Earth Embankment Fissuring Manual

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Binnie Black and Veatch

R & D Technical Report W41

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C W Frith, A M Purcell and A S Powell

Research Contractor:
Binnie Black and Veatch

Environment Agency
Rio House
Waterside Drive
Aztec West
Bristol
BS12 4UD

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Rio House
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Statement of Use
This document is to be used by the Environment Agency in order to identify the extent and effect of fissuring of existing earth embankments using recommended assessment procedures, and to provide guidelines on the control and prevention of fissuring in both new and existing embankments.

Research Contractor
This document was produced under R&D Project 1724 by:

Binnie Black & Veatch
Grosvenor House
69 London Road
Redhill
Surrey RH1 1LQ

Tel: 01737 774155 Fax: 01737 772767

Environment Agency's Project Manager
The Environment Agency's Project Manager for R&D Project 1724 was:
Jon Coultrup - Environment Agency, Anglian Region

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EXECUTIVE SUMMARY

The Environment Agency is responsible for thousands of kilometres of fluvial, tidal and coastal defences within England and Wales, the majority of which are earth embankments.

Earth embankments constructed from clay may develop fissures. Maintenance and repair of these embankments accounts for a significant proportion of the Environment Agency's Flood Defence Budget.

This manual is a guide, for flood defence engineering staff, to the design, construction and maintenance of flood defence earth embankments with regard to the prevention or control of fissuring. It does not cover any other aspect of earth embankments.

Survey results show that there are fissured embankments in every Environment Agency region. The worst affected regions are Anglian, Southern and Wessex. The worst fissuring occurs in areas of high plasticity clays.

There are two forms of fissuring; wide fissures and fine fissures. The former run longitudinally along the crest, are vertical and typically vary in width from 30 to 200mm at the surface. They are typically up to 1 metre deep and are most pronounced during the dry summer months, tending to close up during the wetter winter months. The latter are distributed both horizontally and vertically to a depth of typically 1.2 metres and range in width from a fraction of a millimetre to 2mm. In the body of the embankment they are unlikely to heal during the winter, whereas, those close to the surface may close up. It is likely that, where wide fissures have been identified, then fine fissures will also be present.

The extent of fissuring is dependant upon a number of factors, the main ones being the plasticity index and the moisture content of the embankment material. Vegetation strongly influences moisture content and thus fissuring.

Fissuring has historically been the cause of embankment failure and two potential failure modes are identified in the manual. The first is due to seepage flow through the finely fissured zone. The second is due to a water head in wide fissures in the crest, leading to instability of the landward face during overtopping.

In order to inspect embankments for defects, including fissuring, visual surveys should take place in the late summer or early autumn. A further inspection in the spring is also recommended. Where embankments have been shown to have wide fissures investigations should be carried out to determine the presence, or otherwise, of a finely fissured layer.

The stability of critical embankments should be checked for their design condition allowing for seepage flow through the finely fissured zone and with a head of water in the wide fissures if applicable.

The freeboard allowance for an earth embankment should either include an allowance for the effect of fissuring or remedial works/design measures should be carried out to limit the effect

of fissuring. Suitable remedial works include the use of a hoggin capping layer or impermeable membrane.

Trees and bushes should not be allowed to grow on an earth flood embankment. To limit the extent of fissuring grass should be cut as frequently as possible. This is not always practicable, therefore, it should at least be cut annually to enable inspections of the embankment to be carried out.

An overall policy is required within the Environment Agency relating freeboard allowance to Standard of Service. The actual freeboard allowance should be assessed for each individual situation. Full scale tests to identify the factors governing the reduction in Standard of Service should be carried out.

The effect on future fissuring, of compacting at a slightly lower moisture content than is current practice should be investigated.

The mechanisms governing the evolution of fissures is not fully understood. Neither is the location of wide fissures within the crest. These areas require further research both in the field and in the laboratory.

KEY WORDS

Embankment, Fissure, Crack, Flood Defence, Maintenance, Design, Remedial

1 INTRODUCTION

1.1 Terms of Reference

Binnie Black and Veatch was appointed in February 1996 by the Environment Agency (previously the National Rivers Authority) to carry out National R & D Project, C06(95)04, entitled "Earth Embankment Fissuring". The background to, and the objectives of the project are set out in the following paragraphs.

1.2 Background

The Environment Agency is responsible for several thousand kilometres of fluvial, tidal and coastal defences within England and Wales, the majority of which are earth embankments.

Where clay is available locally it is usually used for embankment construction because of its perceived low permeability and cost. However, clay embankments may develop fissures within them. These commonly occur in the crest and sometimes in the shoulders. (Figure 1 defines some commonly used terms associated with embankments). Fissuring of an embankment may greatly affect its performance and under-estimation of this effect may lead to under-design and over-estimation of the Standards of Service. Over-estimation of the effects of fissuring may lead to over-expenditure. Maintenance and repair of these embankments accounts for a significant proportion of the Environment Agency's Flood Defence Budget.

Flood defence earth embankments are used in various situations; fluvial, tidal or coastal. Each of these categories consists of two types of embankment, those which for the majority of the time are dry on both sides, and those which for the majority of the time are dry on one side and wet on the other, (see Figure 2). Embankments in each category may suffer overtopping at some period during their life. However, coastal embankments may also be subjected to intermittent overtopping by wave wash.

Data for this manual has been obtained from a literature review, an archive review and from responses to three sets of questionnaires. These questionnaires were prepared to target each of the following groups; Environment Agency staff, manufacturers of relevant materials and external consultants.

1.3 Types of Fissuring

Two types of fissuring have been identified; fine fissuring and wide fissuring. These are significantly different from each other in both size and characteristics, but are both referred to as desiccation fissuring (see Figures 3 and 4).

1.4 Objectives

This manual aims to be a guide to the design, construction and maintenance of flood defence earth embankments with regard to the prevention or control of fissuring. It does not aim to be a complete guide to all aspects of the design, construction and maintenance of earth embankments.

The specific objectives of this manual are given below. These are derived from the terms of reference for this project, a copy of which is included as Appendix A.

(i) To identify the scope of the problem by assessing the extent, causes and consequences of fissuring.

(ii) To recommend procedures for assessing an embankment's tendency to fissure and the consequences of any fissuring.

(iii) To identify, describe and comment on the effectiveness of various remedial measures which may be adopted to limit or prevent the occurrence of fissuring and to identify the effect of these measures on the Standard of Service.

(iv) To identify, describe and comment on the effectiveness of various design and construction options, which may be adopted to limit or prevent the occurrence of fissuring, and to identify the effect of these measures on the Standard of Service.

(v) To identify, describe and comment on the effectiveness of maintenance measures and routines, which may be adopted to prevent or limit the occurrence of fissuring, and to identify the effect of these measures on the Standard of Service.

(vi) To make recommendations for further investigations into the cause, effect and control of fissuring.

This manual does not aim to identify specific options for each, but is intended to provide the reader with the knowledge to identify suitable options for any particular situation.

1.5 Readership

This manual has been written with the aim of providing guidelines for Environment Agency flood defence engineering staff, in particular designers and operations staff.

2 SCOPE OF THE PROBLEM

2.1 Introduction

The aim of this chapter is to identify the scope of the problem by assessing the extent, causes and consequences of fissuring of flood defence earth embankments.

The most common failure modes of flood defence earth embankments are associated with one or more of the following:

(i) Seepage through a permeable stratum beneath the embankment;
(ii) Seepage through fissures in the body of the embankment;
(iii) Overtopping of embankments;
(iv) Structural instability eg too steep a slope;
(v) Foundation failure

Fissuring is associated with failure modes (ii), (iv) and (v) above and may be associated with (iii) These modes have been identified as a major feature of many failures of flood defence earth embankments, examples are given below:

- During 1953 many of the earth embankment sea defences of the East Coast of England were breached during an abnormal surge tide. Some of the failed embankments had been overtopped. The remainder had failed without being overtopped. On investigation, the modes of failure of most of these breaches involved fissuring in some form.

- In 1994 catastrophic floods occurred when flood defence earth embankments protecting areas surrounding the Mississippi failed on a massive scale. Reports indicate that fissuring of the embankments was a contributory factor to many of these failures.

Today there is a growing awareness of possible instabilities in embankments due to fissuring. In the UK fissuring of flood defence earth embankments is reported to be extensive, and remedial actions to combat it have already been carried out on some Environment Agency earth embankments. Minor works of this type include the backfilling of wide fissures, cutting back the vegetation and removing trees and shrubs. Major works have been carried out at several locations including Seawick, the Middle Level and South Barrier Banks, East Anglia, and Millbeach to Goldhanger on the River Blackwater.

2.1.1 Seawick

An existing Environment Agency earth embankment at Seawick was raised using locally won clay. A geotextile was laid in the crest 0.5m deep to help prevent fissuring. This measure, however, did not work and fissures reported to be up to 2m deep formed. Further work was then carried out to construct a fully reinforced soil embankment using a geotextile. Fissuring is reported to have been significantly reduced.

2.1.2 Middle Level and South Barrier Banks, East Anglia

Again an existing Environment Agency earth embankment was raised. The existing embankment was reported to be severely fissured and the works were intended to both increase the height of the embankment and to prevent fissuring of the embankment. A geogrid was laid approximately 0.5m deep and it is assumed that this was a measure to help prevent fissuring. The new embankment, however, is only a little better than the original with regard to fissuring.

2.1.3 Millbeach to Goldhanger

The existing embankment was finely fissured and had an insufficient Standard of Service. Works were carried out to strip the top 0.5m of crest and replace it with 1m of hoggin, thus raising the embankment by 0.5m and preventing fissuring of the crest. The works were completed during the summer of 1996 and to date no fissuring has been reported, although it is probably too soon to judge.

2.2 Location

Embankments are normally constructed from immediately available local material or material only a short haul away. It is therefore possible to relate the occurrence of reported fissuring to specific areas of the UK and the associated geology. This data can also be used to predict its likely occurrence and extent.

The geographical extent of fissuring of Environment Agency flood defence earth embankments was identified from responses to the questionnaire. A summary diagram is given as Figure 5. Figure 5 probably shows only the distribution of wide surface fissures, as fine fissures are not very obvious on visual inspection of the surface, especially if the vegetation is dense. However, it is likely that where there are wide surface fissures there are also fine fissures, which may also exist unnoticed. It is also likely that only fissuring which has been a cause for concern has been noted, other fissuring may exist unnoticed. Therefore, the extent of fissuring shown on Figure 5 is likely to be an under-estimate.

Figure 5 shows that the worst affected regions are north east Eastern Anglian, Sussex and Devon. All of these regions have high plasticity clays. There are only a few areas in England and Wales which suffer no reported fissuring, and these are generally where the embankments are constructed of granular materials. It has been estimated that 10% of all flood defence earth embankments throughout the UK are fissured to some degree.

All regions have reported some embankment fissuring to a greater or lesser degree. This manual is therefore relevant to the flood defence engineers of all regions.

2.3 Description of Fissuring

2.3.1 Introduction

Fissuring under normal conditions only occurs in cohesive soils such as clays. Non cohesive soils such as sands will not under normal conditions fissure.

There are two types of fissuring wide fissuring and fine fissuring. Each type has its own characteristics, (see Figures 3 and 4).

2.3.2 Characteristics

Wide Fissures

Wide fissures form soon after clay has been placed, typically within the first year. They open and close seasonally ie open during the summer months and closed during the winter months, and do not reduce significantly with time.

They generally run longitudinally along the crest, (although some have been noted running transversely). They tend to be vertical and are typically 500mm to 1200mm deep and 30mm to 200mm wide. Factors influencing the dimensions include soil moisture content and the plasticity of the clay.

Fine Fissures

Fine fissures form over tens of years and unlike wide fissures are not isolated to one part of the embankment but are distributed throughout the top surface layer to a depth of typically 1.2m. (Regularly wetted surface layers ie wetted at least daily are unlikely to suffer with long term fine fissuring.) They typically range in width from a fraction of a millimetre to 2mm and tend to be both vertical and horizontal. Fine fissuring can be so extensive that the clay between has become nodular and has been likened to pebbles.

2.3.3 Causes of Fissuring

Various literature sources report that both wide and fine fissures are caused by desiccation of the soil. This is further supported by the responses to the questionnaires of Environment Agency staff. These in general report that fissures occur in the dry summer months and close in the wetter winter months.

A desiccated soil is generally considered to be a soil, which under normal conditions, when water is brought into contact with it, some or all of the water will be absorbed. (The soil is said to have a soil moisture deficit.) The extent of desiccation, and thus fissuring, is a function of the soil moisture content and the soil characteristics.

2.3.4 Soil Characteristics

A clay soil, ie a cohesive soil, is one which contains a large percentage of very small mineral particles. It is defined in BS5930:1981 as a soil containing more than 35% clay fraction, ie particles smaller than 0.002 mm. Clays are characteristically plastic, greasy to the touch and stick to the fingers when wet. Dry lumps can be broken but not powdered between fingers.

While clays are defined by the particle size distribution of the constituents, the type of clay mineral influences its behaviour. Soils which do not contain clay minerals will not exhibit clay-like behaviour.

The particle size distribution (clay fraction) and the clay mineralogy influences the volume change and thus the fissure potential of the soil. To a lesser degree the depositional conditions and post depositional history of the soil also influences the shrinkage potential of clays. Reworking of clays for flood alleviation embankments removes the influence of depositional history and depositional conditions; they therefore are not discussed further in this manual.

The percentage clay fraction (the percentage of particles finer than 0.002mm) influences the plasticity of a clay. The greater the clay content, the greater the plasticity index and hence the shrinkage and fissuring potential of the clay.

The clay mineralogy of a soil also has a large influence on the plasticity of the soil. Different clay minerals possess different shaped platelets and thus different abilities to take up water.

Table 2.1 uses the plasticity index and clay fraction to indicate the potential for a soil to shrink and fissure. The soil properties throughout one particular layer of soil may vary considerably and a single soil layer may fit into more than one category in the table.

The plasticity index is the numerical difference, in percent, between the liquid and plastic limits. It indicates the range of moisture content for which a clay acts plastically. The greater the plasticity index, the greater the range of moisture contents over which the clay will act plastically.

Table 2.1 Clay Shrinkage/Fissure Potential

Plastic Index %	Clay Fraction %	Shrinkage Potential
>35	>95	Very high
22 - 48	60 -95	High
12 -32	30 - 60	Medium
<18	<30*	Low

* A clay is a material with a clay fraction greater than or equal to 35%

Skempton (1953), showed that a relationship exists between the percentage clay fraction and the plasticity index for different clay mineralogies. Table 2.2 shows typical ranges of index properties for some common clays.

Table 2.2
Plasticity Index and Shrinkage Potential for Different Types of Clay

Formation Marine Sediments	Water Content %		Liquid Limit %		Plasticity Index %	Clay Fraction <2,4%	Shrinkage Potential
	Weathered	Unweathered	Weathered	Unweathered			
Palaeogene							
Barton Clay	21-32	-	45-82	-	21-55	25-70	Medium/High
Bracklesham beds	-	19-26	-	52-68	41	-	High
London Clay	23-49	19-28	66-100	50-105	40-65	40-72	Medium/High
Reading beds	-		-	42-67	72	-	Very High
Cretaceous							
Gault Clay	32-42	18-30	70-92	60-120	27-80	38-62	High
Atherfield	27-46	-5	41-90	90-110	17-58	17-71	Low/High
Weald Clay	25-34		42-82	55	43	62	High
Jurassic							
Kimmeridge Clay	-	18-22	-	70-81	24-59	57-67	High/VeryHigh
Middle Oxford Clay	20-33	20-28	-	58-76	31-40	35-70	Medium/High
Lower Oxford	-	15-25	-	45-75	28-50	30-70	Medium/High
ClayFullers Earth	26-41	33	41-77	100	20-39	38-68	Medium/High
Upper Lias Clay	20-38	11-23	56-68	53-70	20-39	55-65	Medium/High
Lower Lias Clay	29	16-22	56-62	53-63	32-37	50-56	Medium
Triassic							
Keuper Marl	12-40	5-15	25-60	25-35	10-35	10-50	Medium
Carboniferous							
Etruria Marl	17-44	9-22	43-79	35-32	8-32	12-25	Low/Medium
Coal Measures							
- Mudstone	6-8	8	39-49	42	9-19	24-53	Medium
- Shale	9-14	9	42-45	44-51	12-19	37-87	Medium
- Seatearth	11	-	33-34	30-35	13-41	33-77	Medium/High
- Undivided	3-32	3	27-72	-	26-34	24-74	Medium/High
Limestone Series	15-88	36	40-106	-	28-45	20-74	Medium/High
Culm Measures	2-5	-	39	-	16-17	21-32	Low/Medium
Glacial Clays							
Boulder					32	-	Medium
Alluvial Deposits							
Clayey Silt					*	*	Low
Silty Clay					*	*	Medium/High

* very variable

The consistency of a clay will influence the shrinkage potential. The consistency of clays are defined by relating the moisture content to the Atterberg Limits (Atterberg Limits is a collective term for the plastic limit and the liquid limit). These define the state of a soil as liquid, plastic or solid.

The shrinkage limit is the moisture content at which a further reduction in moisture content causes no appreciable reduction in volume of the soil mass. If the moisture content on placing is below the shrinkage limit then the soil will not shrink, thus will not fissure. But, if the moisture content on placing lies above the shrinkage limit, which is typical of a natural undisturbed clay, then the soil volume will change with changes in moisture content, ie fissuring will occur as the clay desiccates. Volume variation in clay soils is thus directly related to the shrinkage limit. It can also be related to the liquid and plastic limits of soils; published values for which are more readily available than for shrinkage limits. Figure 6 shows how the soil volume typically relates to the moisture content and most notably to the shrinkage limit.

Figure 6 also shows that a clay is workable (ie compactable) between the plastic limit and the shrinkage limit. Traditionally clay has been placed with a moisture content between the plastic limit minus 5% and the plastic limit plus 2%. This is the range of moisture content for which the lowest permeability on compaction can be achieved. As discussed above, if a clay is placed with a moisture content near to the shrinkage limit, there is a negligible reduction in volume as moisture is lost from the soil and therefore negligible fissuring. But, at such a low moisture content satisfactory compaction may be difficult and the material may have a higher permeability. The embankment may therefore be more susceptible to seepage failures.

To reduce fissures it is desirable to place at a moisture content near to the shrinkage limit. There is no data at present, however, to identify the moisture content at which there is an appreciable reduction in fissuring and yet adequate compaction can still be achieved. Until there is more data the designer should place clay with a moisture content in the range of the plastic limit minus 5% and the plastic limit plus 2%, aiming to place towards the lower bound of this range.

Clays in Britain may broadly be considered in three groups:

- Old marine sedimentary deposits
- Glacial clays
- Alluvial clays

Old Marine Sedimentary Deposits

Old marine sedimentary deposits are shrinkable clays, ie those particularly susceptible to fissuring. They occur widely in the SE of England, and include the London, Gault, Weald, Kimmeridge, Oxford, Woolwich and Reading, Lias and Barton Clays.

Glacial Clays

The glacial drift clays of the south, which are derived from old marine sedimentary deposits, are also potentially shrinkable. In the north the surface clays are generally more sandy and their potential for shrinkage is less. However, those derived from the weathering and glaciation of the Carboniferous shales can also be highly shrinkable.

Alluvial Clays

Soft alluvial clays can be highly prone to shrinkage. Examples of these deposits are the Fens, the Somerset levels, the Kent and Essex marshes, the clays of the Firth of Forth and along the Clyde.

The distribution of these deposits can be located with reference to Geological Survey maps of drift and solid deposits. The shrinkage potential of these materials is indicated by the plasticity index and the clay fraction. The preliminary shrinkage potential of most of the clays in the UK can be assessed from Table 2.2. The properties of clay deposits can vary considerably and on-site testing is needed to assess the actual shrinkage potential of a particular site.

It is possible to use the index properties of clays to determine the moisture content at which desiccation starts. Driscoll (1983), suggests that the onset of desiccation can be estimated from the comparison of the soil moisture content to its liquid limit.

Start of desiccation occurs when the moisture content= 0.5 x liquid limit
Significant shrinkage occurs when the moisture content= 0.4 x liquid limit

The liquid limit is preferred to the plastic limit for comparison of volume change as the liquid limit results depend less on the reliability of the test procedure.

This method of determining the moisture content of the soil at which shrinkage will take place however, has some inherent difficulties. The changes in water content that cause desiccation are often small, and may be difficult to detect within the limits of accuracy of determination of the Atterberg Limits.

2.3.5 Soil Moisture Content

The soil moisture content of a cohesive soil has a major influence on the extent of fissuring. Clay is usually placed in an embankment at a moisture content needed to facilitate compaction. The moisture content usually then drops to a long term insitu value. This drop is initially rapid and slows until a point is reached where the moisture content is only affected seasonally by rainfall and river levels ie its natural range. Wide fissures are likely to be due to the initial rapid decrease in soil moisture content from its placed value to its natural range. It may also be partially due to differential settlements of the overall embankment. Fine fissures are likely to be due to a slow long term reduction in moisture content.

As the soil becomes desiccated, moisture is lost from the soil and negative porewater pressures are set up within the soil. Fissuring occurs when negative porewater pressures set up in a soil during states of moisture loss exceed the tensile strength of the material.

Moisture is lost from a soil by various processes namely:

(i) Evaporation from the soil surface
(ii) Transpiration and evaporation from plants

Fissuring of the soil surface increases the effective surface area from which evaporation can take place and the soil therefore becomes more desiccated and fissuring more intense.

Vegetation has a significant effect on the moisture content of a soil. The greater part of any root system extracts water from the soil. Plant roots draw water from a surrounding zone of soil driven by the process of evapotranspiration. The zone of influence of this drawing effect is far greater than the root ball and may be up to 1m deep for grass, 1.5 times the height of a high water demand tree such as willow, or half the height of a low water demand tree such as conifer. The zone of influence is typically the depth to which fissuring can occur. The presence of trees and shrubs on earth embankments would therefore appear to be undesirable.

During the summer months rainfall is usually below the rate at which moisture is being drawn from the soil by vegetation. The soil therefore desiccates (suffers a soil moisture deficit), and so fissures form. As previously noted these desiccation fissures in themselves speed the rate at which moisture is lost from the soil. It should also be noted that root activity is greatly reduced during the winter when rainfall is higher. The situation is therefore, reversed in the winter when the soil may become saturated. Refer to Figure 7.

By definition, when water is available to a desiccated soil, it is absorbed. On absorbsion of water the moisture content rises, the soil gradually swells and the fissures eventually close. This process generally takes place over a period of days.

The soil moisture content is increased by infiltration of water into the fabric of the embankment. Infiltration is greatly aided by a cover of vegetation by means of the following:

- Pipe holes left by decayed fibrous roots (filamentous fibrous roots are subject to annual decay and renewal)
- Increased surface roughness, creating ponding
- Lower soil densities
- Better soil structure of surface soils (surface crusting is prevented, which increases runoff)
- Vegetation induced desiccation fissures

The typical surface runoff from a grassed surface is between 10% and 20%, whereas surface runoff from bare soil is approximately 70%, see Figure 8. On sloping ground sub-surface water flow occurs within the dead and rotting layer of vegetative matter (the superficial litter layer) and within the upper soil layers, which contain a dense mat of roots running parallel to the surface. Sub-surface flows can be as much as 80% of the total slope drainage under trees with a thick humus layer. These flows are still significant on a grass covered slope. The horizontal permeability of the upper layers of well vegetated soils is often significantly greater than the vertical permeability. Shallow subsurface flow thus diverts infiltration water, so that although infiltration on vegetated soils is greater than on bare soils, the depth of infiltration may well be still quite shallow. Also, as the surface layer becomes saturated, the wide and fine fissures close, reducing the vertical permeability of the soil and limiting the infiltration of water to the desiccated layer of soil below. This effect combined with that of the parallel root mass may be the reason why fine fissures remain beneath the superficial surface layer even during wet winters.

