domestic refuse tips, should be expected. This may result from consolidation, compaction or decomposition of putrescible material and can occur on sites which were treated, such as by dynamic compaction of the foundation, at the construction stage. Indications are that the amount of settlement after construction would be small for a site that has been treated effectively (30) but the amount of settlement will depend on the composition of the tip and the amount of putrescible material present, the position of the water table and the degree of compaction.

Landfill Gases and Leachates

General

9.2 The local Environmental Health Officer and the appropriate Overseeing Department must be contacted and consulted if high levels of gas or leachate are discovered or if it is necessary to treat any toxic waste material located within the highway boundary or adjacent to it.

9.3 Guidance notes have been published by the Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL) covering hazards from the redevelopment and assessment of contaminated land (31), landfill sites (32), gaswork sites (33), sewage works and farms (34), scrap yards (35), fire hazards from contaminated land (36), asbestos (37) and metalliferous mining sites (38).

Monitoring

9.4 For earthworks on, within or near to potentially hazardous landfill sites, monitoring for the presence and concentration of gases and leachates is necessary as part of routine maintenance procedures to ensure that they are safe.

9.5 The frequency and type of monitoring will vary from site to site and will depend on a number of factors including:

i. the age of the site;

ii. the nature of the waste materials;

iii. whether the amount of gas or leachate constitutes a hazard or nuisance;

iv the results of previous monitoring;

v whether control measures have been installed;

vi the geology and hydrogeology of the site.

9.6 It is recommended that all earthworks through potentially hazardous landfill and contaminated land sites should be monitored and databases formed from the information obtained. Waste Management Paper No 27 (39) gives details of monitoring methods, equipment and monitoring programmes for different gases and should be used as a guide.

Landfill gases

9.7 The principal gases produced by refuse tips are methane, which on its own is lighter than air, and carbon dioxide, which on its own is heavier than air. Both gases are odourless and colourless (41). Although landfill gases move towards the atmosphere by a number of mechanisms, the proportions of carbon dioxide, methane and air in the emerging gas mixture, and the gas and ambient air temperatures will affect the buoyancy of the gas mixture. As a result it should not be assumed that all mixtures containing methane will always be lighter than air and that for example an open trench will not collect methane in the presence of significant amounts of carbon dioxide. When mixed with air, methane and hydrogen are flammable and explosive as defined by Waste Management Paper No 27; hydrogen may be produced in the early stages of decomposition of a tip. The production of landfill gas in significant quantities depends critically on the nature of the landfill materials. Material with a high putrescible content, particularly domestic and garden refuse, and paper will produce large volumes of gas. Material such as demolition rubble may produce some gas due to incorporation of some organic matter, but it is unlikely to produce significant quantities.

9.8 Landfill gases can migrate considerable distances and are not necessarily confined to adjacent areas. Caution must therefore be exercised when a road is near to a landfill site as well as when next to it. Of particular relevance is the ICRCL Guidance Note 17/78 (32) which contains advice and guidance on matters relating to the presence of landfill gas and other hazards associated with sites of this nature. Monitoring of gases should be conducted in drainage systems, electrical cabinets and any other enclosed areas where gas could collect. Suitable monitoring equipment is described in Waste Management Paper No 27 (39). Extreme caution is required when entering enclosed chambers as gas may have collected in sufficient amounts to produce an explosion or cause asphyxiation. The guidance given in Health and Safety Executive (HSE) Guidance Note GS5 must be followed (40). Warning signs and notices on or under drainage covers indicating that noxious gases and leachates had been detected at that location would be a useful way of warning maintenance teams. Maintenance teams should receive appropriate training and clear instructions before inspecting areas where gases could be found.

9.9 If gas production constitutes a risk, monitoring within wastes must be continued until gas production has fallen to below the level of the risk. It must therefore continue until the maximum concentration of flammable gas from the landfill gas remains less than 1% by volume (20% of the lower explosive limit - LEL) in air and the concentration of carbon dioxide remains less than 0.5% by volume in air measured in any monitoring point within the wastes over a 24 month period taken on at least four separate occasions. (The lower explosive limit (LEL) is defined as the lowest percentage by volume of a mixture of flammable gas with air which will propagate an explosion in a confined space, at 25 C and atmospheric pressure.) An appropriate number of representative points should be monitored to ensure that gas generation and migration is no longer taking place (Ref 39 Section 7.8).

9.10 In confined spaces, if methane is found in excess of 0.25% by volume (5% of the LEL) or carbon dioxide is found in excess of 0.5% by volume (Ref 39 Section 7.13) or any other minor gas constituent is found in excess of recommended or control limits produced by the Health and Safety Executive (42), all relevant statutory bodies should be informed immediately. These statutory bodies include the Highway Authority, Local Environmental Health Officer, waste disposal authority and the Health and Safety Executive.