Figure 9 shows the mean annual rainfall in the UK and Figure 5 shows the reported occurrence of fisuring in England and Wales. There is little discernable relationship between the two figures. Figure 10 shows potential evapotranspiration from grass throughout the UK and this also shows little or no relationship to the reported occurrence of fissuring. The amount of rain and the amount of evapotranspiration have a net effect on the moisture available to a grass embankment for absorption by the soil. It seems that this also bears little or no relationship to the occurrence of fissuring. This may be due to the fact that the UK is a temperate country with no extremes of climate and any relationship which might exist is not easily seen except in extreme climates.

Although the above does not demonstrate a direct relationship between rainfall, evapotranspiration and the occurrence of fissuring, there is much evidence provided by observation and many literature sources (eg CIRIA, Use of Vegetation in Civil Engineering) that vegetation strongly influences the moisture content of a soil.

The moisture content of a soil is often dependent primarily on its characteristics and the type and the extent of vegetation.

2.3.6 Foundation Failure

Differential settlement has been found in general not to be a major cause of fissuring, however, it will lower the embankment and therefore increase the risk of over topping.

2.4 Consequences Of Fissuring

2.4.1 Introduction

The consequences of fissuring are best illustrated by discussing case histories. Soil mechanics is a subject with a considerable empirical emphasis and as such predictions of likely consequences are difficult without reference to previous observations. Unfortunately there are few observations, but the most widely documented are discussed below.

1953 Breaches, Essex and Kent (after Marsland)

The breaches of the coastal flood defence earth embankments of Essex and Kent, which occurred during 1953, were studied in depth. It was observed that wave damage to the front face was confined to only very exposed areas. Most of the damage to the embankments was to the landward side and took the form of shallow slip failures, even where overtopping had not taken place.

On inspection of the sites the following significant observations were made:

- The embankments were constructed of soft marsh clay;
- The rough grass appeared to have intensified the shrinkage of the clay;

- The outer 1m was badly fissured and had formed hard dry nodules and was therefore very permeable;
- The external surfaces of the clay nodules had softened;
- There had been an abnormally high tide, which had remained high for a longer period than normal.

Marsland concluded that the embankments had become unstable prior to or during the initial stages of overtopping. The softening of the clay surfaces and the seepage drag of water flowing through the desiccated and fissured zone, as water approached or overtopped the crest, was the cause of failure.

During the wet weather prior to the failures the outer surface of the nodules of clay had absorbed water and a thin film of very soft material had formed around them. This film of soft clay acted as a lubricant between the nodules and reduced the factor of safety of the embankment against failure. However, even under these circumstances an embankment would be expected to remain stable. But, if sufficient water flowed through the fissures in this highly fissured zone, an appreciable downdrag would have been produced. This additional disturbing force may have been sufficient to cause a shallow slip failure. Under normal circumstances rainfall is the only wetting agent and would not by itself produce sufficient flow through the fissured slopes to develop drag forces sufficiently large to cause failure. If the water level approaches the top of the embankment large quantities of water can flow through the upper fissured zone and cause a local slip. Erosion of the highly fissured vertical face of this slip may then develop into a large breach, see Figure 11.

Marsland concluded after his study of the shrinkage and fissuring of clay in flood banks that the wide fissures which are visible in the first few years are not the primary threat to embankment stability.

BRS Research 1957, Coryton

The Building Research Station (now the Building Research Establishment) carried out full scale tests to study seepage through a surface of fissured clay. These tests showed that as the tide level approached the crest very considerable flow took place through the fissured zone, and as Marsland had theorised based on his observations of the 1953 floods, the drag generated by the flow through this zone caused a shallow slip failure in the back face of the embankment. A succession of further slips followed in the newly exposed material and within a very few minutes the slip surface had worked forward to the front of the embankment and breaching proper then took place.

Tollesbury

HR Wallingford have recently carried out a study for MAFF on a tidal flood defence clay embankment at Tollesbury. This work included a study of the mechanism of embankment breaching.

The breach was induced by lowering the embankment, thus exposing the clay core. The core was reported to be wetted on the estuary side of the embankment. This wetted zone and the intermediate zone in the middle did not display fissuring. The core on the landward side however was extensively finely fissured.

The embankment was allowed to overtop and initially seepage was seen at the back toe up to 7 metres on either side of the site of the experiment. Then during the first half an hour to an hour there was considerable damage to the back face as a gully formed (the soil structure at the experiment site is likely to have been weakened by the seepage). The gulley first formed at the back toe and worked its way up the back face to the crest. Once the gulley had reached the crest a three metre wide breach formed in just 6 minutes. The width of the breach remained fairly stable from then on.

2.4.2 Effect on the Standard of Service

The effectiveness of a flood defence can be expressed as a Standard of Service (SoS), which means the frequency of flooding of the protected area, usually given as the average return period (in years) of the flooding. MAFF in their Project Appraisal Guidance Note (PAGN) published indicative SoS for various land uses. These are reproduced in Table 2.3

Table 2.3
Indicative Standards of Service

Current land use	Indicative Standard of Service (return period in years)	
	Tidal	**Non-tidal**
High density urban containing significant amount of both residential and non-residential property	200	100
Medium density urban. Lower density than above, may also include some agricultural land	150	75
Low density or rural communities with limited number of properties at risk. Highly productive agricultural land.	50	25
Generally arable farming with isolated properties. Medium productivity agricultural land.	20	10
Predominantly extensive grass with very few properties at risk. Low productivity agricultural land.	5	1

These standards are only indicative: the actual standard to be adopted in each case depends on the results of applying benefit/cost and other appraisal techniques, which are detailed in the NRA Flood Defence Management Manual. This uses the concept of Land Use Bands. Higher standards may be appropriate in some cases, as for example on the Thames at London, where the flood defences are designed for a 1,000 year return period event, allowing for sea level rise and long term ground movement (tectonic changes) up to the year 2030. In the Netherlands return periods of up to 10,000 years are used.

Return period is a statistical concept which is best illustrated by means of a table, refer to Table 2.4 eg. an event with a return period of 100 years has a one percent chance of being exceeded in any year, a 39% chance of beng exceded in 50 years, and a 63% chance of being exceeded in 100 years.

Table 2.4
Percentage Chance of a Particular Return Period Event being exceeded During the Design Life of an Asset

Design Life (Years)	Return period T (years)								
	5	10	20	30	50	100	200	500	1000
1	20	10	5	3	2	1	-	-	-
2	36	19	10	7	4	2	1	-	-
3	49	27	14	10	6	3	1	-	-
5	67	41	23	16	10	5	2	1	-
7	79	52	30	21	13	7	3	1	1
10	89	65	40	29	18	10	5	2	1
15	96	79	54	40	26	14	7	3	1
20	99	88	64	49	33	18	10	4	2
30	-	96	78	64	45	26	14	6	3
50	-	99	92	82	64	39	22	9	5
75	-	-	98	92	78	53	31	14	7
100	-	-	99	97	87	63	39	18	10
150	-	-	-	99	95	78	53	26	14
200	-	-	-	-	98	87	63	33	18
300	-	-	-	-	-	95	78	45	26
500	-	-	-	-	-	99	92	63	39
1000	-	-	-	-	-	-	99	86	63

This philosophy is sound provided that the whole of the flood defence system defending an area has the same Standard of Service. A flood defence system includes all the assets in a river catchment, estuary or coastal region where flood defence activities in one part of the system have an impact on another part of the system. A flood defence system is only as strong as its weakest link. This becomes especially important when considering a system which includes a combination of fluvial, tidal and coastal defences, as the methodology for establishing the Standard of Service of each is different.

2.4.3 Freeboard

It is the usual practice when designing flood defences to include a freeboard allowance.

Freeboard is not defined or referred to in the Flood Defence Manual. In R&D Note 199 freeboard is defined as the height of the crest of a bank, flood bank or coastal defence structure above the still water level. An alternative definition could be an increase in the defence level to allow for uncertainties after estimating the still water level at the designated return period event, the predicted change in land and sea levels, local settlement, hydraulic effects and limiting overtopping to acceptable amounts. This does not include for any defects in the flood defences, such as fissuring, which are assumed to be designed, constructed and maintained so that defects do not occur. The local value to be adopted for freeboard will therefore depend on the degree of confidence in the predictions of the various elements allowed for in the design. The current practice within the Enironment Agency varies considerably eg one region uses a freeboard of 600mm for soft defences and 300mm for hard defences for all structures throughout the region irrespective of whether the defence is a fluvial, tidal or coastal defence.

From the responses to the questionnaire regarding earth flood embankments a total of 26 could be used to judge the current Environment Agency practices with regard to freeboard and allowances for fissuring of earth embankments. The responses covered all the regions of the EA. Out of the 26 replies used, 4 of them (15%) covered embankments which for one reason or another do not show signs of fissuring. 10 of the respondents (38%) did not know what value of freeboard is used in their region. Of the remainder the majority (over 60%) indicated they adopt a freeboard in the range 300mm to 600mm, although the overall range is from zero to 1200mm, as shown in Table 2.5.

Table 2.5 Reported Fissure Depth and Freeboard Allowance

Freeboard	Not Known	Nil	0-300	300-600	600-900	900-1200
Fissure Depth (Maximum)						
Nil	1			3		
<100						
100-250	1					
250-500	3			2		
500-750	3					
750-1000						
1000-1250	1	1		1		
Not known	2		2	4	1	1
	10	1	3	10	1	1

The pattern of freeboard allowance is not significantly different for those showing fissuring and those not exhibiting any signs of distress. The cases for concern are those where there is known extensive fissuring and yet either the freeboard allowance is considerably less than the known depth of fissuring or is not known at all.

The impact of providing a freeboard allowance to cater for desiccation fissuring is illustrated by the flood defences to the Harbour of Rye, on the south coast of England. The harbour is a 6km long tidal inlet where traditional local allowances for freeboard have been 300mm for hard defences and 900mm for soft defences: the latter including an allowance for surface fissuring of the clay. Predicted water levels for various return periods are as follows:

Return Period (years)	Water Level mOD
25	4.85
50	4.92
100	4.98
200	5.04

The difference between the 25 and the 200 year return period water level is less than 200mm. The choice of a freeboard allowance completely dominates the variability due to the choice of design return period. This is particularly important when one considers the emphasis that is placed on the selection of the appropriate return period for the standard of protection and the associated economic analysis when considering capital works under PAGN.

The effect of including an allowance for fissuring on the Standard of Service is illustrated in Figure 12. The design level of 3.3m at both sites A and B has a current return period of 50 years. If a freeboard allowance of 300mm is included to cater for desiccation fissuring which is not necessary then the effective Standard of Service increases to 300 years for Site B and over 2000 years at Site A. Conversely if no allowance is made and the top 300mm is ineffective, then the effective Standard of Service drops to about 7 years at Site B and to only 1 year at Site A. Although the examples are hypothetical Site A is characteristic of the east coast of England and B is more representative of the south coast.

2.4.4 Conclusion

Marsland concluded after his study of the shrinkage and fissuring of clay in flood banks that the wide fissures are not the primary threat to embankment stability. (However, a recent report on the condition of the Ouse Washes Barrier Banks notes that there may be a significant destabilising effect when these fissures fill with water). Under these circumstances the factor of safety for the structural integrity of the embankment decreases by an amount dependent on the type and condition of the soil and the depth of the fissure. This reduction may in some cases reduce the factor of safety to less than 1 and result in a failure.

Fissuring is a threat to the stability of an embankment as water flowing through the voids acting in conjunction with the softening of the exposed clay soils may result in failure.

A fissure may widen or heal depending on the relative rates of; erosion of its sides, the swelling of the material and the deposition of eroded particles. These are each dependent on further factors such as the velocity of the water and the size of the eroded particles. The consequence of seepage for a particular embankment is difficult to predict and it may therefore be prudent to assume that the effects would be detrimental to the integrity of the embankment.

The depth of fissuring should be taken into account when calculating the effective SoS of an embankment. The calculation should either include an appropriate freeboard allowance or ensure that remedial measures are put in place to repair defects in the system.

3 ASSESSMENT PROCEDURE

3.1 Introduction

The following assessment procedure aims to be a guide to enable the reader to assess the condition of existing embankments, identify the extent of fissuring and so assess an embankment's vulnerability.

The present frequency of inspection of earth embankments, as reported in the survey of Environment Agency staff, is given in Table 3.1.

Table 3.1 Present Frequency of Inspection

4 or more times per year	2 to 3 times per year	Annually	Less than once a year
29%	25%	46%	0%

The majority of the embankments are reported to be inspected annually and a high percentage are inspected more frequently. The frequency of inspections appears to be dependent on two factors; time available to Environment Agency staff and the considered vulnerability of the embankments. R&D Note 199 "Asset Management Plan" recommends general inspections every 6 months.

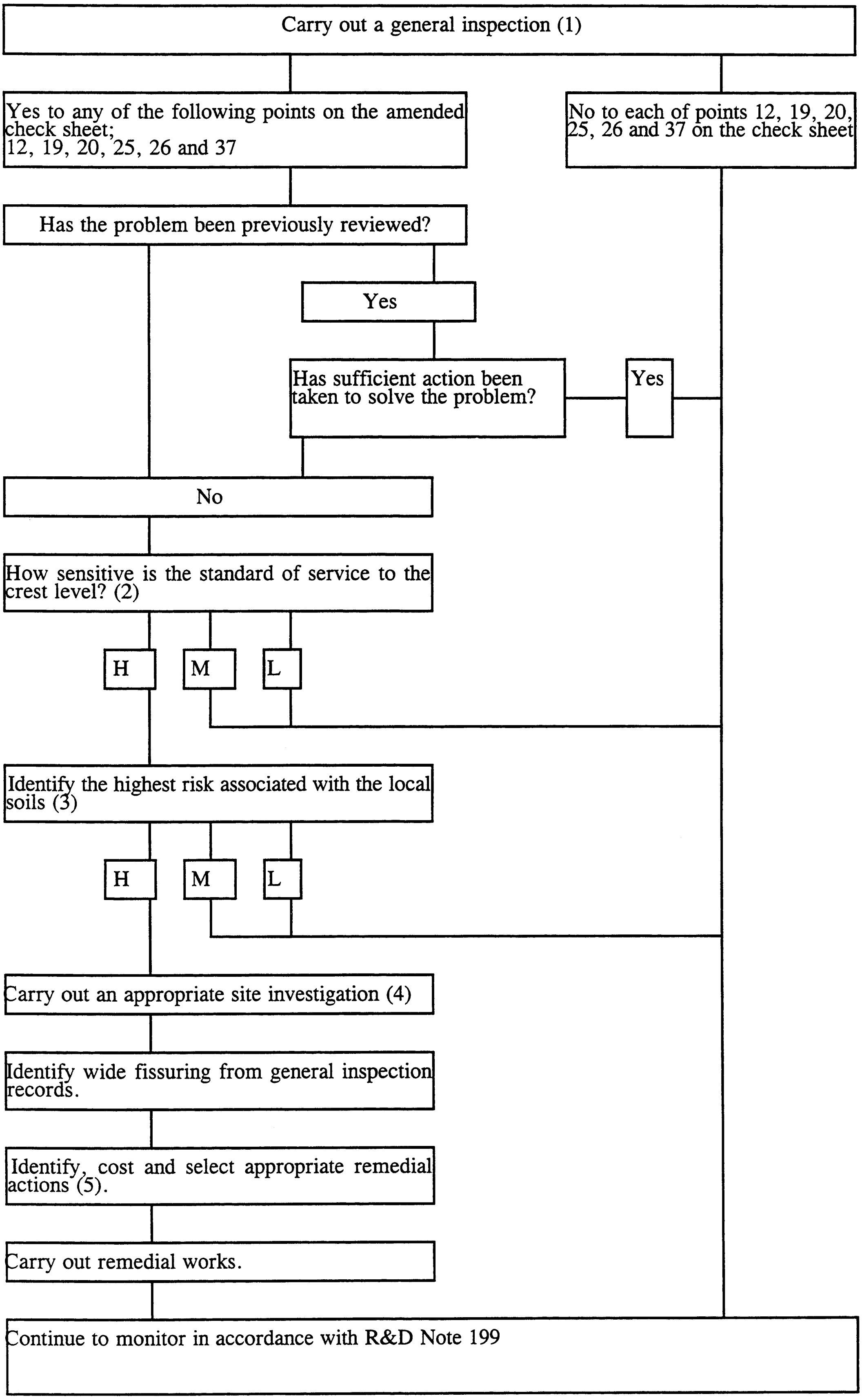
3.2 Procedure

The procedure for carrying out the assessment is set out in the flow diagram over the page. The exercise should be carried out as part of the general inspections outlined in section 9.6 of R&D Note 199, Asset Management for Flood Defences (see Appendix B). The check sheet for inspectors has been amended to account for the greater awareness of fissuring and is also given in Appendix B.

Inspections should be carried out in the autumn, typically during the period from the middle of September to the end of October and ideally again in the spring in line with the recommendations of R&D Note 199. Fissuring is generally due to desiccation of a clay embankment. The soil is usually in its most desiccated state in the autumn, ie after the dry summer months and before the wet winter months. However, any damage is most likely to occur over the winter months, therefore a spring inspection should be carried out to identify any such damage.

Wide and fine fissuring can be identified using the descriptions given in Chapter 2. Wide fissuring will be more obvious. Refer to the photographs given in Appendix C.

Assessment Procedure



1. Details set out in R&D Note 199 "Asset Management Planning for flood Defences".

2. H, M, L (High, Medium and Low) are quantified in the "Flood Defence Manual " produced by the Environment Agency.

3. Refer to geological drift and solid maps to identify the types of soil local to the embankment. Refer to table 2.2 to identify the highest risk associated with any of the local soils.

4. This is to identify the extent of the fine fissuring and to be able to develop a geotechnical cross section to a depth of 5m below the surrounding ground level. The geotechnical cross section will provide data on which to base selection and design of remedial measures. For details of appropriate site investigation techniques refer to Appendix D.

5. Refer to Chapter 4 and review each of the suggested remedial measures and identify appropriate options for the particular situation, consider each of the appropriate remedial options, taking into account the value of the area protected by the embankment, the effect on the serviceability and the cost, then decide on a course of action.

4 REMEDIAL ACTIONS

4.1 Introduction

The aim of this chapter is to outline a number of remedial measures, each of which will either limit or prevent fissuring. More than one scheme has been presented so that the reader may review each scheme and select one, or a combination of several schemes, which best suit a particular situation. This approach has been taken as circumstances are very varied throughout the UK.

The following pages discuss each of the recommended remedial measures in turn, describing the construction procedure, its purpose, cost, effect on the extent of fissuring and the effect on the Standard of Service. This chapter does not give an exhaustive list of measures, but aims to provide the reader with a comprehensive list covering those measures which are likely to be most effective.

The costs shown on the following pages are indicative rates per metre run of embankment assuming an embankment 4m high, 3m wide crest, and 1:2.5 slope on the front face and 1:2 slope on the landward face.

Remedial Measures

Digging In

Procedure:
This procedure has been reported in literature, although there are some major reservations as to its effectiveness. Refer to Figure 14.

This procedure must be carried out when the embankment is at its driest, ie typically during August or September. There is little advantage in carrying out this work if the moisture content of the clay is above the plastic limit. (Use the results of site investigation carried out as part of the detailed assessment procedure to identify the plastic limit of the clay in the embankment). Geotechnical specialists will be able to test the embankment material for its moisture content at the time of the remedial works to ensure that it is below the plastic limit.

Remove all the top soil from the affected area. Dig out the fissured material to the full depth of the fissuring, typically 1.2m to 1.5m deep. For safety it is recommended that for any excavations over 1.2m deep, a mechanical excavator be used, if an excavator is not available and men need to enter, the sides of the excavation should be adequately shored up or battered back. Excavated material should be stored in an area where rain water will not pond. Make sure the material is well protected from rainfall by covering it with a waterproof sheet. It should also be stored separately from the top soil.

Break up the excavated material until it resembles small pebbles, typically 20mm in diameter, ie the width of a thumb. Backfill the excavation using the broken up excavated material as backfill, place and compact in accordance with the Specification for Highway works for a dry cohesive material.

Replace the top soil and seed the area in accordance with the guidelines given in Chapter 5 "Choice of Vegetation and Top Soil".

Purpose:
To significantly reduce the extent of fissuring and increase the effective Standard of Service.

Effect on the Extent of Fissuring:
Reworking the area during a dry period is equivalent to placing the material at a low moisture content,thus reducing fissuring and the surface area from which evaporation can take place, which further reduces the rate of moisture loss. The extent to which fissuring is limited depends on the material, refer to Chapter 2 "Soil Characteristics".

Effect on the Standard of Service:
The embankment will still fissure, therefore, the freeboard should still include an allowance for fissuring, refer to Table 6.1 of Chapter 6. Although the allowance for fissuring may not be reduced, the embankment is likely to be stronger and less likely to be breached than before the work was carried out.

Cost/m Run:
£75 to £90

Remedial Measures

Berms

(also applicable to flattening of the landward slope)

Procedure:
The construction of a berm on the landward side of an embankment is only an effective measure if the slip circle is contained within the embankment or extends only a shallow distance below the embankment. Refer to Figure 15.

The design of a berm should be carried out by an experienced geotechnical engineer. An outline is given here, for further details on the design of berms refer to The Japanese Society of Soil Mechanics and Foundation Engineering, 1993. Firstly identify the soil profile using the results of the assessment, then carry out an iterative design process using slip circle analysis techniques. A berm will have a height typically 40% to 50% of the embankment height, although the width may vary considerably depending on the soil properties and the dimensions of the embankment.

First remove all the top soil and store it where it will not become mixed with any other material. Construct the berm in accordance with the specification as set out by the designer.

Replace the top soil and import further top soil if required. Seed the berm in accordance with the guidelines set out in Chapter 5 "Choice of Vegetation and Top Soil".

Purpose:
To improve the overall stability of the embankment. A berm will, in appropriate circumstances, prevent the failure of an embankment by a head of water in the wide fissures.

Effect on the Extent of Fissuring:
The construction of a berm has no effect on the extent of the fissuring.

Effect on the Standard of Service:
The construction of a berm will significantly reduce the risk of failures associated with water filled wide fissures. However, the construction of a berm does not prevent seepage through fine fissures, which in extreme events can lead to failure, but the additional stability will compenstate to some extent. Although an allowance for fissuring should still be included in the freeboard calculation, this allowance may be reduced, as the embankment is structurally more stable. A greater reduction may be made if the berm is constructed from a hoggin material.

Cost/m Run:
£50 to £60

Remedial Measures

Replacement with Hoggin

Procedure:
This procedure is technically suitable for all unreinforced clay embankments. Refer to Figure 16.

Use the detailed assessment results to provide information on the depth of fissuring and the structure of the embankment. First remove the top soil and store it separately from any other material. Then remove the fissured zone of the embankment, extending the excavation work to a minimum of 200mm below this zone. (The depth to which the zone extends will be indicated by the detailed assessment soil sampling). Also carry out a visual check to ensure no fissured material remains.

Remove the fissured material from site so that it will not be used in the future. Alternatively it may be cheaper to reuse the material to form a berm on the landward face.

Replace the fissured material with hoggin, see Appendix F for the recommended grading and moisture content for hoggin. Place and compact the hoggin in accordance with the Specification for Highway Works for a well graded granular material.

Replace the top soil and seed in accordance with the guidelines given in Chapter 5 "Choice of Vegetation and Top Soil".

Purpose:
The purpose of this measure is to prevent fissuring and thus retain the Standard of Service.

Effect on the Extent of Fissuring:
Fissuring will be significantly reduced

Effect on the Standard of Service:
This measure retains the full Standard of Service without any need for a freeboard allowance for fissuring.

Cost/m Run:
£450 - £550

Remedial Measures

Impermeable Membrane

Procedure:
Remove the top soil and stock pile it nearby. Install the impermeable membrane as shown in Figure 17. This membrane should be at least a 1.5mm thick high density (HDP), textured (friction enhanced) polyethylene membrane. (An alternative material would be a PVC membrane. PVC is more flexible than HDP, it can also be punctured and sealed to allow soil fixings. PVC is, however, approximately twice the price and degrades when exposed to sunlight, although as the membrane will be covered, degredation due to exposure to sunlight should not be a problem).

Lay the membrane and anchor it each side of the embankment. If the underlying foundation layers are permeable, the designer may wish to extend the front face membrane to below these permeable layers to prevent seepage.

Lay a "Geoweb" type product on top of the membrane. Specialist contractors should be employed to carry out the work.

Top soil and seed in accordance with the recommendations set out in Chapter 5 "Choice of Vegetation and Top Soil".

Purpose:
The purpose of this measure is to prevent water building up in fissures, thus prevent failure of the embankment due to seepage and reduce the risk of slip circle failure.

Effect on Extent of Fissuring:
This measure will substantially reduce the extent of fissuring.

Effect on the Standard of Service:
The designer does not need to take account of fissuring when calculating the freeboard, and the Standard of Service is retained. However, the grass cover will dry out and die earlier in the summer and the reader must consider the amenity value of the embankment.

Cost/m Run:
£200 to £300

Remedial Measures

Sheet Pile Cut Off Wall

Procedure:
Install sheet piles longitudinally along the centre of the crest. Refer to Figure 18. The sheet piles should be toed into an impermeable layer by at least 500mm. As fissuring is typically 1.2m to 1.5m deep, the sheet piles would normally be driven to at least 2m depth. The depth of fissuring should be identified from the results of the site investigation carried out as part of the assessment procedure. If the site investigation has identified permeable foundation layers, the designer may wish to consider extending the depth of the sheet piling to 1m below this permeable layer.

The thickness of steel sheet piles may decrease slowly with time due to corrosion although this should not be a major problem. A cut off wall could also be constructed of mass concrete, or plastic sheet piles.

Purpose:
The purpose of this measure is to greatly reduce seepage through the finely fissured layer. The clutches of sheet piled walls are not sealed, therefore there will still be some slight seepage.

It may be prudent to also include a berm in the design. A berm would reduce the risk of slip circle failures due to water filled wide fissures.

Effect on the Extent of Fissuring:
This measure has no effect on the extent of fissuring.

Effect on the Standard of Service:
The designer does not need to take account of the fine fissuring when calculating the freeboard. However, wide fissuring, which is a concern in the event of over topping must still be considered. The effect of a head of water in a wide fissure is to lower the factor of safety of the slope stability, if this lowers the factor below 1 the slope will fail. To compensate for the reduction in the slope stability due to water filled wide fissures, the designer should consider adding a berm on the back face or slackening the back slope, each of which increase the stability of the back slope.

Cost/m Run:
£130 to £160

Remedial Measures

Granular Crest

Procedure:
Carry out this procedure during the winter when the surface fissuring has closed. If the surface fissures are open the granular material will tend to fill the fissures and an even distribution of granular material throughout the clay will not be achieved. Refer to Figure 19.

Remove the topsoil from the crest of the embankment and store it where it will not become mixed with other materials.

Roll and harrow a 100mm thick layer of well graded granular material into the crest of the embankment. Continue to add layers of material until a dense granular surface is produced. The grading, type of roller and number of passes may need to be adjusted in the light of experience.

Purpose:
The purpose of this procedure is to increase the amount of granular material in the clay. This has the effect of reducing the plasticity of the clay and thus its tendency to fissure.

Effect on the Extent of Fissuring:
It is unlikely that the embankment will be treated to the full depth of the fissuring, although the treatment of the surface may help to prevent surface fissuring and thus reduce evaporation from the embankment.

Clay below the treated layer will still fissure, but there will be little or no wide fissuring at the surface. The wide fissures are unlikely therefore to fill with rain water or water from overtopping, thus reducing the likelihood of failure due to a slip circle failure induced by a head of water in a fissure. It is not possible at present to quantify the reduction in risks associated with this treatment due to the variable nature of the factors involved. Empirical guidelines could be developed if full scale tests were carried out, or if treated embankments were monitored.

Effect on the Standard of Service:
The absence of fissures and the reduction of seepage into the fissured zone should enable the Standard of Service to be maintained without the need for a freeboard allowance.

Cost/m Run:
£60 to £80

Remedial Measures

Geotextiles and Geogrids

Procedure:
Geotextiles and Geogrids can be used in many ways to improve the stability of an embankment and so compensate for fissuring.

When considering the use of geotextiles the designer must be aware of exactly what they can and cannot do and how to select the best product. They will not prevent fissuring, however, they will limit it and improve the stability of the embankment.

The available techniques and the possible situations are very varied and are described in "Guidelines for the design and construction of flexible revetments incorporating geotextiles for inland waterways" published by PIANC. Also seek the advice of a specialist geotechnical engineer.

Purpose:
To reduce width of wide fissures and improve the stability of the slope.

Effect on Extent of Fissuring:
Fissuring occurs when the negative water pressure induced by desiccation (negative porewater pressure) exceeds the strength of the material. Under normal circumstances the negative porewater pressures will not exceed the strength of a geotextile or geogrid (the selected geotextile or geogrid strength is dependent on the system adopted and the dimensions of the embankment). Wide fissures are not able to transfer across the Geotextile or geogrid and their extent are therefore limited. Fine fissures, however, will be unaffected by the presence of a geotextile or geogrid and are likely to occur to the same extent.

Effect on Standard of Service:
The increased strength of the embankment should compensate for any flow through the fissured zone. The Standard of Service can probably be maintained without the need for a freeboard allowance for fine and wide fissuring.

Cost/m Run:
£150 to £200

5 DESIGN RECOMMENDATIONS

5.1 Introduction

The fissure prevention or control measures outlined in this Chapter are intended to be used with existing standard design procedures. They should be incorporated into the design of major reconstruction works of existing embankments, or the design of new embankments.

These measures are only applicable to the construction of clay embankments. Embankments constructed from other materials will not be prone to the wide or fine desiccation fissuring discussed in this manual. Design procedures other than those outlined in this chapter should be followed to prevent fissuring due to excessive differential settlements, suitable references include "Foundation Design and Construction" by Tomlinson and "Normal Consolidated and Lightly Over Consolidated Cohesive Materials" Conference on Settlement of Structures, University of Surrey 1974.

5.2 Historical Review

The Environment Agency has inherited several standard specifications for the construction of flood defence earth embankments from the National Rivers Authority (some extracts are included as Appendix G). In general these specifications have not been fully implemented, particularly with respect to construction materials. This has mainly been due to the cost of importing suitable material to meet the requirements of the specification.

Construction materials for clay embankments are often excavated from delph ditches, salt marshes, the foreshore, or river dredgings. The clay is often placed in a very wet state, ie it has a moisture content far higher than the plastic limit and is therefore prone to fissuring, although in some regions the material is left to dry before placing.

The additional freeboard allowance made for fissuring is very varied throughout the UK, but is typically between 300mm and 600mm. The consequences of this allowance are discussed in Chapter 2.

5.3 Fissure Control Measures

The following pages outline the measures that should be incorporated into the design of a clay embankment to counteract fissuring. The designer must assess the circumstances of a particular situation to decide which measures to take.

The extent of fissuring may be reduced by a number of measures including:

- placing at a lower moisture content;
- choice of a suitable top soil and vegetation;
- good workmanship during placing;
- adapting the design of the embankment.

A freeboard allowance should be made to account for fissuring if no active measures are taken to prevent their occurrence. As fissuring is typically up to 1.2m deep, it is probably impractical to assume that an additional freeboard of 1.2m is required. Therefore, the designer must consider the sensitivity of the site that the embankment protects, and the tendency of the clay to fissure. Table 5.1 below gives suggested freeboard allowances to account for fissuring.

Table 5.1
Suggested Freeboard Allowances to Account for Fissuring

	Site Sensitivity		
	High	**Medium**	**Low**
Tendency to Fissure			
High	900mm	900mm	600mm
Medium	900mm	600mm	600mm
Low	600mm	600mm	300mm

The costs shown on the following pages are indicative rates per metre run of embankment assuming an embankment 4m high, 3m wide crest, and 1:2.5 slope on the front face and 1:2 slope on the landward face. The basic construction cost is taken as £400/m. These costs are intended only to be used as a tool in the selection of a solution. The designer should confirm these costs as they may vary considerably in different areas of the UK.

Design Measures

Increase Freeboard

Procedure:
If the only immediately available material is a clay and no fissure prevention measures are practical then an additional freeboard allowance should be included in the design. The increased height of embankment should be constructed to the same specification as the basic structure, eg the crest width should be the design width at the increased height.

Purpose
The purpose of this measure is to compensate for fissuring by adding height to the embankment.

Effect on the Extent of Fissuring
This measure has no effect on the extent of fissuring.

Effect on the Standard of Service
As fissuring has been allowed for in the design, the Standard of Service is achieved but with a higher embankment.

Cost/m Run
The capital cost of the basic embankment has been taken as £400/m.

Increase in Freeboard mm	Cost/m £	% Increase
300	450	12%
600	500	25%
900	560	40%

Design Measures

Hoggin Capping

Procedure
Cap the clay core with a layer of hoggin to a depth of at least 1m (see Appendix F for a suitable specification also refer to Figure 16).

Purpose
As hoggin is unlikely to fissure, the purpose of this measure is to significantly reduce fissuring.

Effect on the Extent of Fissuring
Hoggin material is a well graded material which under normal circumstances is unlikely to fissure. It is however, permeable, but the permeability is very low and is considerably less than that of a fissured clay.

Effect on Standard of Service
The embankment should not fissure. The effective Standard of Service can therefore be achieved with no freeboard allowance for fissuring.

Cost/m:

The increased cost of using a hoggin capping layer is likely to increase the cost of the embankment by 20% to 25% of the basic embankment cost ie £480 - £500/m.

Design Measures

Use of Lime Stabilised Materials

Procedure:
The addition of lime to clays has a cementing effect and reduces the plasticity of the soil and hence its tendency to fissure. The amount of lime required to stabilise clay soils ranges from two to eight percent by weight. It is reported that "the design lime content may be designated as, that lime content above which no further appreciable reduction in plastic index occurs, or, a minimum lime content which produces an acceptable reduction in the plastic limit".

For the best results the top 1.2m (ie the typical maximum depth of fissuring) of the embankment should be constructed from lime stabilised material. However, if only the top 0.5 m is treated this will significantly reduce surface desiccation fissuring, thus reducing the exposed surface and so further evaporation. In this way the rate of desiccation of the embankment is slowed and over the period of a summer it is unlikely that a lime stabilised embankment will desiccate, and so fissure, to the same extent as an untreated embankment.

It is recommended that lime stabilisation is carried out by a specialist contractor, as specialist plant and skills are required to ensure an even mix.

The strengthening (cementation) reaction of lime takes many months, it is therefore not recommended to account for this increase in strength in design calculations.

Effect on the Extent of Fissuring:
Lime stabilisation cannot be guaranteed to prevent fissuring completely but should significantly reduce fissuring. Over several months it also adds strength to the embankment, therefore reducing the risk of damage due to any seepage or overtopping.

Effect on the Standard of Service:
Although fissuring may not be completely eliminated, the reduction is such that, combined with the increased strength of the embankment material, there is probably no need for a freeboard allowance for fissuring to maintain the Standard of Service.

Cost/m^3
Cost based on 3% by weight of "Quick Lime": £6.50/m^3 the total cost of the embankment depends on the extent of lime treatment. typical cost are given below:

- top 1.2m treated, likely increase in cost of bank by 45% to £589/m
- top 0.5m treated, likely increase in cost of bank by 20% to £480/m

Design Measures

Impermeable Membrane

Procedure:
Design and construct the embankment in the usual manner in line with existing guidelines, but incorporate into the design an impermeable membrane. This membrane should be at least a 1.5mm thick high density polyethylene, textured, membrane, which should be installed as shown in Figure 17. (An alternative material would be a PVC membrane. PVC is more flexible than HDP it can also be punctured and sealed to allow soil fixings. PVC is, however, approximately twice the price and degrades when exposed to sunlight. As the membrane will be covered, degradation due to exposure to sunlight should not be a problem).

Lay the membrane and anchor it each side of the embankment. If the underlying foundation layers are permeable, the designer may wish to extend the front face membrane to below these permeable layers, as embankments have failed due to seepage through an underlying permeable material.

Lay a "Geoweb" type product on top of the membrane. Specialist contractors should be employed to carry out the work.

The specification for topsoil and seeding should be made in line with the recommendations made in this section.

Purpose:
The purpose of this measure is to prevent both seepage through fissures and water filled fissures forming.

Effect on Extent of Fissuring:
This measure will substantially reduce the extent of fissuring.

Effect on the Standard of Service:
The designer does not need to take account of fissuring when calculating the freeboard. However, the grass cover will dry out and die earlier in the summer. The reader must therefore consider the amenity value of the embankment.

Cost/m Run:
The addition of an impermeable membrane together with a geogrid to retain topsoil increases the cost by approximately 50% to about £600/m

Design Measures

Geotextiles and Geogrids

Procedure:
Geotextiles and geogrids can be used in many ways to improve the stability of an embankment and so compensate for fissuring.

When considering the use of geotextiles the designer must be aware of exactly what they can and cannot do and how to select the best product. They will not prevent fissuring, however, they will limit it and improve the stability of the embankment in compensation.

The available techniques and the possible situations are very varied. For further guidance refer to "Guidelines for the design and construction of flexible revetments incorporating geotextiles for inland waterways" published by PIANC and also seek the advice of a specialist geotechnical engineer.

Purpose:
To reduce width of wide fissures and improve the stability of the slope.

Effect on Extent of Fissuring:
Fissuring occurs when the negative water pressure induced by desiccation (negative porewater pressure) exceeds the strength of the material. Under normal circumstances the negative porewater pressures will not exceed the strength of a geotextile or geogrid (the selected geotextile or geogrid strength is dependent on the system adopted and the dimensions of the embankment). Wide fissures are not able to transfer across the geotextile or geogrid and are therefore limited in extent. Fine fissures, however, will be unaffected by the presence of a geotextile and are likely to occur to the same extent.

Effect on Standard of Service:
The increased strength of the embankment should compensate for any flow through the fissured zone. The Standard of Service can probably be maintained without the need for a freeboard allowance for fine and wide fissuring.

Cost/m Run:
The cost of geotextile varies considerably but it is considered that the cost of the embankment is likely to increase by between 35% and 50% to £540 to £600/m

Design Measures

Increase Width of Crest

Procedure:
Design the embankment with an increased crest width, maintaining the same side slope. The designer should seek the advice of a specialist geotechnical engineer to calculate this width. The geotechnical engineer should take into account the type of material and its tendency to fissure as indicated in Table 2.2. It is not possible to give specific guidelines in this manual due to the variability of circumstances throughout the UK.

Purpose:
The construction of a wider crest increases the factor of safety of the embankment against structural failure, thus compensates for the reduction in the factor of safety due to fissuring.

Effect on Extent of Fissuring:
This procedure has no effect on the extent of fissuring.

Effect on Standard of Service:
There should be no requirement for the freeboard allowance to include fissuring, as the destabilising effect of the fissuring should be fully compensated for by the widening of the crest.

Cost per m Run:
The increased cost is likely to be between 15% and 20% of the basic cost of the embankment which increases to between £460 and £480/m.

Design Measures

Construct Berm (also applicable to the flattening of the back slope)

Procedure:
The inclusion of a berm on the landward side of an embankment is only an effective measure if the slip circle is contained within the embankment or extends to a shallow depth below the embankment. Refer to Figure 15.

The design of a berm should be carried out by an experienced geotechnical engineer. An outline only is given here, for further details on the design of berms refer to Japanese Society of Soil Mechanics and Foundation Engineering, 1993. Carry out an iterative design process using slip circle analysis techniques. A berm will have a height typically 40% to 50% of the embankment height.

Purpose:
To improve the stability of the embankment, thus compensate for the weakening induced by the fissuring.

Effect on the Extent of Fissuring:
No effect on the extent of the fissuring.

Effect on the Standard of Service:
The construction of a berm will significantly reduce the risk of failures in the embankment slopes often associated with water filled fissures. However, the construction of a berm does not prevent seepage through fissures, which in extreme events can lead to failure of the embankment, firstly by erosion of the landward toe and then a gulley cutting its way up the landward face. However, adding extra material to the landward toe of the embankment will increase its Standard of Service. Although an allowance for fissuring should still be included in the freeboard calculation, this allowance may be reduced, as the embankment is structurally more stable. A greater reduction may be made if the berm is constructed from a hoggin material.

Cost/m Run:
The increased cost is likely to be very variable but should be of the order of 15% to 20% of the basic cost of the embankment cost at £460 to £480/m.

Design Measures

Placing Moisture Content of Clay

Procedure:
Clays for the construction of flood defence earth embankment should be placed with a moisture content between the plastic limit plus 2% and the plastic limit minus 5%, aiming to place as near to the lower bound as possible.

Take care that the clay does not come into contact with water prior to or during compaction. If it rains the clay must be covered with a water proof sheeting or the top wetted layer must be removed. For this reason it is suggested that construction takes place in short manageable lengths, the length of which will depend on the resources on site, both men and machines, and the size of the embankment. To ensure each separately constructed length of embankment ties in with the next, construct in a series of interlocked layers, see Figure 20. It is recommended that clay should not be stockpiled as it makes it difficult to control moisture contents.

With the exception of the above measure, the embankment should be designed and constructed in line with existing guidelines and specifications.

Effect on the Extent of Fissuring:
Wide and fine desiccation fissuring will still occur but to a lesser degree than if no measures had been taken to lower the moisture content on placing. A reduction in fissuring means a reduction in the exposed surface area from which to lose water by evaporation, further secondary fissuring is thus limited.

The extent of fissuring depends on the plasticity of the clay, Table 2.2 indicates typical plasticity indices and expected extent of fissuring.

Effect on the Serviceability:
The embankment is still likely to become fissured to a depth of up to 1.2m depending on the vegetation, however, the fissuring is likely to be less extensive. The designer should make an allowance for fissuring in the freeboard calculations, refer to Table 5.1.

Cost/m Run:
No additional cost, this measure is just good practice.

Design Measures

Design Measures

Choice of Vegetation and Top Soil

Procedure:
Embankments need a good cover of grass to protect against erosion in the event of over topping. There are many types of grass, each have their own root, shoot and water demand characteristics, therefore the choice of grass has an influence on the rate at which desiccation fissuring occurs. The ideal choice of grass would be one which has a low water demand, dense strong short shoots for erosion protection and a good strong root mass to aid infiltration and strengthen the soil. This grass unfortunately does not exist, however, measures can be taken to improve the situation.

The first of the measures is to select a suitable top soil. The top soil should be sufficiently fertile so as to produce good growth, but not so fertile so as to promote too much growth. Too much growth will encourage desiccation of the embankment and require frequent mowing. A class B top soil is recommended, refer to Table 5.2.

Inspection of the diagrams included as Appendix H, illustrating soil suitability for specific purposes based on texture, show that a sandy clay loam is the only soil which is both in the most suitable top soil for erosion protection class and is also a class B top soil. The diagram in Appendix H also shows the clay, sand and silt fractions to specify.

Having identified the top soil, the designer must then specify a suitable grass mixture. This mixture will contain a percentage of small broad leafed plants (herbaceous) such as clover. Advice on specific seed mixtures is beyond the scope of this manual as the suitability of different species will vary widely depending on the soil type and the climate. It is recommended that the designer seek the advise of a specialist agricultural engineer when selecting seed mixtures for specific projects. The designer must make sure that the agricultural engineer fully appreciates the importance of all the requirements demanded from the vegetation cover, ie erosion protection, low water demand and soil strengthening.

Purpose:
The purpose of this measure is to ensure that the vegetation has the least effect on desiccation of the embankment possible.

Effect on Extent of Fissuring:
If no other fissuring limitation or compensation measures are taken, fissuring will still occur. The designer in taking care when preparing the specification for the top soil and seed mixture ensures that the fissuring is no worse than necessary. The embankment should be assumed to be fissured to a depth of approximately 1.2m.

Effect on Standard of Service:
An allowance for the fissuring should be made when calculating the freeboard. As previously discussed it would be unreasonable to discount the top 1.2m of the embankment, refer to Table 5.1 for guidance on suitable allowances for fissuring.

Cost/m Run
There is no additional cost associated with this measure as it is just good practice.

Table 5.2
Assessment of Soil Potential

Class A is the highest quality and suitable for situations where good quality fertile topsoil is necessary. However, class C, whilst of poorer quality, would still be suitable for many situations. In many cases it would be possible to modify or manage a class B or C soil to improve its quality.

Parameter	Unit	Suitability class			Unsuitable
		A	B	C	
Soil type					
Texture	description and clay %	fLS,SL SZL,ZL	SCL,CL ZCL,LS	C<45% SC,ZC, S	C>45%
Stoniness	% vol	<5	5-10	10-15	>15
Available water capacity (at packing density 1.4-1.75)	% vol	>20	15-20	10-15	<10
pH		5.7-7.0	5.2-5.5 7.0-7.3	4.7-5.5 7.3-7.8	<4.7 >7.8
Conductivity	mho/cm	<4	4-8	8-10	>10
Pyrite	% weight	-	<0.2	0.2-3.0	>3.0
Soil fertility					
Total nitrogen	% weight	>0.2	0.05-0.2	<0.05	
Total phosphorus	mg/kg	>37	27-37	<27	
Total potash	mg/kg	>360	180-360	<180	
Available phosphorus	mg/kg	>20	14-20	<14	
Available potassium	mg/kg	>185	90-185	<90	

Notes 1. f = fine, S = sand, C = clay, L = loam, Z = silt
*Extracted from CIRIA "Use of Vegetation in Civil Engineering"

Design Measures

Good Workmanship

Procedure:
The designer should implement procedures to ensure all earth works are carried out in accordance with BS8002 and the guidelines set out in this manual. These procedures should include the appointment of an experienced geotechnical engineer, experienced site supervision and competent contractors.

Purpose:
To ensure design measures are satisfactorily incorporated and prevent the need for unnecessary remedial works. The importance of good workmanship is best illustrated by the experience of the Mississippi floods; of the federally constructed embankments approximately 20% failed, however, of the more poorly designed and constructed privately owned embankments 77% failed.

Effect on Extent of Fissuring:
The extent of fissuring will be limited to the lowest extent possible for the material. The embankments will have a stability equal to or greater than that calculated during the design process, ie the best performance possible for the embankment will be achieved with no further capital outlay.

Effect on Standard of Service:
Calculations for the Standard of Service must include an allowance for fissuring in line with those suggested in Table 5.1.

Cost per m Run:
No additional cost, this measure is just good practice.

6 MAINTENANCE

6.1 Introduction

Maintenance is "all operations necessary to keep an asset in a defined state" (R&D Note 199) "Asset Management Planning For Flood Defences".

To date there are no formal records of best practice techniques or standard specifications for the maintenance, improvement and monitoring of flood defence earth embankments. However recommendations for general maintenance have been made in R&D Note 199. Techniques adopted for much of this work have been based on local experience. This chapter has drawn together much of the available information and aims to provide guidance on suitable maintenance techniques with regard to fissuring.