9.11 Gas released directly to the atmosphere through a slope is unlikely to cause an explosion due to the slope being well ventilated.

9.12 Dead vegetation could be an indication of gas percolating to the slope surface. In such cases, remedial measures to vent the gas may be necessary. Vents installed to remove gases when the road is in service should be checked regularly to ensure they are clear and operating satisfactorily. Where vegetation has been killed by gas or leachates, remedial measures may be necessary to prevent topsoil erosion.

9.13 If landfill gases are found during the monitoring of a highway near or adjacent to a landfill site, control measures will be required to ensure the gases are released safely into the air, at a distance from the road and without accumulating in confined spaces. The design of the control measures are likely to be site specific but the key requirement in all systems must be to have adequate protection against failure.

9.14 If gas is migrating from a nearby dormant landfill site not owned by the Highway Authority, then the legal responsibility for the control of gas emissions entering the highway lies with the land owner under his obligations under civil law, that is a duty of care. However, this does not negate the responsibility of the Highway Authority once the gas is within the highway boundary and control measures will need to be taken. If the Highway Authority owns the land producing the gas the responsibility is clear and there is a public duty to uphold. On landfill sites that are active, site operators are responsible under legislation for emissions.

9.15 For low volumes of gas, in the early and very late stages of landfill gas generation, passive venting is usually adequate to maintain safe gas levels. Passive gas wells consist of a perforated or slotted pipe of the order of 225mm diameter set in no-fines aggregate within the waste material and capped with a seal. The height and design of the vent above ground will depend on the proximity of the road, service ducts and the drainage system, associated with the requirement of preventing accumulation of gases in any voids. Also, the vent's design will need to include measures to prevent vandalism. The gas wells are the outlets for gas from all levels within the waste material. They are usually located at the top of cutting slopes, to divert gas away from the road and slope, and at the base of embankments to intercept gases. From a safety point of view, these locations also ensure that the wells are away from the road itself.

9.16 Gas drains are an alternative to gas wells. They consist of about one metre square cross-section trenches filled with crushed aggregate or stones. The gas drains are laid at the surface of the waste material, for example on a cutting slope in landfill or at the base of a shallow embankment on landfill which has gas accumulating within the road structure or drainage and service ducts. In some circumstances, the gas drains may act as leachate drains and care must be taken to ensure that the leachate is disposed of to a separate treatment works and not allowed to enter a watercourse. Gas drains can become distorted, may be flooded by perched water tables or may not intercept all levels of waste as occurs with gas wells. They do however disperse gases over a large surface area. They can be useful for low volume gas productions on slopes in cuttings.

9.17 Where large volumes of gas are being produced, during the middle phase of landfill gas generation, or where a controlled system is required, such as at a motorway service area, active gas systems will be required to ensure safe gas levels. These consist of deep wells connected to a gas pumping system which is monitored and controlled to ensure overpumping does not occur which will draw air into the waste material and produce confusing monitoring results. This type of system is quite complex and will require careful design depending on the use of the site. For these reasons a specialist should be consulted to design and advise on the operation and maintenance of these types of system.

Leachates

9.18 Drainage designed to carry only leachates should be checked for leakages to avoid contamination of adjacent land and aquifers. The leachates should be directed away from the carriageway drainage system and safely collected and transported to a treatment works. Signs of seepage on cutting slopes through tips should be investigated and if harmful leachates are detected remedial measures will be necessary.

9.19 Drainage systems may also receive noxious substances from adjoining land where, for example, fly tipping has occurred or development has disturbed an old landfill site. Such events should be noted by maintenance teams and reported to the local Environmental Health Officer who should be able to give advice.

9.20 The National Rivers Authority (NRA), as well as the local Environmental Health Officer, will require notification of any sites where leachates are being removed by highway drainage.

9.21 British Standard BS 6068 (43) and Draft for Development DD 175 (44) give details on tests and sampling methods for leachates. It may be necessary to carry out a number of different analyses on leachates, for example heavy metals, diesel, pH, and chloride.

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10. SPILLAGES OF NOXIOUS SUBSTANCES

General

10.1 Spillages of noxious substances fall into two categories.

i. Major single spillages, ie when a tanker overturns and spills its contents.

ii. Minor persistent spillages, ie frequent small oil and petrol leaks from traffic.