Only clay soils (ie cohesive soils) fissure. The extent of which depends on the plasticity of the soil and its moisture content relative to its moisture content when it was placed. For further details refer to Chapter 2. Maintenance procedures aiming to control the extent of fissuring must therefore be considered in terms of soil plasticity and moisture content.

Soil plasticity is a characteristic of a clay soil and it cannot be altered without carrying out major works. Therefore, control of soil plasticity is beyond the scope of maintenance procedures. Major works which alter the plasticity of a clay are included in Chapter 5 as remedial measures.

A degree of control of the moisture content of a soil can, however, be achieved with routine maintenance procedures. These procedures are all concerned with the management of vegetation.

6.2 Historical Review Vegetation Management

Historically the aim of vegetation management has been to prevent the growth of trees and shrubs, to clear the embankment for inspection and in some cases clear the embankment for amenity purposes.

The responses to the questionnaire of Environment Agency staff showed that different Environment Agency regions have different regimes for grass mowing. One third of the regions mow their embankments annually, one third mow them less than once a year and one third of the regions mow their embankments between 2 and 4 times a year. This variability appears to be the based on intuitive judgements and historical practices as to suitable regimes by the different regions.

6.3 Recommended Procedures for Managing Vegetation on Clay Flood Defence Embankments

The preferred regime, with regard to fissuring, is to mow 2 to 6 times a year depending on the soil fertility and the vigour of the grass species. Frequent cutting stimulates the growth of many dense shoots (tillering) in grasses and results in a plant, which is thicker and better able to withstand surface abrasion eg abrasion due to walkers or animals. Frequent cutting also reduces the depth and density of rooting and the leaf area for transpiration. Frequent cutting is therefore desirable for minimising the moisture loss from the embankment. It is also desirable where the embankment is used for amenity purposes.

The reduction in root depth and density is not desirable with regard to the control of surface erosion by water. Grass managed for surface erosion control should only be cut every 1 to 3 years. For environmental purposes the grass should be cut as infrequently as possible.

This manual recommends that inspections for fissuring should be carried out in the autumn and ideally again in the spring and that this is when the grass should be cut. R&D Note 199 also recommends that general inspections should be carried out every 6 months. In order to inspect the embankment the grass should be cut in the autumn and, if necessary, again in the spring.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Scope of the Problem

A survey of Environment Agency Engineers has shown that fissures in earth flood defence embankments occur in every region of the Environment Agency. The worst affected regions are Anglian, Southern and Wessex which account for over 80% of all reported incidents. Approximately 10% of all the flood defences in England and Wales are reported to be cracked earth embankments.

The incidence of fissuring is related to the local geology. The worst fissuring occurring in areas of high plasticity clays.

Two forms of fissuring have been identified; wide fissures and fine fissures. The former is what has generally been reported by the survey, these being longitudinal, vertical fissures in the crest and are reported to vary in width from 30 to 200mm at the surface and up to 1 metre deep. Wide fissures are most pronounced during the dry summer months and tend to close up during the wetter winter months.

Fine fissuring is not confined to any one part of the embankment but is distributed throughout the top surface to a depth of typically 1.2 metres. These fissures range in width from a fraction of a millimetre to 2mm and are both vertical and horizontal, forming small nodules (pebbles) of clay. It is thought that fine fissures in the body of the embankment do not heal during the winter whereas fine fissures at the surface are likely to heal during the winter. The surface fissures fill with water, the clay swells to form a low permeability surface layer. This prevents further water percolating deeper into the embankment in sufficient volume.

Fine fissuring has only been identified at a few locations but it is considered that as both forms of cracking are due to desiccation of clay it is likely that, where wide fissures have been identified, then fine fissures will also be present. Wide fissures are formed by the rapid loss of moisture from an embankment during the first year or so of its life, while fine fissuring is a much longer process taking a number of years to form.

The extent of fissuring is dependant upon a number of factors, the main ones being;

- the plasticity index of the embankment material, which itself is determined by the clay content and the mineralogy of the clay particles
- the moisture content of the clay when placed relative to its final insitu moisture content

Fissuring has been identified as both a potential and actual cause of embankment failure. During the 1953 floods on the East Coast of England and during the recent Mississippi floods in the USA, a number of banks failed without the flood level reaching the design level. Research at the Building Research Establishment and the recent controlled embankment failure at Tollesbury have reproduced a failure mechanism due to seepage flow through a deeply fissured surface zone.

Two potential failure modes are identified in the manual, firstly due to seepage flow through the finely fissured zone in the outer surface of the embankment. Secondly due to a water head in wide fissures in the crest, leading to instability of the landward face during overtopping.

7.2 Assessment Procedures

Vegetation plays a significant role both in reducing soil moisture content during the dry summer months and in increasing the moisture content during the wetter winter months. There is however no discernible countrywide correlation between mean annual rainfall or the evapotranspiration potential of the UK and the incidence of fissuring. Grasses help to bind the surface of the embankment and provide erosion protection should the bank overtop. Grasses can influence the soil moisture content up to a depth of 1 metre. Trees and bushes influence much greater depths, up to 1.5 times the height of the tree, and also prevent the growth of grasses beneath their branches.

Methodologies (Chapter 3, Appendix D) have been proposed for investigating embankments which are suspected of being fissured. Where embankments have been shown to have wide fissures, investigations should be carried out to determine the presence, or otherwise, of a finely fissured layer.

Recommendations have been made as to the fissuring potential of a wide range of clays. The potential of each material in an Environment Agency region should be checked before materials are used for flood defence embankments.

In order to inspect embankments for defects, including fissuring, visual surveys should take place in the late summer or early autumn. A further inspection in the spring is also recommended.

7.3 Remedial Measures

The stability of critical embankments should be checked for their design condition allowing for seepage flow through a finely fissured surface zone or with a head of water in wide fissures if applicable.

The freeboard allowance for an earth embankment should include an allowance for the effect of fissuring otherwise remedial works need to be carried out to prevent fissuring lowering the effective Standard of Service.

Various remedial measures to remove fissuring have been included (Chapter 4). The most cost efficient appears to be the addition of a layer of granular material rolled into the crest. The resulting material still has a low permeability but also has a lower plasticity index and less tendency to shrink with loss of moisture and hence crack.

The effectiveness and cost of various remedial measures should be monitored.

Good practice recommendations have been included to limit the extent of fissuring. These include the use of a hoggin capping layer or impermeable membrane. Alternatively amendments to the structure are recommended to prevent the presence of fissures reducing the Standard of Service. These include the addition of a berm on the landward face, widening the crest or increasing the height of the crest.

7.4 Design Measures

The freeboard allowance for an earth embankment should either include an allowance for the effect of fissuring or the design needs to include measures to prevent fissuring lowering the effective Standard of Service. Various design measures to limit the effect of fissuring are included in Chapter 5.

The effectiveness and cost of various design measures should be monitored.

Good practice recommendations have been included to limit the extent of fissuring. These include the use of a hoggin capping layer, lime stabilisation or impermeable membrane. Alternatively, amendments to the structure are recommended to prevent the presence of fissures reducing the Standard of Service. These include the addition of a berm on the landward face, widening the crest or increasing the height of the crest.

7.5 Maintenance Measures

The stability of critical embankments should be checked for their design condition allowing for seepage flow through a finely fissured surface zone or with a head of water in wide fissures if applicable.

Trees and bushes draw water from a significant depth. They should therefore not be allowed to grow on an earth flood bank.

In order to inspect embankments for defects, including fissuring, visual surveys should take place in the late summer or early autumn. A further inspection in the spring is also recommended.

Grass cutting practice varies throughout the Environmental Agency regions. In order to limit the extent of fissuring grass should be cut as frequently as possible. It also enables inspections of the embankment to be carried out.

Inspection forms produced as part of R&D Note 199 should be amended to include for fissuring as part of the inspection.

7.6 Further Investigations

The following section outlines the further investigations which have been identified during the course of this project.

Freeboard Allowances - General	Identify the composition of freeboard allowances and standardise throughout the Environment Agency.
Freeboard Allowances - Fissuring	Identify how fissuring should be allowed for within the freeboard, if it cannot be eliminated.
Failure Mechanisms	Determine the staged failure of an embankment with a combination of wide and/or fine fissures.
Embankment Material	Determine the optimum material grading for earth flood embankments, allowing for permeability, ease of placement and liability to fissure.
Moisture Content	Determine the relationship between moisture content at placing, with its liability to fissure and ease of placing.
Mechanisms of Fissuring - 1	Prove the theory that where wide fissures are present in an embankment, fine fissures are also found.
Mechanisms of Fissuring - 2	Establish the sequence of events from the first fissure forming to a highly fissured embankment.

These are discussed in more detail below.

7.6.1 Freeboard Allowances - General

Freeboard allowances are included in the design of earth flood embankments in most Environment Agency regions, although in many responses to the questionnaire issued as part of this project (38%) the actual value of freeboard allowance was not known. The consensus (about 60%) was that they adopt a freeboard allowance of between 300mm and 600mm, although they do not know the composition of that allowance. At present the Environment Agency does not issue any guidance on this subject.

Although not directly relevant to this project, it is considered that the Environment Agency should produce guidelines detailing the various parameters that need to be considered, and quantified, when applying a freeboard allowance to either an earthen embankment or a hard flood wall.

7.6.2 Freeboard Allowances - Fissuring

It is considered that one factor that needs to be considered when either determining the current Standard of Service of an embankment or designing a new embankment, is the tendency of the embankment material to fissure. At present the freeboard allowance does not generally appear to bear any relationship to fissuring. For new embankments the recommendations of this report should eliminate, or significantly reduce, the effects of fissuring. For existing embankments however fissuring is likely to reduce the SoS, although by how much is not known.

Some preliminary freeboard allowances are proposed in this report, if no measures are taken actively to prevent the occurrence of fissures, based on the tendency of the material to fissure and the sensitivity of the site protected. Investigation of the logic of this approach and a more detailed assessment of the parameters involved need to be carried out to produce a relationship between fissure depth and freeboard allowance.

7.6.3 Failure Mechanisms

This report has identified two possible failure mechanisms associated with the presence of fissures; one due to fine fissures and the other to large fissures. Fine fissuring can lead to flow through the upper surface of the embankment, with subsequent washout and breach, without the still water level reaching the crest. This may occur without the action of waves. Failure due to the presence of wide fissures is associated with significant quantities of water within the fissures, generally in the crest, leading to slip failures of the landward face. Although rainwater has been cited as a possible source of the water, it is more likely to be due to overtopping by waves. Failure of most fissured earth embankments is likely to be due to a combination of these two mechanisms.

The opportunities to study the failure of an earth embankment at prototype scale are few. It is therefore recommended that these two failure mechanisms be studied both separately and jointly using physical models.

7.6.4 Embankment Material

The use of locally won material for earth flood embankments is an established practice within most Environment Agency regions. Recently, due partly to the recognition of the potential problems associated with fissuring, there has been a move in some regions actively to select the material for forming the embankment. This has led to increased costs for what is perceived to be a more reliable product. The 'ideal' material is seen as a 'hoggin'; a well-graded mixture of granular and cohesive soils. Opinions differ as to the grading required. The more prescriptive the specification the more difficult the material is to source and hence more expensive.

The requirements for an earth flood embankment are that it should not fail by any means during the design event and should prevent significant leakage at all water levels. These are matters of design based on the particular materials used. Using either a short drainage path through a low permeability material or a much longer drainage path through a more permeable material can reduce leakage. The use of clay as a low permeability material compared with the more permeable hoggin needs to be investigated. No independent tests have been carried out to quantify the benefits of a hoggin material over a clay regarding its tendency to fissure.

7.6.5 Moisture Content

To achieve maximum compaction, and thus minimum permeability, clay for embankments is usually placed at the optimum moisture content: between the plastic limit minus 5% and plus 2%. The ability to achieve compaction generally reduces with lower moisture content. If clay could be placed at a much lower moisture content then its tendency to fissure would also reduce.

An investigation into the practicability of placing clay at lower moisture contents should be carried out with an assessment of the increased permeability produced for clays of different plasticities. The ideal would be a range of moisture contents at which the clay is still workable and produces a compacted material with sufficiently low permeability but without the tendency to fissure.

7.6.6 Mechanisms of Fissuring - 1

This report has postulated the theory that where wide fissures are present fine fissures also occur. This cannot be established without further extensive site trials. Embankments of different ages need to be investigated by the construction of trial holes, looking at the occurrence of wide surface fissures and fine fissures at depth. The depth and extent of fine fissures should be measured at the same time.

7.6.7 Mechanisms of Fissuring - 2

Although wide fissures have been observed in many embankments during this investigation, the sequence of events leading to the transition from wide surface fissures to fine fissures within the body of the embankment has not been established. The mechanism by which an embankment begins to fissure and how these individual fissures propagate through the surface layer is not understood. A series of field mapping of fissure patterns in embankments of different ages, allied with laboratory experiments is required. Any correlation between fissure development and cohesive strength should also be investigated.

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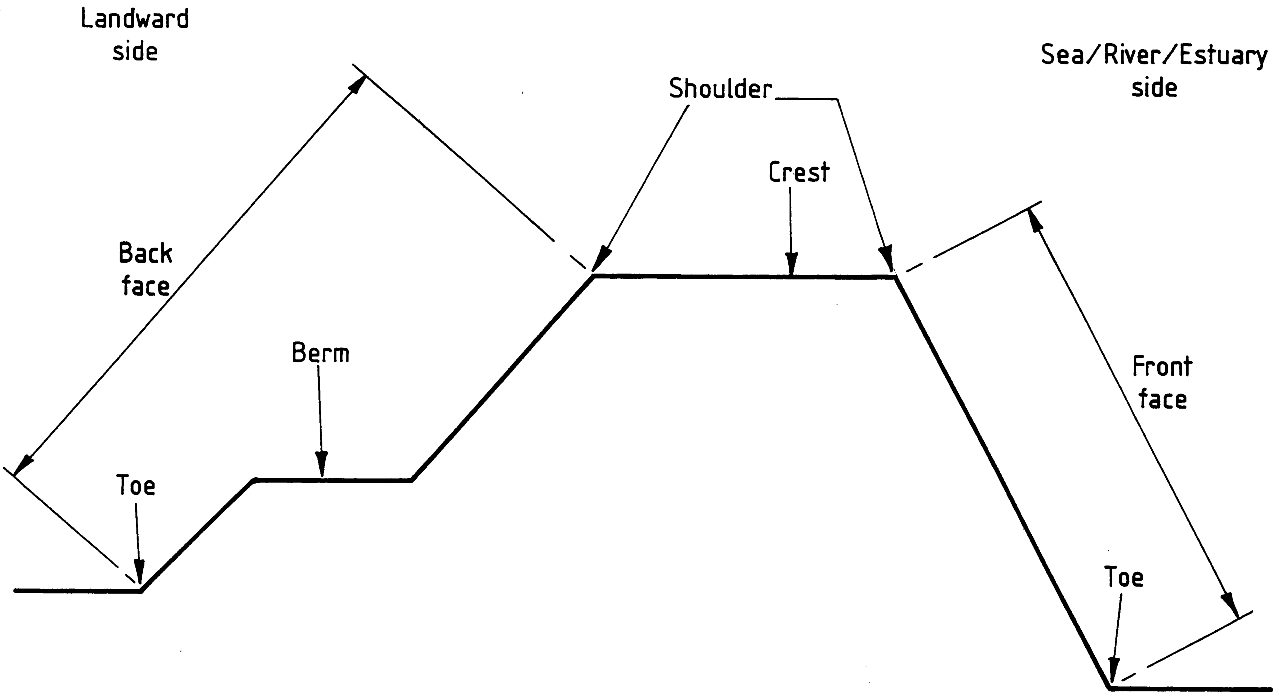
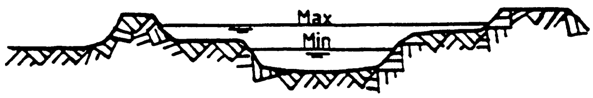


Vertical Section

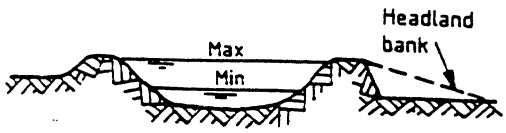
Definitions

Fig. 1



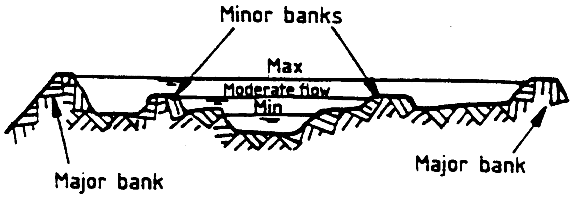
Flood banks set back from river

Under normal conditions dry both sides



Flood banks next to river

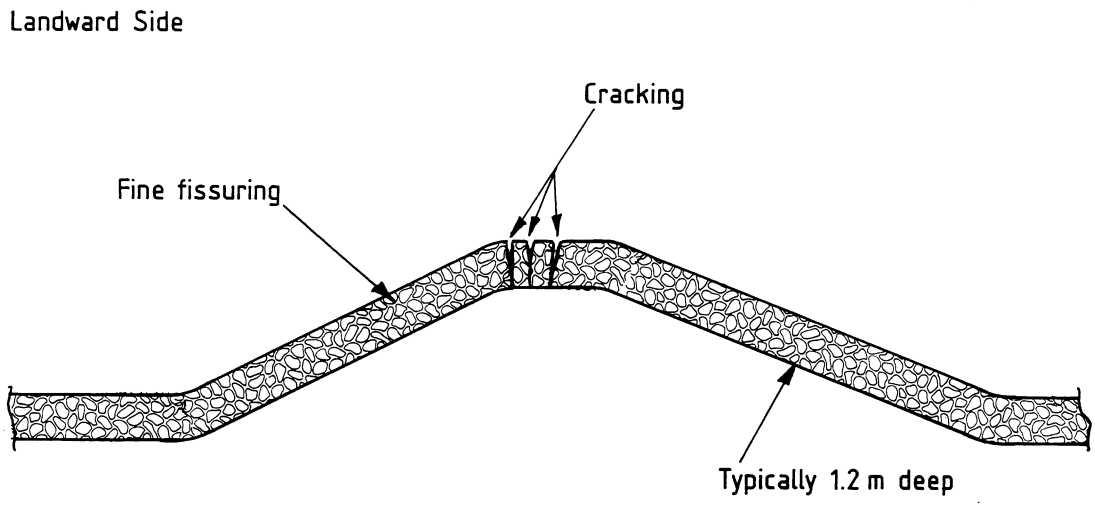
Under normal conditions dry one side and wet the other



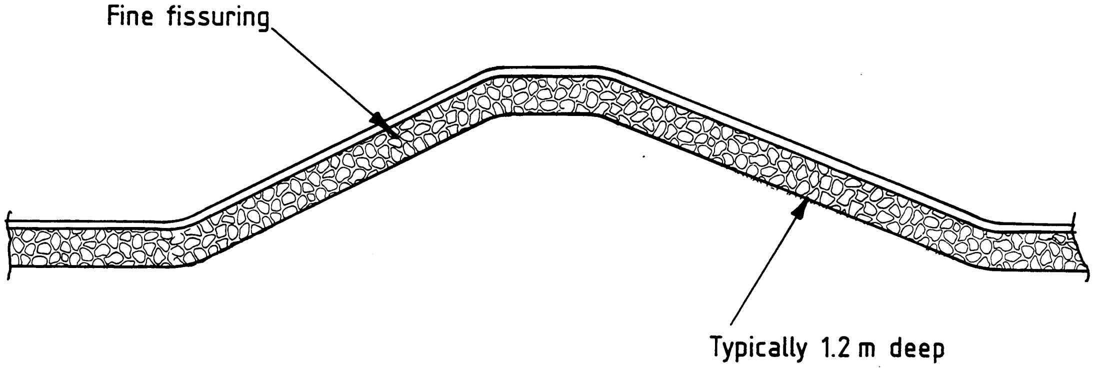
River with minor and major flood banks

Under normal conditions major banks dry both sides, minor banks wet one side

Types of Flood Defence Earth Embankments	Fig. 2



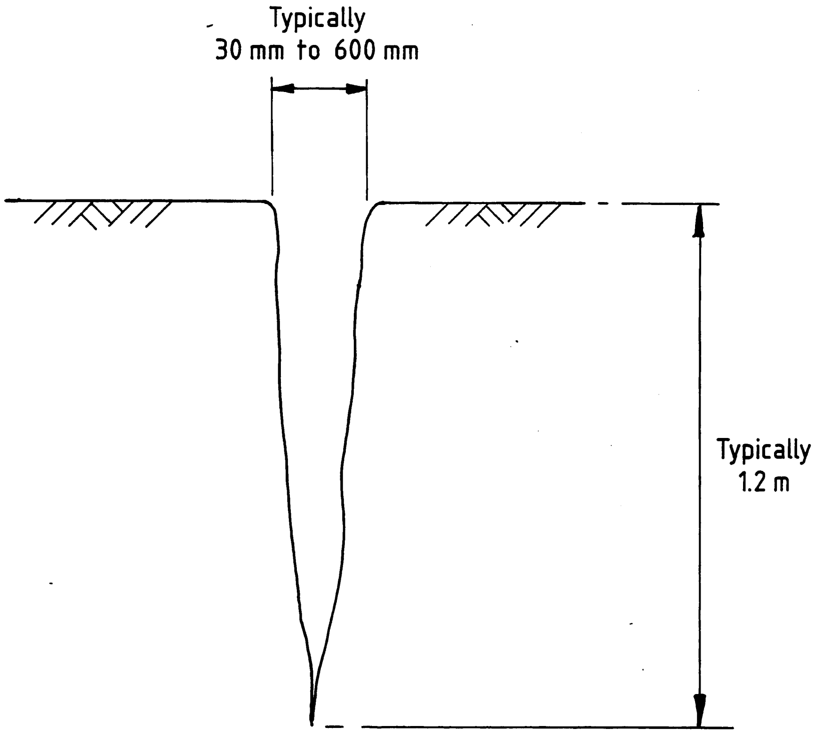
Summer



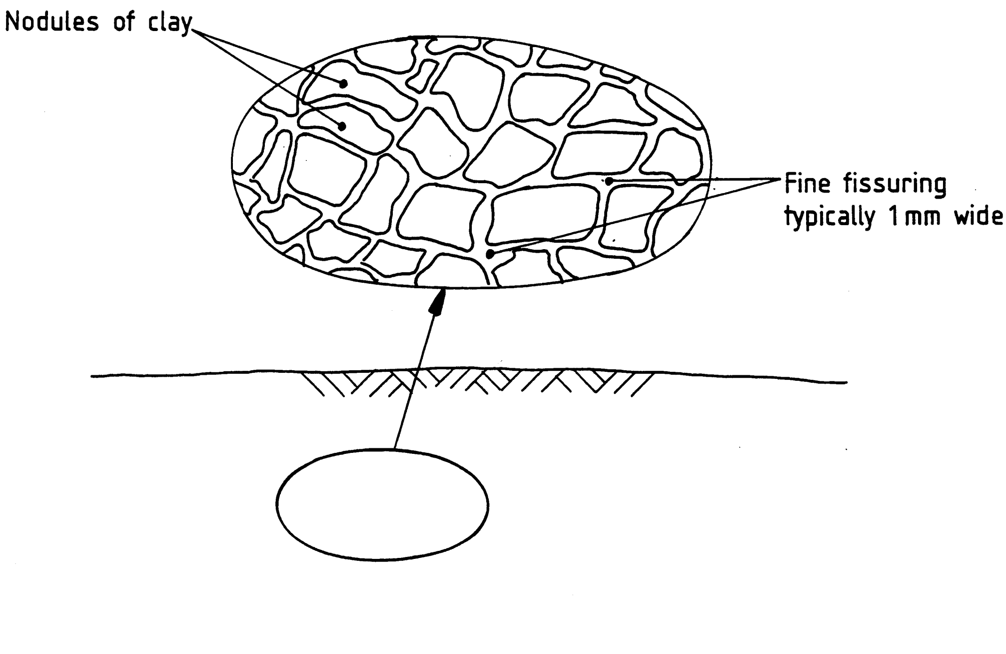
Winter

Typical Distribution of Cracking and Fissuring

Fig. 3



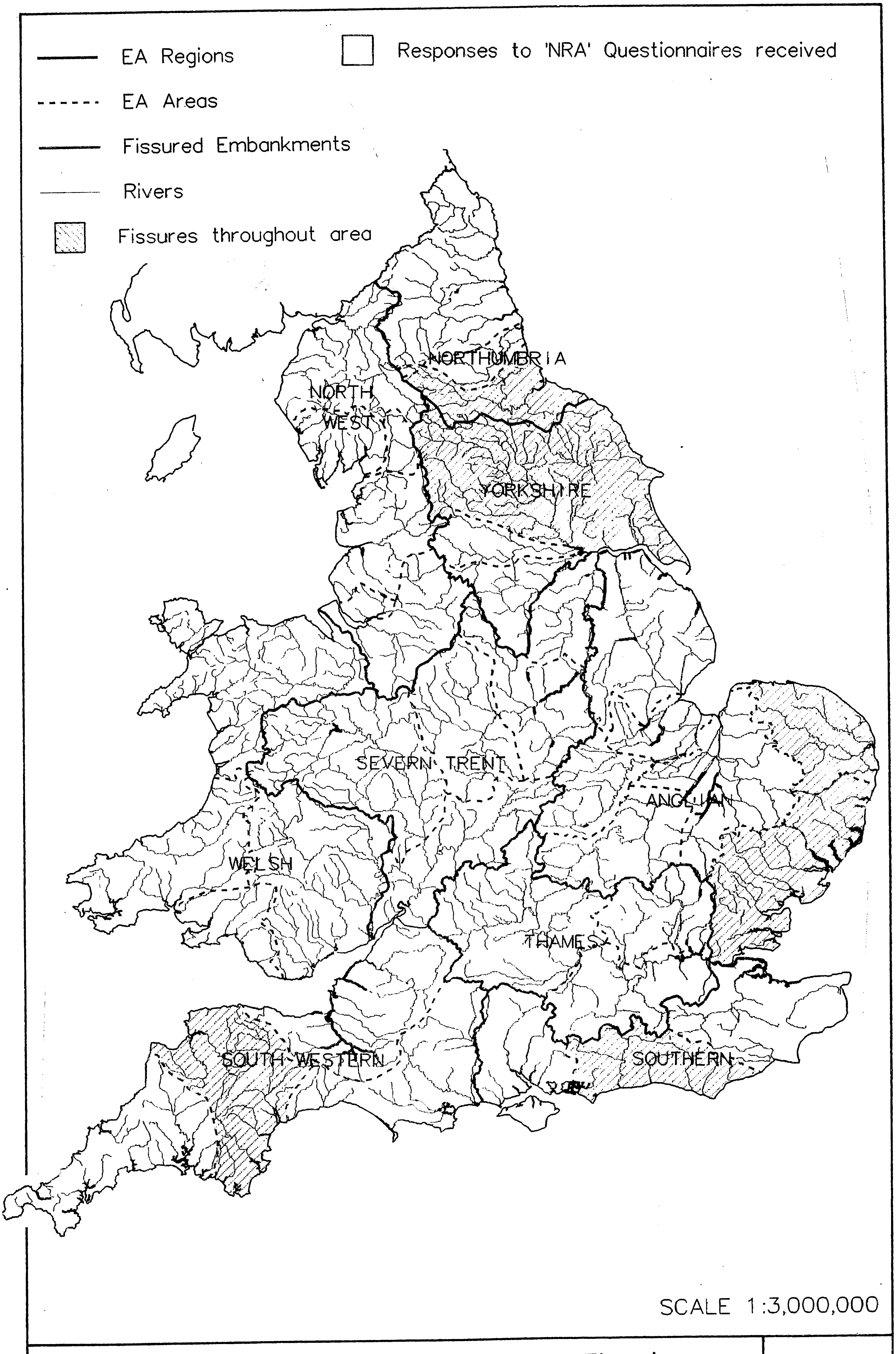
Crack



Fine Fissures

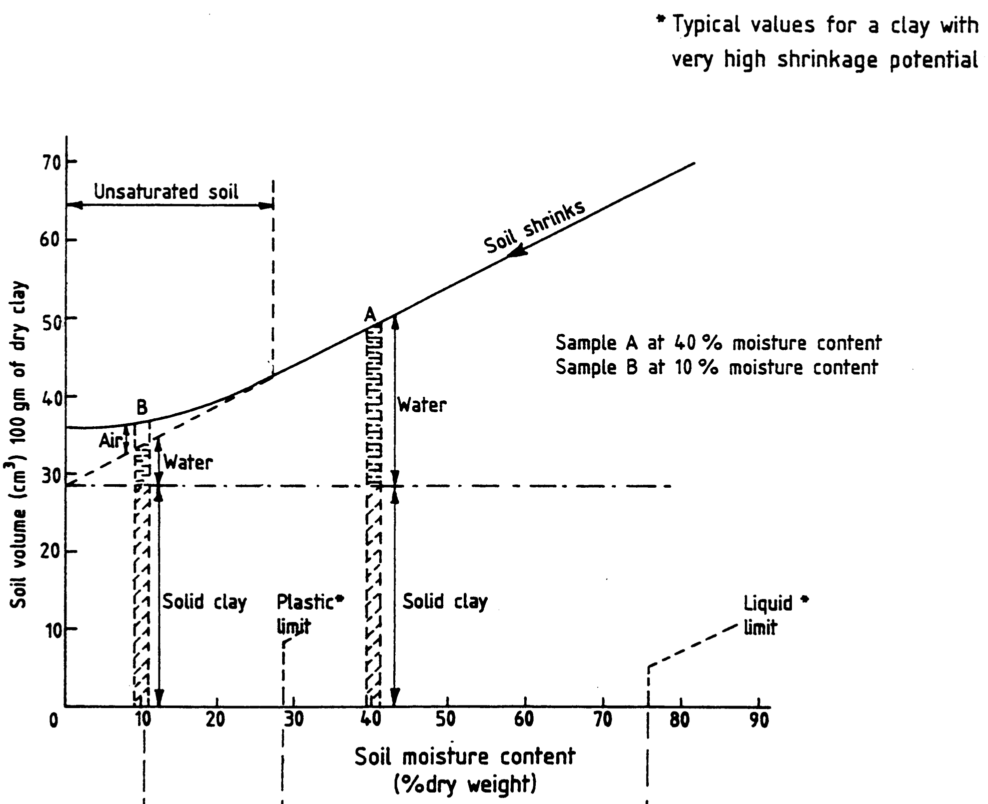
Fissure and Crack Characteristics - in Section

Fig. 4



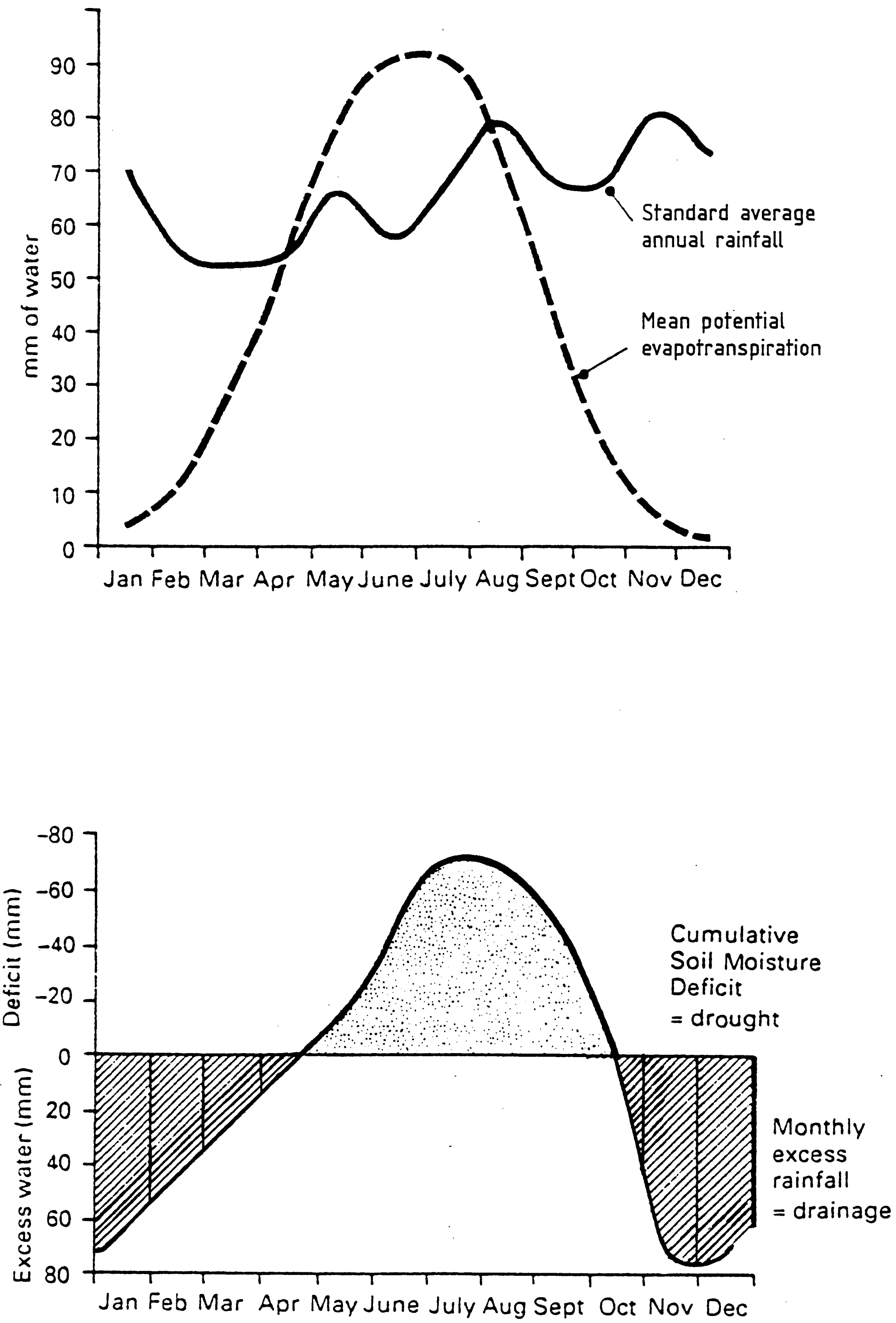
Geographical Extent of Reported Cracking and Fissuring

Fig. 5

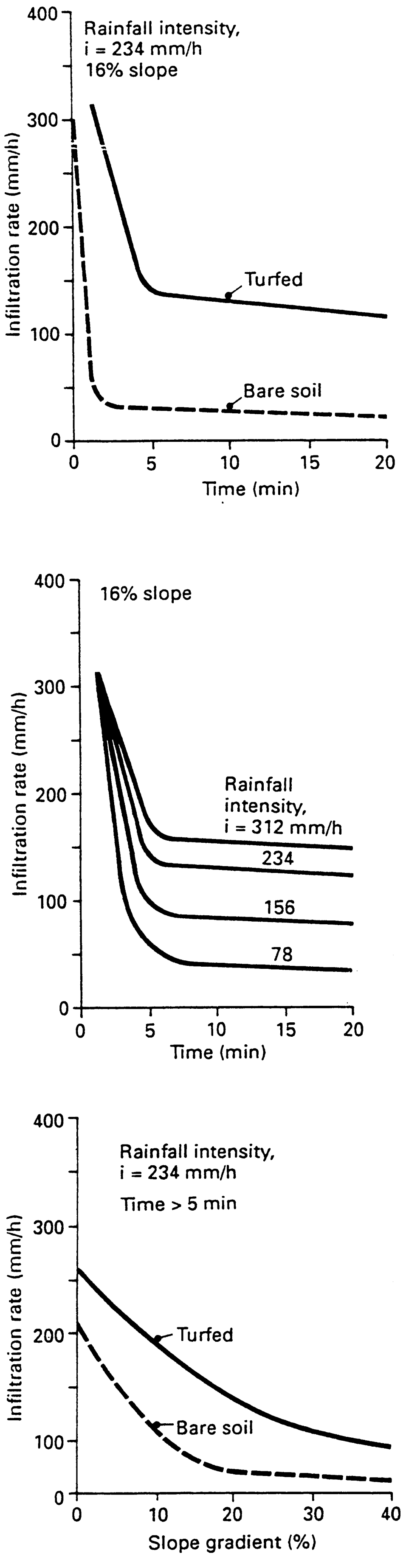


Phase	SOLID STATE	SEMI-SOLID STATE	PLASTIC STATE	LIQUID STATE	SUSPENSION
Water	← Water content decreasing				
Limits	Dry soil	Shrinkage Limit SL	Plastic Limit PL — Plasticity Index I_p	Liquid Limit LL	
Shrinkage	Volume constant	← Volume decreasing			
Condition	Hard to stiff	Workable	Sticky	Slurry	Water-held suspension
Shear Strength (kN/m²)	← Shear strength increasing		(~170) (~1.7)	Negligible to nil	
Moisture content	0	W_s	W_p — PI	W_L	

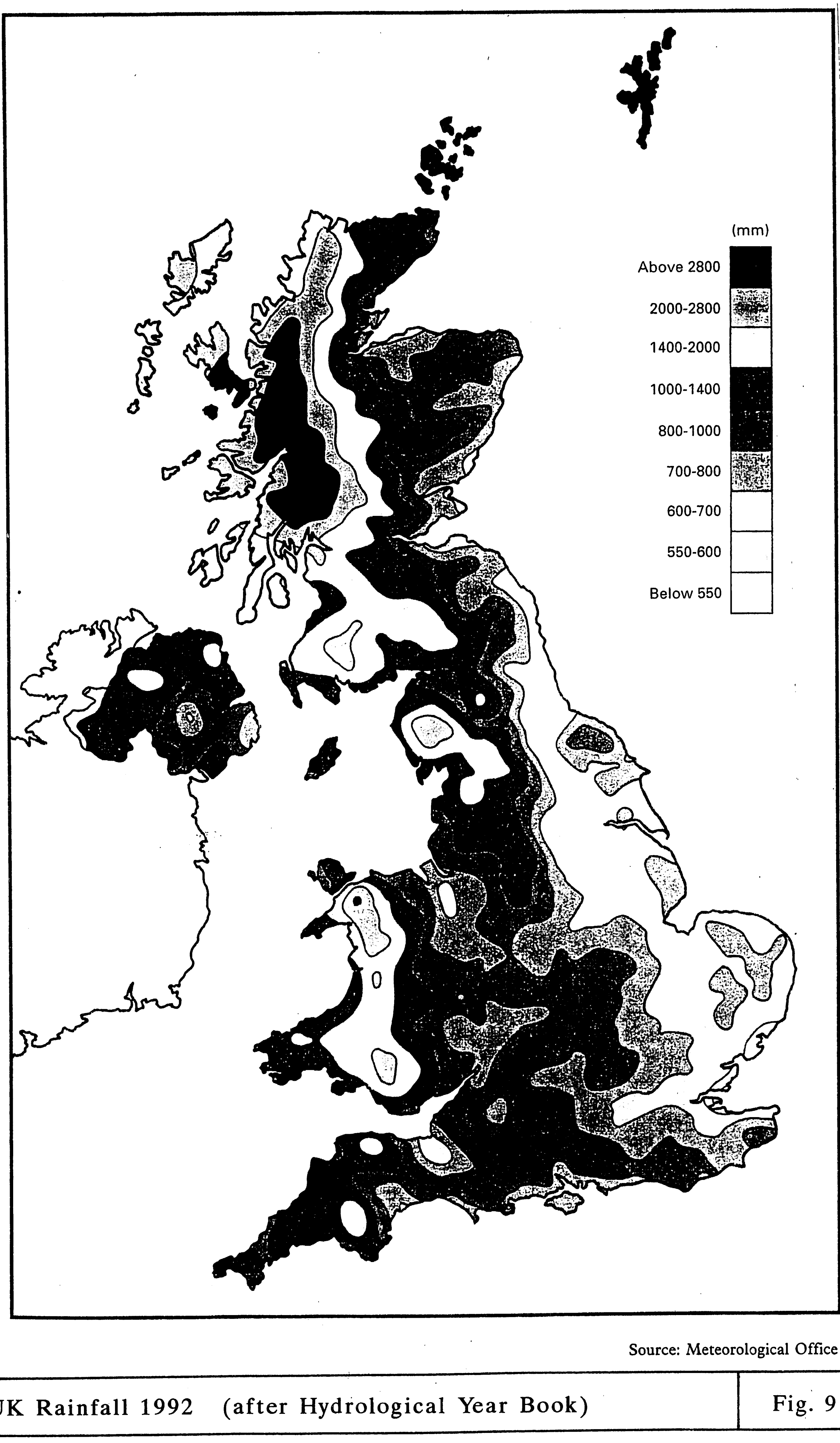
Phases of Soil and the Atterberg Limits | Fig. 6



Soil Moisture Balance (after CIRIA) | Fig. 7



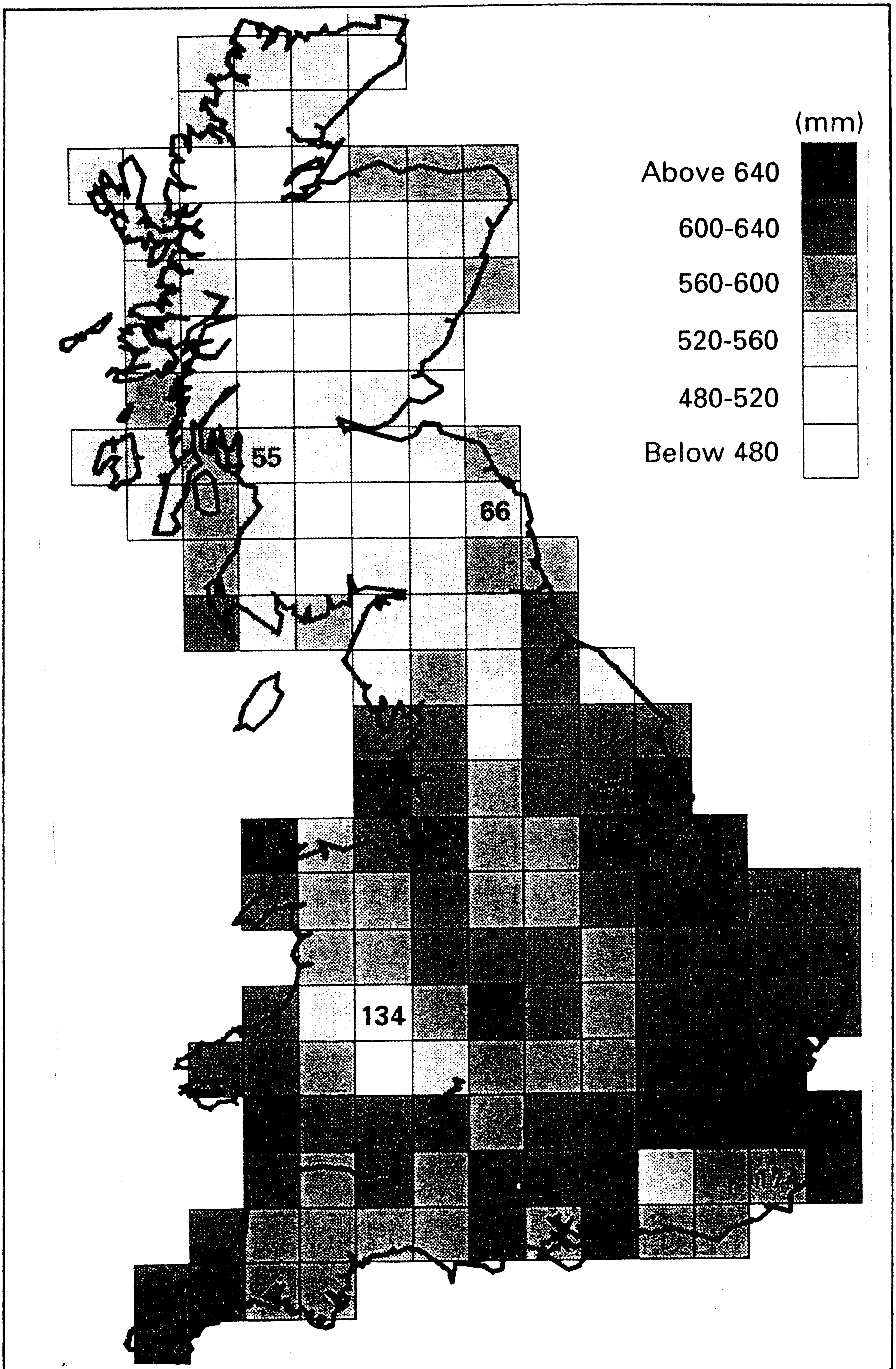
Variation of Infiltration Rate with Vegetation, Rainfall and Slope Gradient (after Nassif and Wilson, 1976)	Fig. 8



Source: Meteorological Office

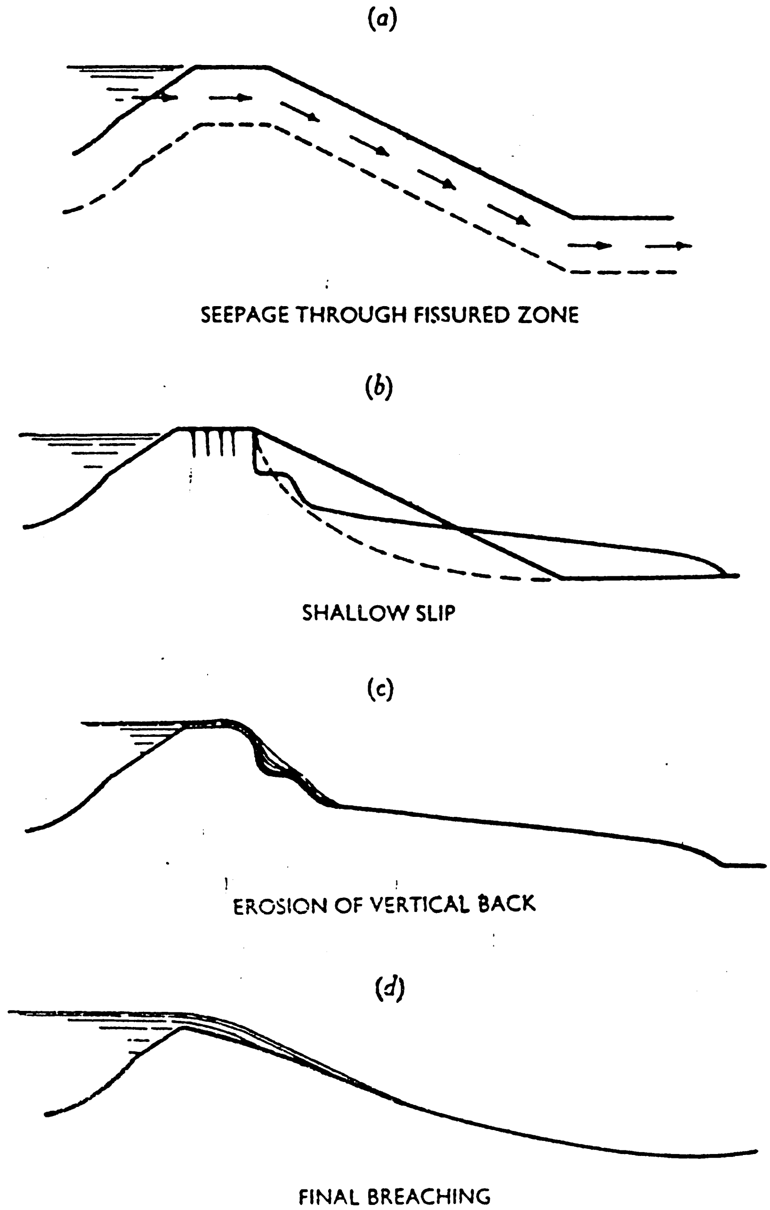
UK Rainfall 1992 (after Hydrological Year Book)