Major Single Spillages

10.2 Headwalls in drainage ditches with a pipe running through them allow National River Authority (NRA) incident control officers or emergency services's personnel to block the pipe with expandable bungs, or by other means, and hold back major spillages within the ditch until the fire brigade has completed its treatment. Oil interceptors installed as pollution traps for surface waters will retain quantities of oily substances and other liquids lighter than water and not miscible with it. Oil intercepters should be adequately vented: in many cases ventilated covers will have been fitted. Interceptors and silt traps need to be emptied regularly, at the intervals given in the Overseeing Department's Code of Practice for Routine Maintenance (4), to ensure they are effective. Accumulated pollutants at the outlet of balancing ponds should be contained and removed.

10.3 In order to assist the emergency services when dealing with spillages and subsequent treatment, all pollution control devices, such as interceptor cut-off valves, should be clearly identified. Manholes should indicate the direction of flow and the pipe arrangement. A contact within the Maintenance Agent should also be ascertained to aid identification of pollution control devices.

10.4 Long-term migration of volatile products from old spillages may enter the drainage systems and so the precautions detailed in Chapter 9 should be taken when entering confined spaces. Drainage design should be such as to prevent these products reaching watercourses in dangerous concentrations but inspections and regular emptying, as described in the Overseeing Department's Code of Practice for Routine Maintenance (4), are essential to the continued satisfactory operation of drainage systems.

11. PROBLEMS WITH EARTHWORKS IN AREAS OF ARGILLACEOUS ROCK AND COAL BEARING STRATA

11.1 The use of limestone aggregate as a drainage material with general fill composed of argillaceous rock, or layers of limestone or chalk on an argillaceous rock subgrade may lead to two major problems. Firstly, gypsum may form as a result of oxidation of pyrite within the argillaceous rock and the presence of limestone. This may lead to drain blockages and heave of the road structure. Secondly, the reaction leading to the formation of gypsum also generates carbon dioxide which may collect in confined spaces and at the bottom of trenches. Consequently, wherever there are combinations of limestone and argillaceous rock, safety procedures for entering confined spaces and trenches must be observed in order to avoid the risk of asphyxiation (see Chapter 9). If it is thought that gases could possibly be generated in a particular situation, monitoring should be conducted to study the extent and magnitude of the potential problem. Remedial measures, such as ventilating or sealing, may be required as a result of the monitoring.

11.2 Oxidation of pyrite in argillaceous rock, as well as producing sulphuric acid which reacts with calcium carbonate in limestone to form gypsum as described in 11.1, produces ferrous sulphate which can also lead to blocked drains. The ferrous sulphate oxidises to ferric hydroxide in drains and can precipitate as an ochreous deposit. This may cause blockage of the drains and the unsightly orange staining in ditches. The sulphuric acid, ferrous sulphate and its ochreous deposit may attack concrete or cause pollution of watercourses.

11.3 Another possible source of methane in drains, other than from landfill sites, is from old shallow coal-workings and coal seams. Again, in these areas, the procedures for entering confined spaces must be observed. Monitoring and remedial measures may again be necessary. Settlement may also result from the collapse of old mine workings.

11.4 It should not be assumed that the Coal Measures are the only source rocks of methane. Other geological strata produce methane, and these include argillaceous beds and coals in the Namurian (eg Millstone Grit Series and Limestone Coal Group) and Jurassic (45). Other permeable non-carbonaceous materials such as jointed limestones and sandstones may act as reservoirs for methane as a result of migration from a source rock.

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13. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:-

Head of Highways Engineering Division The Department of Transport St Christopher House Southwark Street London SE1 0TE	N S ORGAN Head of Highways Engineering Division

The Deputy Chief Engineer The Scottish Office Industry Department Roads Directorate New St Andrew's House Edinburgh EH1 3TG	J INNES Deputy Chief Engineer

Head of Roads Engineering (Construction) Division Welsh Office Y Swyddfa Gymreig Government Buildings Ty Glas Road Llanishen Cardiff CF4 5PL	B H HAWKER Head of Roads Engineering (Construction) Division

Assistant Chief Engineer (Works) Department of the Environment for Northern Ireland Commonwealth House Castle Street Belfast BT1 1GU	D O'HAGAN Assistant Chief Engineer (Works)

Orders for further copies should be addressed to:

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FORM A SLOPE FAILURE REPORT

To:

Maintainance Agent Ref

Overseeing Department Ref

Road
Location
(km post or chainage)

From:

Embankment ☐ Cutting ☐ Natural ☐

Slope 1 in ____________

Total height ____________m

Width affected ____________m

Date of Report

Date of Slip (if known

CATEGORY OF SLIP

Dimensions: Estimated ☐ Measured ☐

SKETCH OF FAILURE
(include if possible:-
approx dimensions, soil types, drainageat top and bottom of the slope, and drainage on the slope, type of failure)