Fig. 9

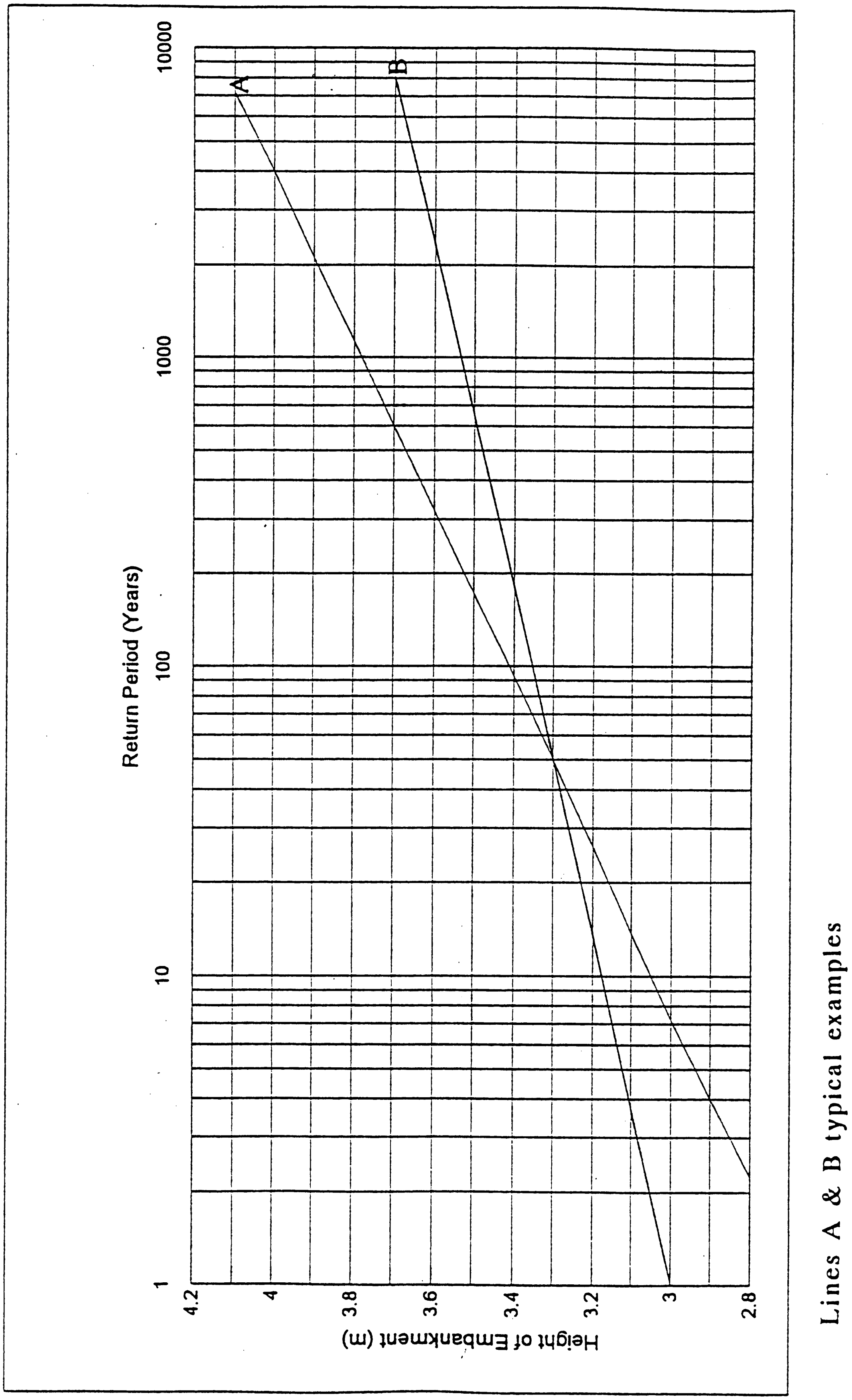


Potential Evapotranspiration from Grass (after Hydrological Year Book)

Fig. 10

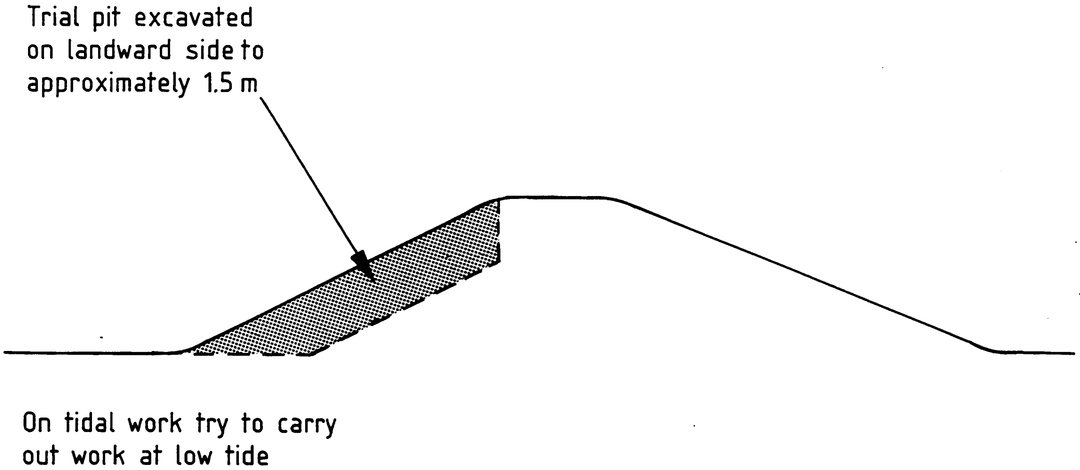


Development of Breaches from Shallow Slips (after Marsland 1953) | Fig. 11

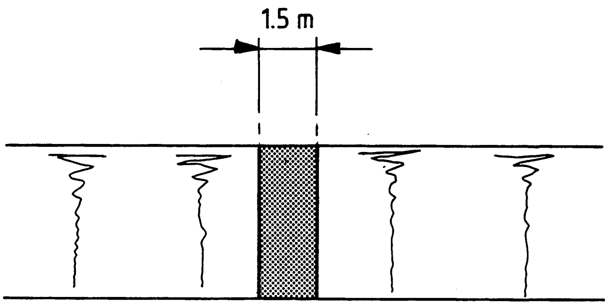


Plot showing Embankment Height/Return Period

Fig. 12



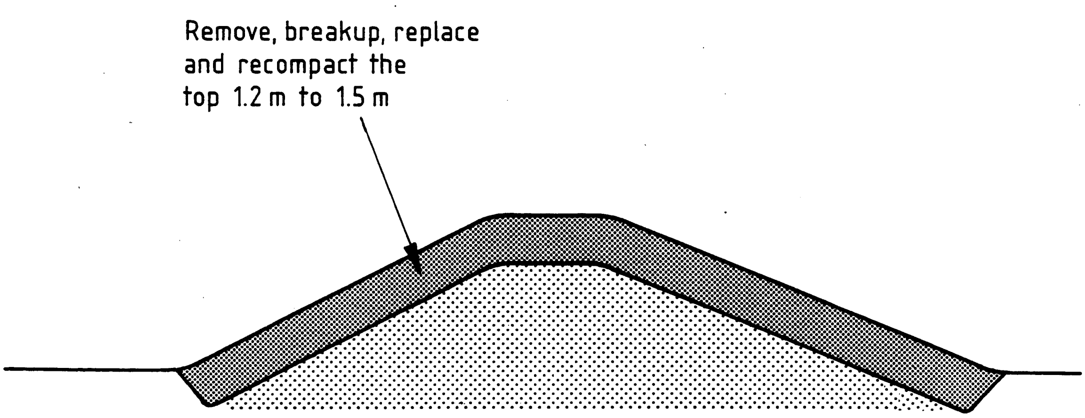
Vertical Section



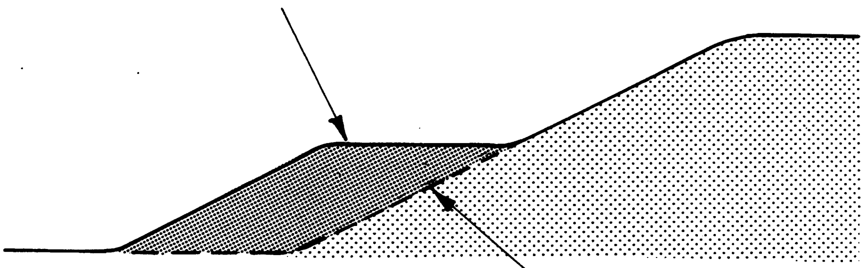
Elevation

Location of Trial Pit to Identify Fine Fissuring

Fig. 13

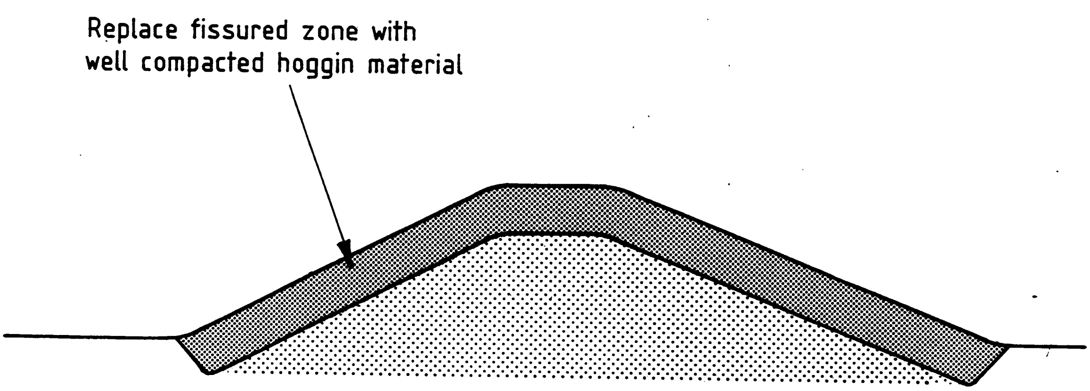


Vertical Section



Vertical Section

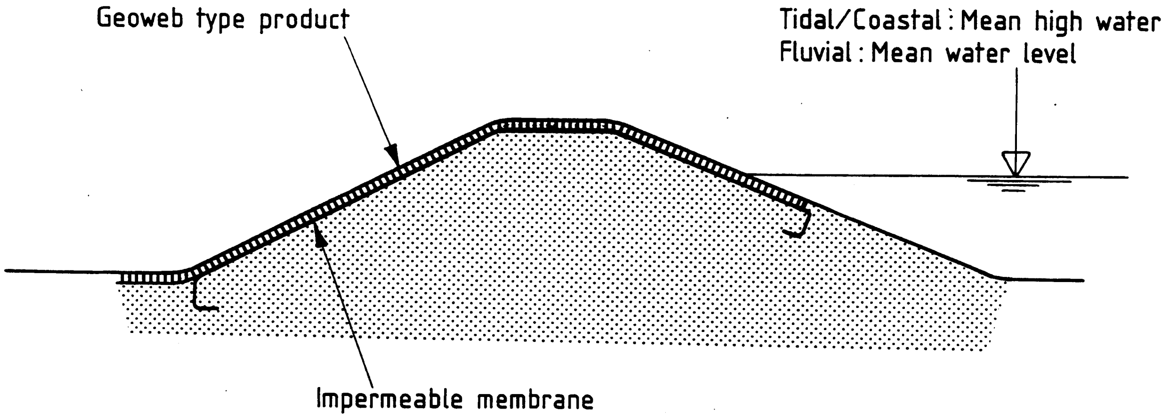
Berm	Fig. 15



Vertical Section

Replacement with hoggin

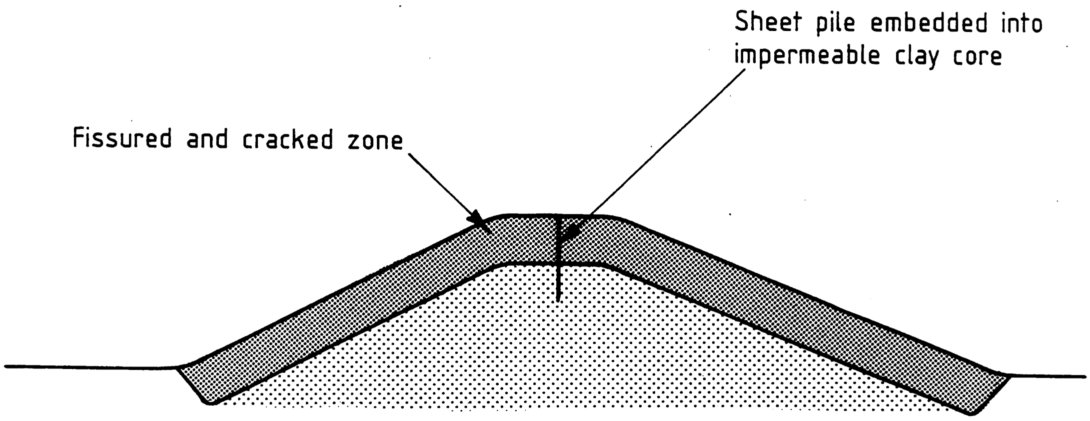
Fig. 16



Vertical Section

Impermeable membrane

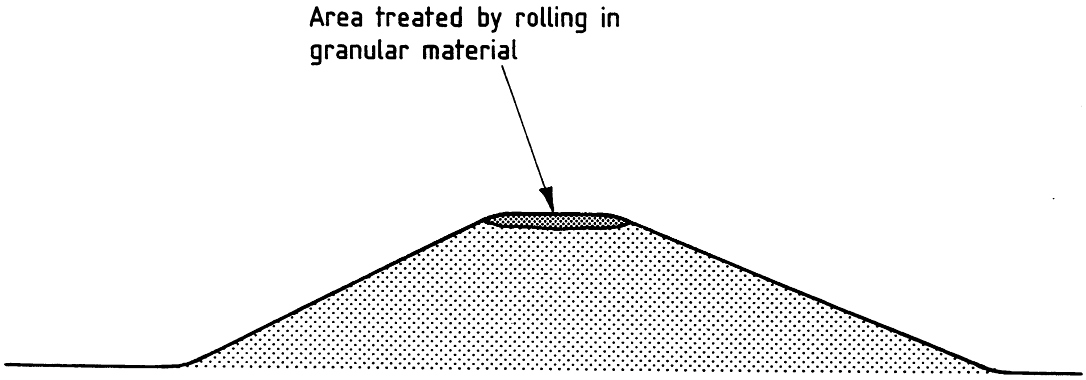
Fig. 17



Vertical Section

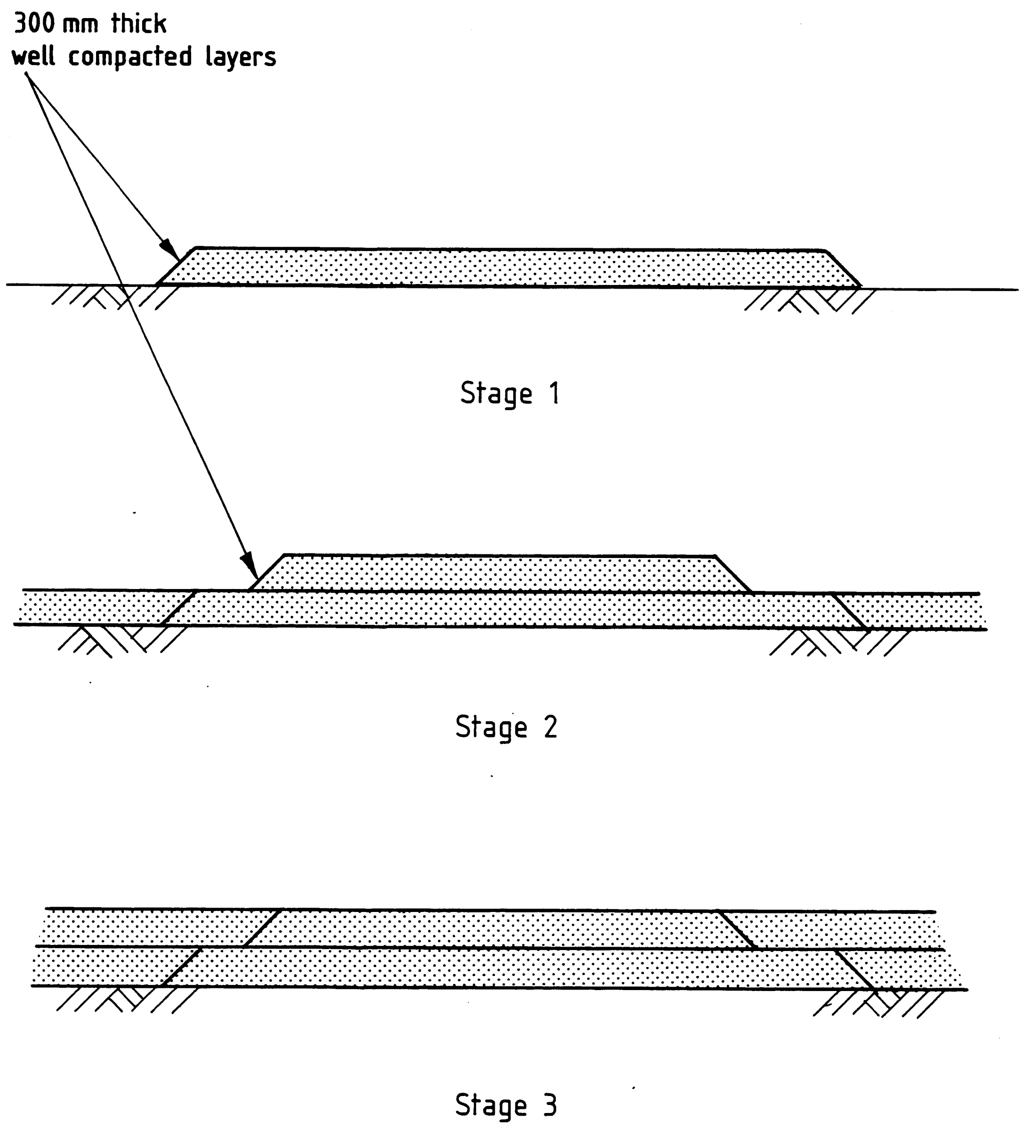
Sheet Pile Cut Off Wall

Fig. 18



Granular Crest

Fig. 19



Layered Construction

Fig. 20

APPENDIX A
Terms of Reference

SCHEDULE II
SPECIFICATION FOR SERVICES

NATIONAL R&D PROJECT C06(95)04: Earth Embankment Fissuring

D9.1 Introduction

D9.1.1 Overall Objective:

To investigate the extent and causes of fissuring in flood defence earth embankments and the implications for standards of service, design and maintenance procedures.

D9.1.2 Specific Objectives:

D9.1.2a To undertake a desk study to review the available international literature on embankment fissuring;

D9.1.2b To undertake a closely targeted questionnaire survey of relevant interest groups internally and externally to the NRA/Environment Agency;

D9.1.2c Following the above exercise, to determine preliminary details of flood defence embankments, their performance and fissuring problems in terms of an assessment of existing flood defence standards, maintenance and design;

D9.1.2d To recommend actions and develop guidelines for management of flood defence embankments liable to fissuring and subject to varying water loadings, in particular:

- ☐ to assess standards of service;
- ☐ to achieve cost effective design;
- ☐ to achieve cost effective construction;
- ☐ to achieve cost effective maintenance.

Please note, NRA also maintains flood defences embankments which have weak foundations, and any actions and recommendations should ensure that this is taken into account.

D9.1.2e To finalise the draft guidelines, as appropriate, to form either a Guidance Manual or an Interim Guidance Note;

D9.1.2f To provide advice, in the form of recommendations in an R&D Note, on the need for further research, or other investigations, which might be necessary (ie: site investigations, laboratory experimentation, full scale tests, etc);

D9.1.2g To produce a summary draft Project Initiation Document for any further research projects identified, in the form of an R&D Project Record.

D9.2 Background

NOTE: The duties of the National Rivers Authority, Her Majesty's Inspectorate of Pollution and the Waste Regulation Authorities will be transferred to the Environment Agency (EA on 1 April 1996. This project will be delivering to the Environment Agency. The objectives and approach required should not alter as a result of the changes in organisation structure.

The NRA/EA is responsible for thousands of miles of inland and coastal flood defences consisting in whole or in part of earth embankments. An unknown number of these are thought to be liable to fissuring.

Maintenance and the periodical improvement, replacement and repair of these embankments accounts for a significant proportion of the NRA's Flood Defence budget.

Fissuring can greatly affect the performance of an earth embankment. To underestimate its effect may lead to an over-estimation of the standards of service and under-design. To overestimate its effects leads to unnecessary expenditure.

There are indications that the Authority is losing the awareness of fissuring and that the continuing of established procedures is becoming impossible. It is therefore timely for the NRA/EA to review its response to embankment fissuring.

The results will tie into the management of assets and standards of service data required to provide effective flood defence.

The condition and properties of earth embankments need to be determined in order to enable maintenance and renewal activities to be carried out in the most effective manner.

D9.3 Contractor Performance

Contractors should be aware that their approach to the work described below must meet and fully satisfy the objectives of the project, including both timescales and reporting requirements. The performance of any contract will be monitored against these criteria.

Assessment of the quotes will be as specified in Schedule II, Section D6 of this Invitation to Quote.

D9.4 Programme of Work

D9.4.1 The study will consider the extent and significance of the occurrence of fissuring in flood defence embankments and make recommendations for assessment of standards, design techniques for avoidance, operational management and further research if required.

D9.4.2 Literature Review

A literature review of available published information is to be undertaken in order to determine the extent of present knowledge concerning fissuring in earth embankments. The review should take into account NRA, external and international publications.

Tenderers should indentify preliminary sources of information in their quote.

D9.4.3 Questionnaire Survey

(a) A questionnaire is to be prepared in conjunction with the Project Leader and Regional R&D Co-ordinator for circulation to NRA Regions and other embankment managing Authorities. The consultation will be undertaken prior to issuing the questionnaire in order to ensure that staff are carefully targeted within the organisations identified. This list will need to be approved by NRA/EA before the questionnaire is issued.

(b) Key staff will be identified from the returns and follow up discussions held in order to secure the maximum understanding of the areas of concern, knowledge/understanding and extent of the problem.

D9.4.4 Review of Archives

A review of archive data will be required in order to fill any gaps in knowledge, or where information obtained from the questionnaire is unsatisfactory. It is likely that this will take the form of further studies at identified archives of interest.

If possible, Contractors should identify likely archives of interest.

D9.4.5 Recommendations

Make draft recommendations for actions taking into account the information obtained in the project to date. These recommendations will be reviewed by Flood Defence staff prior to being agreed for inclusion in the final reports.

D9.4.6 Draft Guidelines

Draft guidelines will be required for review by EA staff. These will be in the format specified by the EA (based on the draft format document supplied with this invitation to quote). The guidelines should show an awareness of the needs of the EA for the information, the target audience, other relevant documentation and the use to which they will be put.

These guidelines will be produced as a permanent document or to an interim document, as appropriate.

Contractors should provide information on how they view this document and provide an initial outline of the expected contents.

D9.4.6 Final Reporting

(a) Write a draft R&D Project Record for review by the Project Board providing draft Project Initiation Documents for any identified further projects (R&D or other). The Project Record will also include all relevant information on the research undertaken throughout the project;

(b) Write a draft final R&D Note for review by the Project Board to include discussions, conclusions and recommendations on the uptake and implementation of the research to the EA and provide linkage to the guidance report;

(c) Make amendments to the project reports as required by the Project Board and provide final versions (single copies) for a quick review;

(d) Produce the specified number of the R&D Project Records, R&D Notes and guidelines for EA staff and wider dissemination.

APPENDIX B
R&D Note 199, Asset management for Flood Defences, Section 9

9. INSPECTION AND MONITORING

9.1 Introduction

The purpose of this chapter is to consider how to plan, carry out and make use of the results of inspection and monitoring of flood defence assets.

Monitoring in this context means the recording and comparing of a condition or a parameter over a period of time. It is therefore an integral part of the inspection process.

9.2 Reasons for inspection

Inspection is an important task which serves a number of purposes:

- to provide a baseline set of data. Baseline surveys have been previously mentioned in Chapter 3 where they were stated as being needed to provide data for checking that assets were capable of performing to the specified standard. Such surveys can also provide a datum against which subsequent inspection results can be compared.

- to record that the asset is in a serviceable condition or to record the degree of unserviceability. Another term for this is condition assessment.

- to identify the need for preventive action, such as some type of routine maintenance to prevent deterioration e.g. repainting of steelwork.

- to detect incipient defects at an early stage.

- to monitor the development of such defects and to determine the timing and type of corrective action. An example would be steel sheetpiles which are allowed to go on corroding until the residual thickness of steel is below an acceptable level. The corrective action is either the repair or replacement of the sheetpiles.

- to check that construction and maintenance work have been properly carried out. Such inspections are particularly needed where the client/contractor split is operating or where an outside contractor is employed.

- to prepare records of the rate of different types of deterioration to assist with maintenance planning and the assessment of asset lives. Such records will provide data for optimising inspection intervals and the times between routine maintenance operations.

- to provide feedback on the performance on particular types of asset to the NRA.

- to check on changes in service conditions (i.e. the operating environment of assets). An example is construction by others of structures which interact with flood defences or the local water environment.

- to ensure compliance with legal and other obligations. Examples are Health and Safety regulations and conditions attached to agreements with landowners.

The wide range of purposes served by inspections needs to be allowed for in the way inspections are planned, carried out and recorded.

9.3 Inspection strategy

One method of classifying the main types of inspection is that used by the Department of Transport for the inspection of bridges. Their "Bridge Inspection Guide" identifies four main types of inspection:

- superficial;
- general;
- principal;
- special.

Superficial inspections are a quick check for damage or obvious faults and are made during the course of other duties.

General inspections are made at intervals of not more than two years by visual methods, without any special access or other equipment.

Principal inspections involve close examination of all parts of the structure at intervals not exceeding 6 years, with whatever access and other equipment may be needed.

Special inspections are made after an incident such as impact damage, overloading or flooding.

Inspection of mechanical and electrical equipment on bridges is carried out separately by specialists.

Another possible comparison is with the system of monitoring and inspection required for reservoirs as a result of the Reservoirs Act 1975. The Act applies to all *large raised reservoirs*, which are those 'designed to hold, or capable of holkding, more than 25 000 cubic metres of water above the natural level of any part of the land adjoining the reservoir'. This comparison is particularly relevant to large flood banks or embanked rivers where the volume of water which might be released in the event of a failure could be substantially more than this threshold volume.

Under the Reservoirs Act a series of 'panels' of engineers have been constituted, comprising engineers qualified to carry out periodic inspections and to undertake the supervision of reservoirs covered by the Act. Inspections are carried out by an *inspecting engineer*, who must be independent of the owner of the reservoir, at maximum intervals of ten years, or at any lesser interval that may have been recommended in the report of the previous inspection. The Act also requires the employment of a *supervising engineer*, who need not be independent of the owner, whose duty is to 'supervise the reservoir and keep the undertakers advised of its behaviour in any respect which might affect safety'. He must give the owner an annual report of his actions and would be expected to visit the reservoir at a maximum interval of one year for a low-hazard reservoir, but perhaps as oftens as monthly for a major reservoir representing a major hazard.

Another approach is given in the PIANC report on *Supervision and control of long lateral embankments* which suggests visual inspections every two weeks for embankments retaining major waterways.

There is a wide range of existing arrangements within the NRA for the carrying out of inspections. It is proposed that the NRA inspection strategy should be based on a modified form of the DoT bridge inspection procedure as follows:

Type of inspection and frequency:

- baseline survey - once only
- superficial inspections - casual as opportunity arises
- general inspections - at intervals of 6 months to 2 years
- principal inspections - replaces general inspections every 3 or more years
- special inspections - after storms or high flow or other incident
- level surveys - at intervals of one to ten years.

Other types of inspections:

- structural inspections - if called for as result of general or special inspection
- underwater inspection - if called for as result of general or special inspection
- culvert inspections - once every five years
- electrical and mechanical inspections - as planned for each installation

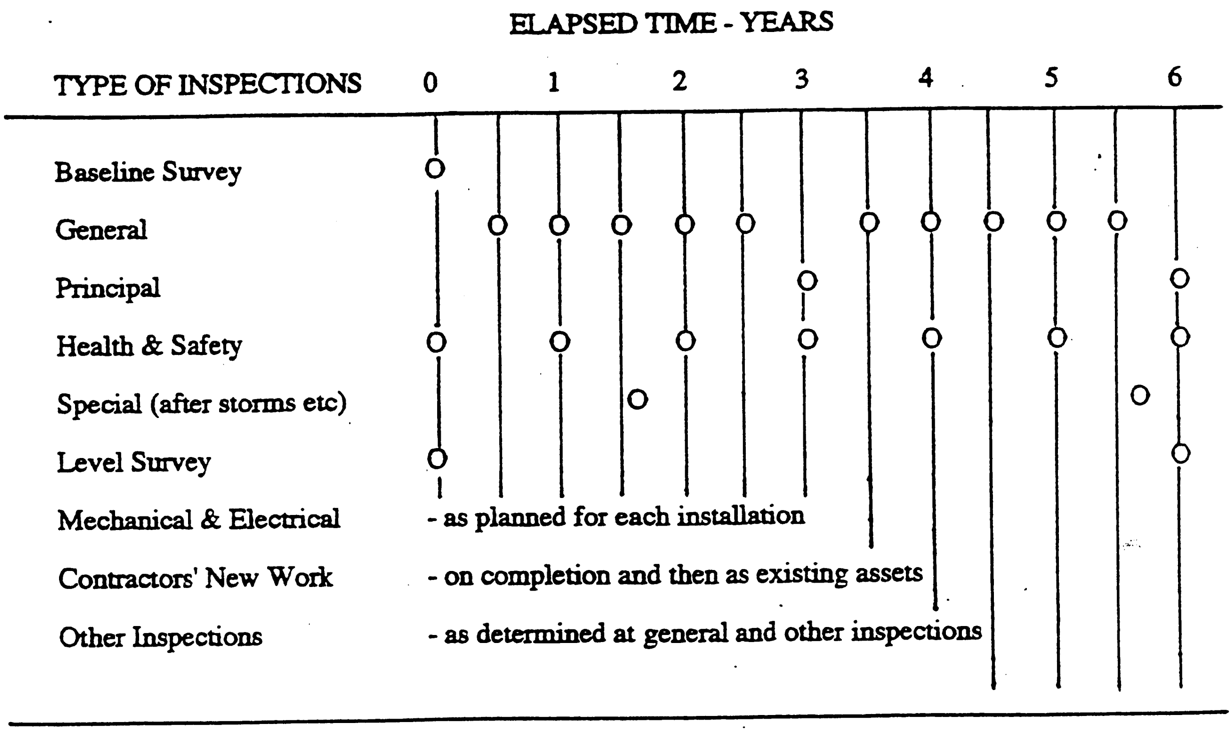


Figure 9.1 Typical inspection programme

- health and safety inspections - once a year
- inspections of work by contractors - during and after completion of work.

A typical programme of inspections is shown as Figure 9.1.

The various types of inspections are explained in the following paragraphs.

9.4 Baseline Surveys

Baseline surveys were referred to briefly in Chapter 3 where it was stated that they were required if insufficient information was available to define a flood defence system and to check the serviceability of individual assets in the system. Ideally the original *as made* drawings and construction specifications would provide the data for the baseline survey. In most cases such information is not available and, where justified by the importance of the assets, special baseline surveys have to be planned and carried out. The scope of such work goes beyond normal inspections and includes investigations. The output of such a survey will be data on the characteristics and functioning of the flood defence systems, together with an asset register of the individual components of the systems. One form of an asset register given as the modified version of the NRA Severn-Trent Region internal document *Flood Defence Asset Surveys - Specification for the Final Report* which is based on the methodology of Stage 1 report of this project.

The first stage of the baseline survey will consist of the assembly of available maps, drawings and reports, a walkover survey and the assessment of what further surveys and investigations will be required to provide the necessary information. As mentioned in Chapter 3, the extent of that information will vary according to the likely frequency of flooding and the importance of the area at risk. Thus for areas where the risk of flooding is low and/or the importance of the area at risk is low, the amount of data required will be small. Conversely, comprehensive data will be required where important urban areas are at risk.

The minimum data needed to define a flood defence system is given in Chapter 3 in paragraph 3.6 although some of the information could be omitted for the least important areas. For more important systems as much data as possible should be collected on individual assets, unless it can be shown by visual inspection and engineering assessment that the asset is fully adequate for its role in the system. Where no construction drawings are available, details of assets such as walls are difficult to find out without very extensive and expensive investigations. If, from knowledge of the range of water levels, waves, loadings and currents to which the wall has been subjected and from observation of the wall, it can be assessed as stable and adequate, there is no point in undertaking further investigations. Thorough inspection and assessment by experienced engineers is needed in the first stage of a baseline survey to plan the extent of investigations in the second stage. Advice on some of the above aspects is given in Chapter 10.

The most important outputs from the baseline study are the following:

- the asset data base
- details of asset upgrading work required to meet target standards of service
- rational strategies for inspection and maintenance
- reach specifications of parameters to be achieved

- baseline condition data from which to measure any further deterioration.

9.5 **Superficial inspections**

Superficial inspections are checks for damage or obvious faults. These inspections are carried out by NRA staff, NRA contractors, farmers and others going about their own business, but sending in reports of anything which may affect the performance of watercourses or flood defences. This practice is to be encouraged. Such reports may then give rise to Special Inspections by NRA inspectors or engineers.

Reports of Superficial Inspections will normally be informal reports - often by telephone - describing an apparent fault in the flood defences or watercourse. In the fens where the river banks retain the river water above the surrounding land, there is a well established arrangement whereby farmers report any signs of damage or leakage in the banks. The report will be logged in with the location and description provided. Further action such as a special inspection, immediate remedial work, include in next maintenance schedule or 'do nothing', will be decided on, put into effect and recorded.

9.6 **General Inspections**

General inspections would be carried out by trained NRA inspectors at intervals based on the importance of the asset in the flood defence system and its reliability (i.e. does experience show that the asset requires frequent attention?). A programme of inspection can be combined with a programme of repetitive routine maintenance as has been done by NRA Wessex Region for a group of assets - see Figure 9.2.

A typical frequency of General Inspections for the whole of a flood defence system of moderate importance would be twice a year - once at the end of the summer and once after the winter.

The purpose of general inspections is to report on the following:

- the serviceability of assets
- the need for preventive or corrective action
- the presence of any incipient defects
- the rate of deterioration
- any changes in service conditions
- compliance with legal and other obligations

General inspections would not involve any special access or other equipment other than a boat where appropriate - some assets need inspection from the water side as well as from the landside.

Ideally, General Inspections would be carried out after a baseline survey had been completed. The inspector would then have available the printout from the asset data base and the associated maps, drawings and reach specifications. He could identify the individual assets by their number and location and have a clear idea of the role and significance of each asset in the system. If a baseline survey has not been done, a General or Principal Inspection should be undertaken to identify and record the individual assets in accordance with the method given in Appendix A. The results of

MAINTENANCE SCHEDULING INFORMATION REFERENCE DATA						MAINTENANCE SCHEDULING INFORMATION REFERENCE DATA								
DRAW'G NO.	REF NO.	CHAIN. /IDENT REACH	SITE	RIV BNK L/R	DESCRIPTION OF WOR	MAINTENANCE WORK REQUIREMENTS	MEASURES QTY	UNITS	RESOURCES PLANT TYPE	REQ. LAB. NO.	FREQ PER ANN.	JOB DURATION JOB SHV	TRAV. SHV	TOTAL HOURS
	1				Earth Bank	gen. stability & level	852	m		1	1			
						survey crest level	850	m		1	1/5			
						reprofile as required	850	m	bulldozer	1	1/8			
	2				Blockstone 2 lengths	check general stability and erosion at two locations	350	m		2	1			
	3				Enkamat	check for stability	350	m		2	1			
						check for erosion	350	m		2	1			
	4				Gabions	check stability								
						check condition of cages	250	m		2	1			
	5				Outfall	check concrete headwalls etc			ladder	2	4			
						check for seepage / erosion			shovel, rake					
						around structure			selection of	2	4			
						clear silt / debris			nuts, spanners	2	4			
						check square alloy flap			grease	2	4			
						check operation / grease flap			etc	2	4			
						check pipe clear	22	m	lamp	2	4			
	6				Loose stone pitching	check general stability and erosion of slope	250	m		2	1			

Figure 9.2 Example of programme of inspection and maintenance

the inspection should be recorded on standard forms or on an electronic notebook. Photographs, sketches and additional notes and measurements will also be needed.

General or Principal Inspection should be undertaken to identify and record the individual assets in accordance with the method given in Appendix A. The results of the inspection should be recorded on standard forms or on an electronic notebook. Photographs, sketches and additional notes and measurements will also be needed.

9.7 Principal inspections

Principal Inspections would be carried out by engineers and would replace one of the General Inspections every three or more years. Principal inspections would be more thorough than General Inspections and might involve special equipment for access or making special measurements. They would provide an opportunity for an engineering assessment of the flood defence system and its assets and of whether changes should be made in the inspection and maintenance regime.

9.8 Special inspections

Special Inspections would be carried out by inspectors or engineers after a storm or other extreme event or after a report by others that something was amiss. A Special Inspection may be of the whole or a part of a flood defence system with the scope of either a General or a Principal Inspection as appropriate. It could also involve a single asset only.

9.9 Level surveys

Level surveys should be carried out to check that the specified flood defence levels are being maintained. The frequency of such surveys will depend on the previous record of settlement. Slight and regular settlement may only call for level surveys every 10 years but more rapid and irregular settlement may call for level surveys every year. Surveys of levels within a watercourse will be required if there is likely to have been a significant loss of cross-sectional area. These and other types of survey are discussed in Chapter 10.

9.10 Structural inspections

Inspections of structures would be called for where the engineer reviewing the results of one of the more general inspections (described above) concludes that there is cause for concern. This decision should be based on the information given on structures in Chapters 4 to 7 and on materials in Chapter 8. The inspection would be based on the same principles set out in Chapters 4 to 7 and asking a series of questions to find out whether the structure is capable of achieving the specified performance. The inspection may lead on to investigations and back analysis of the stability and the strength of the structure.

9.11 Underwater inspections

Underwater components can be inspected by a team of divers, a remote operated vehicle (ROV) or such devices as an echo sounder or sector scanning sonar where only measurements of shapes are required. Diving inspection must only be entrusted to fully qualified teams with appropriate civil engineering experience and complying with the latest regulations which require that a team of at least three persons, including a supervisor and standby diver, should be on site. Closed circuit television (CCTV) can be used by a diver or mounted on an ROV. Modern low light cameras with their own light source can provide a very good picture even in murky conditions, but areas to be inspected will need to be either scraped clean or cleaned with a high pressure water jet with a balancing jet. Still photographs can be taken with underwater cameras and should include a scale and clearly indicated location and orientation of the object being inspected.

9.12 Culvert inspections

Inspections of man entry culverts have to be carried out separately from other inspections, because of the need to comply with confined spaces Health and Safety regulations and to use a qualified team, often with breathing apparatus. Details of the layout, size and entry points need to be available for use by the culvert inspection team. Smaller culverts should be inspected with closed circuit television. The inspections and interpretation of the condition should be carried out in accordance with the procedures given in the WRc *Sewer Rehabilitation Manual.*

9.13 Electrical and mechanical inspections

Inspection of electrical and mechanical equipment should be combined with maintenance in a joint programme of actions planned to ensure that the asset continues to fulfil its intended functions in its operating context. One way of doing this is discussed further in Chapter 11. Certain types of inspection of electrical and mechanical equipment are required by law for safety reasons.

9.14 Health and safety inspections

Health and Safety inspections are usually undertaken as a separate activity to comply with legal requirements and NRA policy documents.

9.15 Inspections of contractors' work

Inspections to check that maintenance work has been properly carried out should be planned as part of the arrangements for supervising contracts or in-house work forces.

Contracts for new work or alterations should require that record drawings are produced. The drawings shall be checked for accuracy before being accepted.

9.16 Condition coding

The method of recording the results of general and principal inspections will be influenced by the purpose of the inspection. If the purpose is a condition assessment for an overview of the condition of the assets then the coding procedure as given in Appendix A should be followed. Important points to consider include:

- identifying whether the defect or continuing deterioration will cause flooding of an important area in the design event:

  Example: Erosion of a river bank of an upland river with no flood banks and only grassland at risk from flooding is unlikely to be important.

- the interpretation of an apparent defect in relation to the failure modes given in this report for that type of asset and to checks on the adequacy of the asset carried out in the baseline survey:

  Example: Steepening of the water side slope of a flood bank beyond that shown to be stable.

- the comparison of the condition of the asset to specified performance criteria in the reach specification derived from an analysis of how the flood defence system is required to perform:

  Example: Degree of blockage of channel compared to the specified minimum depth and width.

An alternative way of assigning the condition grades would be as follows:

Grade

1.	Very Good	(A)	No remedial work required
2.	Good	(A)	Minor routine maintenance work required
3.	Fair	(B)	Significant maintenance works required
4.	Poor	(B)	Major remedial works required
5.	Very poor	(B)	Requires complete reconstruction

Notes: (A) Inspector's decision on grading and the action required.

(B) Decision referred to Engineer who may inspect himself or arrange specialist inspections or investigations.

Examples of points which need to be considered:

- Condition of a flood bank: the condition grade assigned to the crest and back slope of a flood bank will depend not only on the state of the grass and the surface but also on whether the flood bank will be subject to overtopping and the amount of overtopping (see paragraph 7.2.12). A further factor is whether overtopping occurs for normal events within the design event or only in exceptional events. If it is not subject to overtopping, a better condition grade would be justified.

- Sheet pile wall in Figure 9.3: questions which need to be asked are:

  - is the retained height of soil excessive for the stability of this particular design of wall?

  - was the movement caused by some temporary condition since rectified such as overloading of the backfill or excavation in front of the wall?

  - is the stability of an important flood bank at risk?

  - is the potential reduction of the cross section of the channel significant to the functioning of the watercourse?

  - is the corrosion progressive or the result of a temporary contamination?

  - what has changed since the previous inspection, e.g. the level and profile of fill behind the wall, the level of the channel bed and the slope of the wall?

Unless comparison with previous surveys shows that there has been no recent deterioration, an engineering investigation would be needed to establish what further action is required.

9.17 Equipment for inspections

The equipment needed by the inspector will depend on the types of asset to be examined. Figure 9.2 includes notes where particular equipment is needed (such as lamp for culvert inspection).

A list of equipment which may be needed for carrying out inspections is given in Appendix B.

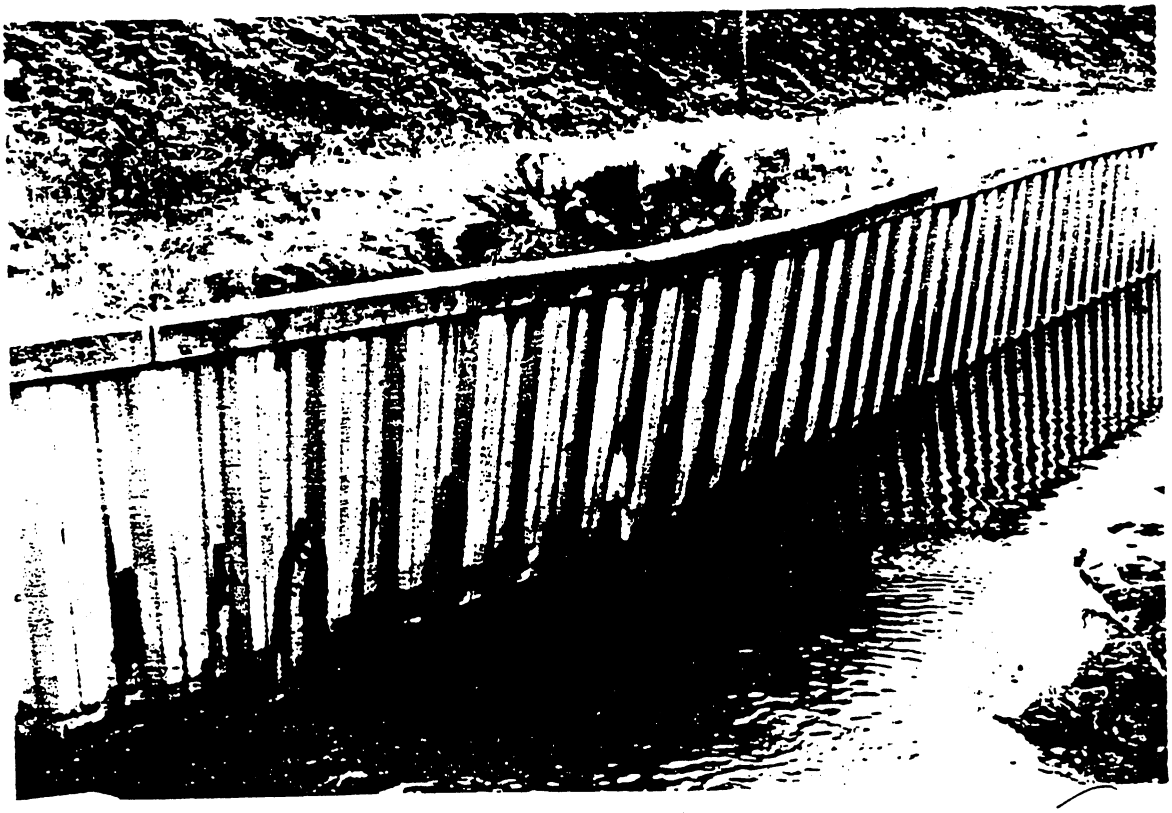


Figure 9.3 Damaged sheetpile wall

9.18 Inspectors

Inspectors will require training in the recording and interpretation of evidence of the condition of assets and in the use of the asset database forms and coding. They will need time before each inspection to plan the work and familiarise themselves with the existing records.

9.19 Monitoring

Monitoring usually involves measuring significant parameters at fixed intervals and then plotting the results to see whether there is any change and whether there is any trend. Examples are such parameters as the vertical slope of a wall or the width of a crack. Effective monitoring can provide evidence that expensive rehabilitation work is unnecessary when the fault was the result of a one-off accident or overload. Another effective form of monitoring is taking and comparing photographs over a period of time.