SPECIAL FEATURES
(ie water seepage, broken pipes, type of vegetation, service ducts, carriageway affected etc plus any special features to improve stability, walls, reinforcement, nails etc)

DETAILS OF ANY PREVIOUS INSTABILITY
(including details of any previous remedial measures)

LIKELY CAUSE OF SLIP

RISK **(a)** to road
(b) to adjacent property

COMMENTS

FORM B REMEDIAL WORKS PROPOSAL

To:

Maintainance Agent Ref

Overseeing Department Ref

Road
Location
(km post or chainage)

From:

Date
Date of Failure Report (FORM A)

SKETCH OF REMEDIAL PROPOSALS
(Give details of materials to be used including volumes)

INVESTIGATION WORK PROPOSED (if any)
(Please submit detail)

ASSOCIATED DRAINAGE WORKS

PLANT LIKELY TO BE USED

ACCESS ARRANGEMENTS

COST ESTIMATE
(Give breakdown as necessary)

PROPOSED DATE OF REPAIRS

COMMENTS

Agreement in Principle (signed)... Date ....
(Geotechnical Engineer)

Agreement to proceed with works (signed).. Date ....
(Area Engineer)

INSTALLATION OF SLIP INDICATORS

1. DESCRIPTION AND PRINCIPLE OF OPERATION

1.1 A slip indicator is a tube inserted into the ground which passes through a potential slip plane in order to determine the depth of movement. Movement of the soil mass distorts the tube preventing the free passage of a thin heavy rod suspended by a cord within the tube. If a rod is left at the base of the tube, it may be pulled up using the cord to the underside of the distortion. A second rod may then be lowered down the tube until it is stopped by the upper part of the distortion. The mean of the two distances gives the approximate depth of the slip plane. If the difference between the two distances is excessive, when compared to the height of slope, it may indicate that movement is occurring at more than one depth.

2. FORMING THE HOLE FOR THE INDICATOR TUBE

2.1 Several techniques are available as follows:-

a. Shallow Depths and/or Non-Stony Ground

Two methods which have been used are:-

i. A hole is preformed with a Mackintosh probe tool or similar instrument and then the slip indicator tube inserted.

ii. Flush-jointed tubular steel auger sections provided with a point, and of internal diameter sufficient to accept the slip indicator tube are driven to below the required depth and the plastic tube inserted. The auger tubing is then withdrawn leaving the plastic tube and point in position. This method is described by Waters and Bartlett (46).

b. Greater Depths and/or Stony Ground

The slip indicator is installed in an augered borehole, typically 75mm or 100mm diameter, produced by hand augering or by using a portable motorized continuous flight auger.

3. PREPARING AND INSERTING THE INDICATOR TUBE

3.1 Any type of rigid walled plastic pipe with a bore from 10mm to 20mm will be suitable for use as an indicator pipe. Suitable lengths of pipe should be prepared, sealed at one end and fitted with a rubber bung at the other end. Flexible plastic tubes must be fed into the borehole through a sleeve of larger diameter stiff sectional tubing. The annular space between the slip indicator tube and the sides of the borehole must be backfilled with a suitable dry sand and this should be compacted by tapping the sleeve as it is withdrawn. The sand fill will then support the tube and prevent binding.

3.2 The steel rods should be the longest which can pass through the tube without being trapped after installation: 6mm diameter mild steel rods each 300mm long, with a hole at one end for attachment of a strong nylon, or similar, line, have been used successfully. One rod should be left at the bottom of the tube attached, by a line of known and recorded length, to the rubber bung at the top of the tube. A second rod should be available for lowering from the surface. The depth of the slip plane is determined from the mean of the depths between the indicator below and the indicator above the slip plane.

4. ALTERNATIVE METHODS

4.1 When a drilling rig is available, larger tubes, such as agricultural clay tile or corrugated plastic pipe, may be inserted into the borehole before the casing is withdrawn. The slip plane, when formed, may then be plumbed. An undisturbed sample may also be taken through the slip layer where the clay tile or plastic tube has been sheared.

Inclinometers provide a sophisticated means of measurement including the measurement of small deformations (47). They can, however, be quite expensive especially when it is necessary to measure deformations at great depths. If the slip is active, the access tube for the sensor probe can become kinked even if the amount of deformation is small. This may prevent the sensor from passing down the tube or disorientate the sensor. Inclinometers, therefore, require installation and monitoring by specialist geotechnical engineers.