References

9.1. Department of Transport (1984), *Bridge Inspection Guide*, HMSO.

9.2. Brandon, T.W., Editor (1989), *River Engineering - Part 2 Structures and coastal defence works*, IWEM.

9.3. PIANC (1989) *Supervision and control of long lateral embankments*, PIANC.

9.4. WRC *Sewer Rehabilitation Manual.*

9.5. NRA *Flood defence asset surveys - Specification for the final report.*

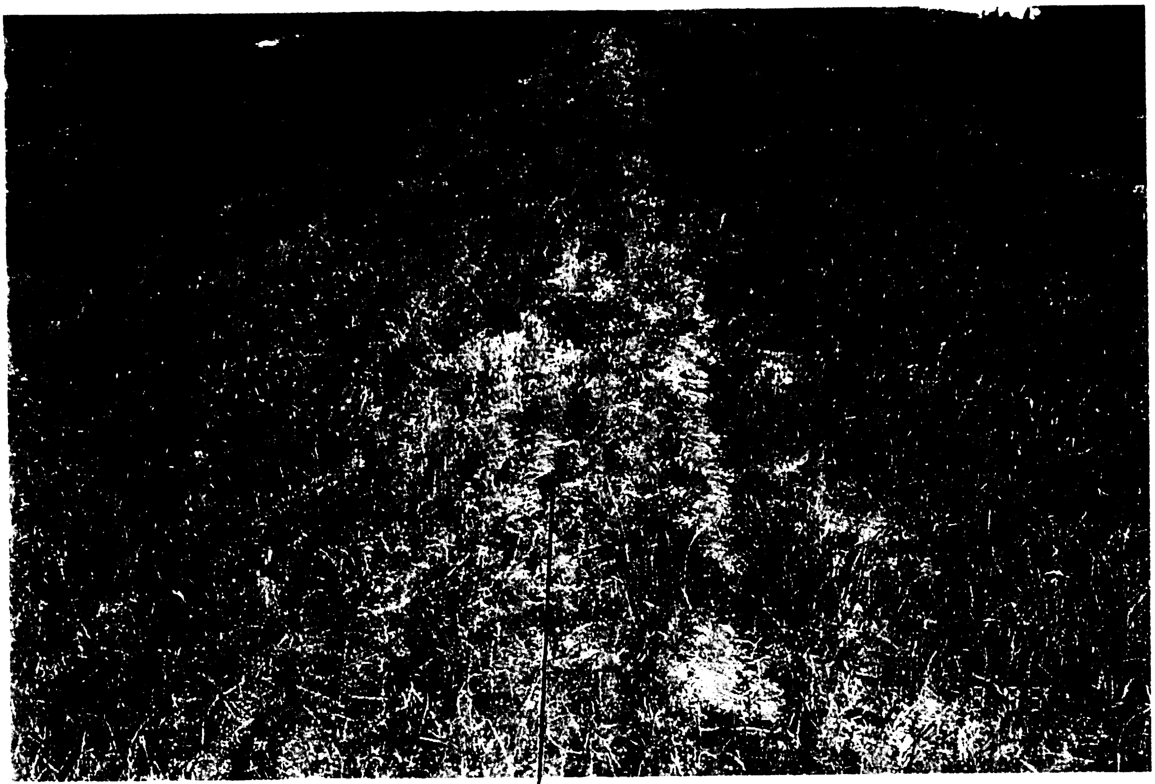
Checklist for Inspectors Amended from R&D Note 199

		Chainage	Yes	No	Photograph	Report
	Watercourse					
1	Siltation in channel					
2	Erosion of bed					
3	Erosion of banks					
4	Weed growth in channel					
5	Debris in channel					
	Riverside slope of banks and berm					
6	Grass in poor state					
7	Revetment damage					
8	Bank damaged					
9	Bank too steep a slope					
10	Excessive weed growth					
11	Animal burrows in bank					
12	Cracks and or deformation in bank					
13	Damage to structures in bank					
14	Trees					
	Crest of bank					
15	Local reduction I flood defence level					
16	Width of bank too small					
17	Revetment damage					
18	Grass in a poor state					
19*	Cracking					
20*	Fine fissuring (may not be obvious from a surface observation)					
21	General cracking indicating movement					
	Landward slope of bank					
21	Grass in a poor state					
22	Bank damaged					
23	Bank too steep					
24	Animal burrows in bank					
25*	Cracking					

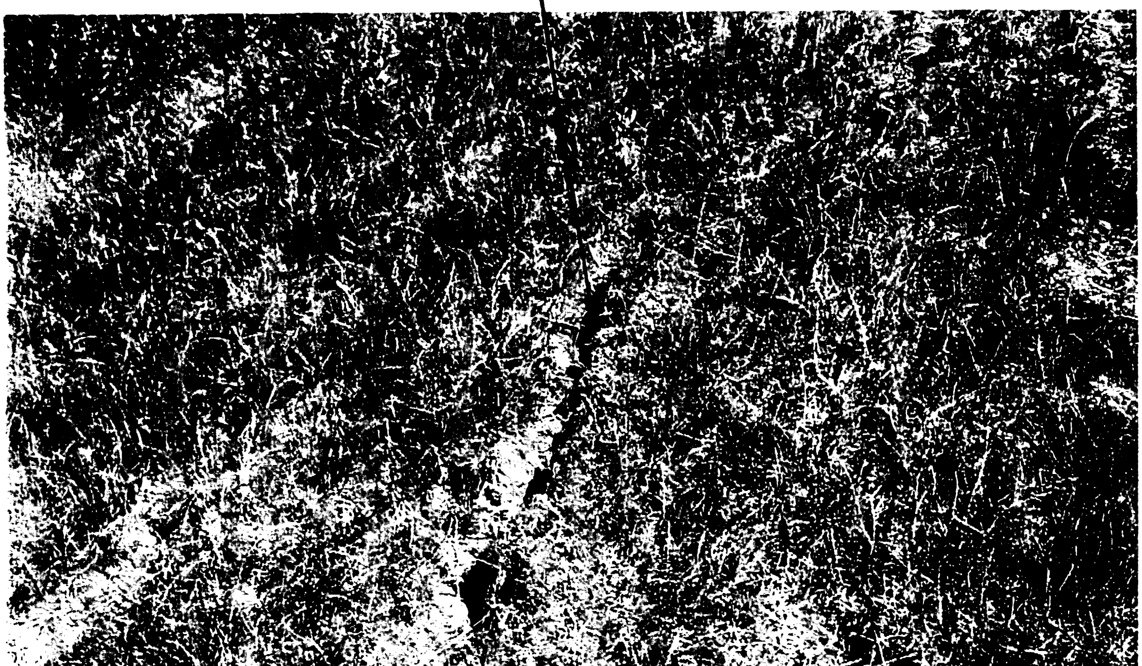
		Chainage	Yes	No	Photograph	Report
26*	Fine fissures					
27	General cracking indicating movement					
28	Damage to structures in bank					
29	Trees					
30	Leakage through bank - clear water					
31	Leakage through flood bank - cloudy water					
32	Wet patches					
	Drainage ditch on landward side					
33	Blocked by debris					
34	Excessive weed growth					
35	Water level too high					
36	Ditch damaged					
37*	Unusual seepage					
	Landward of bank and ditch					
38	Wet patches					
39	Ground settlement					
40	Cracks in ground					
Where the answer is yes take photographs and or make notes and sketches as necessary						

* Denotes additional items not included in R&D Note 199

APPENDIX C
Photographs



WIDE FISSURES



MAXEY CUT TALLINGTON

FINELY FISSURED ZONE

MILLBEACH TO GOLDHANGER

APPENDIX D
Site Investigation Techniques

D Investigation Techniques

D1 Introduction

It is important to regularly inspect flood defence earth embankments and maintain records of any inspections carried out; procedures for doing this are set out in R&D Note 199. However as part of an assessment (refer to Chapter 3) more onerous investigations may be required to identify suitable remedial measures.

D2 Appropriate Techniques

Site investigations aim to assess fine fissuring and develop a geological and geotechnical cross section of the embankment to a depth approximately 5m below the surrounding ground level. The following section identifies appropriate inspection techniques to do this, Table D.1 below refers. The techniques should be carried out by experts in the field of geotechnics. The data given below is intended to provide the reader with appropriate information so that they are able to oversee the works.

Table D.1
Appropriate Detailed Inspection Techniques

Purpose	**Identification of Fine Fissuring**	**Geotechnical Cross Section**
Technique		
Desk study		*
Trial pits	*	*
Geophysical	*	
Sampling	*	
Sampling and soil mechanics tests		*
Topographical survey		*

* Denotes appropriate technique for the purposes

D.2.1 Identification of Fine Fissuring

Trial pits

Trial pits are the best way of obtaining detailed information to identify the extent of fine fissuring. The trial pit should be excavated by hand, taking care not to disturb the sides of the pit so that signs of fine fissuring are not obscured. The pit should extend slightly beyond the depth of fine fissuring, typically to a depth of 1.5m (note any pit greater than 1.2m deep should be adequately shored). The plan area of a trial pit is typically 1.5m by 3m, for this reason pits are not recommended on the crest where they would significantly influence the integrity of the embankment, but should start on the landward side of the crest and be dug towards the landward toe, see Figure 13.

The trial pit should be back filled as quickly as possible after the pit has been logged and photographed. The pit can be backfilled with the excavated material removed from it on the assumption that any remedial measures will include the area of the trial pit. The backfill should be placed in 300mm layers and each of the layers should be well compacted with a vibrocompactor.

Trial pits are ideally dug at the end of the summer when fissuring is at its worst. But, fine fissures, if they exist, are likely to be visible on close inspection throughout the year.

Geophysical Investigation Techniques

Geophysical methods are unlikely to be of value for the identification of fine fissures, since they only record changes in stratification, where layers have appreciably different geophysical properties. Also vital information on ground water conditions is often lacking. For details on geophysical techniques refer to BS 5930.

Sampling

Samples are taken from boreholes. The aim of soil sampling for the identification of fine fissures is to obtain a sample in a sufficiently undisturbed state so that fine fissuring can be seen. As with the excavation of trial pits it is preferred that this be carried out towards the end of the summer or early autumn when fissuring is at its worst. Sampling should be undertaken by experienced staff.

Sampling methods are classified in accordance with the quality of the sample obtained, Table D.2 refers.

Table D.2
Quality Classification for Soil Sampling

Quality class (as BS 5930)	Soil properties that can be determined reliably (BS 5930)
1	Soil classification, fabric, moisture content, density, strength, deformation and consolidation characteristics
2	Soil classification, fabric, moisture content, density
3	Soil classification fabric, and moisture content
4	Soil classification
5	None, sequence of strata only

Only quality classes 1, 2 and 3 are suitable for the identification of fine fissuring. Table D.3 shows the appropriate techniques which may be used to obtain quality class 1, 2 and 3 samples.

Table D.3
Quality Classification 1, 2 and 3 for Soil Sampling; Appropriate Techniques (each of the techniques can provide samples of quality classification 1, 2 or 3)

Site Investigation Technique	Sampling Method
Trial pit	Block sample
Rotary open hole drilling using an appropriate flushing medium	For soils sensitive to disturbance: thin wall piston sampler For soils insensitive to disturbance: thick or thin walled open sampler
Light cable percussion boring (shell and auger)	For soils containing discontinuities (eg geotextile); thick wall large diameter sampler

D2.2 Plotting a Geotechnical Cross Section

The aim is to obtain a clear understanding of the structure of the embankment and its foundation in order to identify and plan suitable remedial measures. Table D.1 above gives information on the appropriate techniques which can be used to obtain data. These are trial pits, desk study, sampling and soil mechanics tests, and topographical survey . The following paragraphs are intended only as a guide to enable the reader to oversee works: the works themselves should be carried out by an expert in the appropriate field.

Desk Study

The purpose of the desk study is to identify likely embankment material, but primarily to identify any inconsistencies in the local geology either man made or natural. For example the embankment may be founded on an old river channel or other feature currently not visible. Sources of information for a desk study are given below:

- Geological maps can be obtained from the Geological Museum, London
- Geological records can also be obtained from the Geological Museum, London or Her Majesty's Stationary Office
- Soil survey maps can be obtained from the Ordnance Survey

Trial Pits, Sampling and Soil Mechanics Tests

The same trial pit and sampling techniques as outlined for the identification of fine fissuring should be used. However, in addition soil mechanics tests should be carried out on the samples. The aim of the tests is to identify the soil characteristics and the soil profile to approximately 5m below the embankment. Table D.5 below shows which are the appropriate soils tests to carry out and the information which they provide on the soil. The interpreted results of the tests will be a factor when selecting appropriate remedial actions.

Table D.5
Appropriate Soil Mechanics Tests

Information About The Soil	Parameter/Test	Comments
Soil classification	Moisture content	
	Particle size distribution	
	Atterberg limits	Laboratory test for cohesive soils
Strength	Cone penetration test	On site test for soft cohesive, laminated or granular soils
	Standard penetration test	On site test for non cohesive soils
	Insitu vane test	On site test for soft cohesive soils
	Undrained shear	Laboratory test for all cohesive soil types
	Effective shear	Laboratory test for all soil types
Consolidation	Odoemeter	
Permeability	Rising head test Falling or constant head	On site test for assessing permeability for soils below the water table
Water table	Piezometer	Various types depending on the soil type and other requirements.

Topographical Survey

A topographical land survey is a very important element in the assessment of remedial measures. Cross sections should be taken at regular intervals along the embankment and at changes in section. The survey should be to a vertical accuracy of plus or minus 10mm. Sections should also be taken where any geotechnical investigations have been made. The intervals at which the cross sections are taken depends on the variability of the profile of the embankment, cost and the length of effected embankment.

APPENDIX E
Example Plan for the Detailed Assessment of Fissuring

Plan for Detailed Assessment of Fissuring

Description of location	Left bank River Other between Post house Farm and upstream weir						
Start Chainage	2500	**End Chainage**	3000	**General Inspection Sheet RefNo.**	xxxxx	**Date of Detailed Assessment**	27/10/95
Suitable Site Investigations				**Appropriate Remedial Options**	Cost/m run	Effect on Fissuring	Final selection
Identification of Fine fissuring	Selection	Cross Section	Selection	Digging in		May not be very effective	
Trial pit	Y	Topograph-ical	Y	Berm		Compensates for cracks	Y
Rotary core	Y	Rotary core	Y	Impermeable membrane (a)		Compensates for fissures	Y
		Sampling	Y	Impermeable membrane (b)		Compensates/ prevents cracks and fissures	
				Granular crest		Limits cracks and fissures in crest	
				Sheet pile cut off wall		Compensates for fissures	

APPENDIX F
Recommended Grading and Moisture Content for Hoggin Placing

Imported Material for Embankment - Type B (Hoggin Fill)

1. Type B fill shall be naturally occurring material and shall lie within the following grading limits:

Particle size (mm)	% finer
75	98 - 100
37.5	69 - 100
28	58 - 100
20	53 - 100
14	46 - 89
10	42 - 81
6.3	34 - 68
5.0	30 - 62
3.35	27 - 57
2.0	22 - 50
1.18	17 - 44
0.6	10 - 35
0.30	8 - 32
0.15	7 - 28
0.063	5 - 24
0.002	4 - 17

2. The liquid limit of the material, as defined by BS 1377 : Part 2 : 1990 : Clause 4.5, shall lie between the values of 30% and 65% and the corresponding plasticity index (BS 1377 : Part 2 : 1990; Clause 5) shall lie between 15 and 40.

3. The moisture content of the material shall be controlled preferably at the borrow area, to give a uniformly distributed in situ moisture content after compaction between −2% and +4% of the optimum moisture content determined by BS 1377 : Part 4 : 1990 Clause 3 (vibrating rammer method).

4. The material shall be obtained from an approved source.

5. If Type B fill is produced from mixed materials the Contractor shall ensure that there is an adequate method of stockpiling and testing the material at the borrow pit. Type B fill produced from mixed materials shall not be brought on site unless the test results for that material have been received by the Engineer.

APPENDIX G
Extracts from Environment Agency Standard Specifications for Embankment Construction

F.A.O. Mrs Alex Purcell.

Re surface cracks in embankments.

Attached - relevant spec for Longton Embankment works.

ENVIRONMENT AGENCY

16 APR 1996

Reply Date

with compliments

Bill Leighton.

The Environment Agency
Lutra House, Dodd Way, Off Seedlee Road, Walton Summit, Bamber Bridge, Preston PR5 8BX
Tel 01772 39882 Fax 01772 627730

1.34 cont'd

2. The accesses referred to shall be maintained throughout the currency of the Contract free from potholes and clear of spillage insofar as this is directly attributable to the Contractors operations on Site. The Contractor shall also ensure that his own vehicles and those of his sub-contractors and suppliers, if any, are free of mud, loose materials wedged brickbats and other potential hazards before leaving the Site.

1.35 The Works Generally

1. The Permanent Works will be required to withstand the effects of tidal surge including variations in water level and associated wave action. They may also be subject to the battering effect of floating debris and care shall be taken therefore to ensure that all steel and concrete elements are soundly constructed so as to prevent any leakage taking place through the structures.

2. The Works can be broadly categorised into five types of construction namely :-

   (i) New embankments

   (ii) Embankment reconstructions

   (iii) Outfall modifications and reconstructions

   (iv) Road constructions

   (v) Miscellaneous works

3. A new section of embankment is to be constructed between the northern limit of the Lancashire County Council tip site and the present embankment to the north of access road No.2. Filling material for the new bank will be obtained from levelling operations within the newly reclaimed area or from the designated borrow area indicated on Drawing No. H117/10/5. Excavated material for incorporation in the new embankment shall be stockpiled on the Site until such time as all excess moisture has drained away and thereafter shall be incorporated into the embankment structure as specified. New embankment surfaces are to be provided with a layer of meadow turf on the seaward side and given additional protection against tidal action by way of a complete covering of galvanised wire netting, firmly anchored into the embankment face and lapped at joints. The crest and landward slopes of all new embankments are to be sown down with selected grass seed.

1.35 cont'd

4. The present embankments to the south of the tip site are to be heightened and strengthened in accordance with the details shown on Drawings H117/10/3 and H117/10/4. Shortfall filling material is to be obtained from either the borrow area indicated on Drawing No. H117/10/4 or from the old clay stockpile adjacent to Becconsall railway bridge. In locations where clay filling is used, the Contractor shall ensure that it's use is limited solely to the formation of the embankment core as per the specified detail. On no account will the Contractor be permitted to use clay filling in the surface layers of embankments. The Contractor shall also ensure that all vegetation and topsoil are removed from embankment faces and stockpiled prior to the deposition of additional filling material. Upon completion of the resectioning work, previously excavated topsoil shall be replaced in the surface layers of the embankment and all seaward facing slopes shall be turfed in the same manner as new embankments, i.e. reinforced turf. The crest and landward slopes of all reformed embankments shall be sown down with selected grass seed.

   Where the present defences run close to the River Douglas channel approximately 240 linear metres of flexible revetment are to be installed on seaward facing slopes. The revetment will comprise the "Petraflex H-51224 cellular block system" as manufactured by Ardon International Ltd. and in order to avoid any unnecessary delays the units will be purchased by the Employer and delivered to the Site not less than seven days after giving appropriate notice to the Contractor. The Contractor shall take delivery of the units (dimensions 5.185 metres 2.42 metres, weight 2.31 tonnes) and any ground anchors and shall store them on site until required for installation. They shall be adequately protected to prevent damage until such time as they are required to be installed in the permanent works.

5. Three new tidal outfalls are to be constructed at the following locations :-

   (i) Tarra Carr Gutter/Hall Carr Pool

   (ii) Rakes Brook

   (iii) Much Hoole Marsh Drain

1.35 cont'd

7. A number of additional minor works are to be included in the Contract, the more significant of which are listed below :-

   (a) The construction of a link culvert between Much Hoole Marsh Drain and an existing ditch to the north. The culvert is to be constructed using 300 millimetre diameter asbestos cement pipes which will be purchased and supplied to the Site by the Employer. The Contractor shall take delivery of the pipes, couplings and gaskets and shall store them on the Site until they are required for installation. All components shall be adequately protected to prevent damage until such time as they are required to be installed in the Permanent Works.

   (b) The extension of three land drainage outfalls south of the Lancashire County Council Tip Site incorporating culvert extensions in both Armco type pipe and asbestos cement ware.

   (c) Site fencing and gate erection as protection against stock damage to the Permanent Works or as replacement for sections previously removed.

   (d) Grass seeding to areas of disturbance.

8. During construction of any of the works comprised in the Contract the Contractor shall ensure that adequate measures are taken to prevent the ingress of tidal water in areas where existing defences have been temporarily reduced in level or removed completely prior to installing new works. Such measures shall be subject to prior approval by the Engineer and shall remain in force until such time as replacement defences have been constructed.

1.36 Earthworks

1. The Contractor's attention is drawn to the fact that all the earthworks involved in the Contract are to be carried out in locations which are subject from time to time to the influence of the tide. The Contractor should acquaint himself with the information contained in Clause 1.40 "Tidal Information" and should pay particular attention to the predicted levels contained in the Astronomical Tidal Prediction Tables when formulating his methods of operation.

1.36 cont'd

2. During construction of the Permanent earthworks, the working surfaces of excavations shall at all times be maintained on such a gradient that water can drain away freely from the workings and they shall be free from localised low places in which water can be retained.

   The side slopes of channel excavations shall be laid back to the specified batters as the work proceeds with the avoidance of sheer faces that are liable to undercutting or slumping. Where revetment is required it shall be installed as quickly as possible after completion of the excavation.

3. All excavated material will be required either as backfill to the structures where suitable or as filling to excavations. Any deficiencies in the amount of filling required to complete the Permanent Works shall be obtained only from the specified sources.

4. The specified sources for obtaining shortfall filling material have been indicated on the Drawings and will be identified as follows :-

   1) The old clay stockpile near Becconsall railway bridge

   2) Borrow area No.1

   3) Borrow area No.2

   Certain restrictions apply to the removal of material from these areas and these are fully outlined below :-

   (a) <u>The old clay stockpile</u>: Access to the stockpile will be from the adjacent disused railway track; however, the Contractor will be required to provide a ramped access from the railway to the stockpile which is located at a somewhat lower level. Removal of the clay will only be permitted from a single face running the full width of the stockpile, the whole of the face being excavated evenly down to existing field level as the work proceeds.

   The section of railway track between Haunders Lane and the clay stockpile is currently surfaced with a layer of ash and clinker and this should provide a reasonable running surface for the haulage of spoil. The Contractor is advised however that no provisions have been made

1.36 cont'd

for surfacing any access across the stockpile area and the Contractor will be deemed to have included for any such provisions within his rates and prices for clay removal which has been entered in the Bill of Quantities.

(b) Borrow Areas 1 and 2: Access to both borrow areas is to be constructed in accordance with the detailed layout which is included on Drawing Nos.H117/10/4 and H117/10/5. Excavated material shall be stockpiled locally until such time as all excess moisture has drained away and thereafter it shall be transported into position via the designated access routes.

1.37 Cofferdams

1. The Contractor shall ensure that so far as is practicable all constructional work is carried out in the dry and that excavations for such work are kept well drained and free from standing water. In this connection the Contractor shall construct, operate, maintain and subsequently remove temporary dams and other works of all kinds including pumping and well point dewatering plant that may be necessary to exclude water from the works while construction is in progress. Such temporary works and plant shall not be removed without the approval of the Engineer. The Contractor's proposals for cofferdamming and the maintenance thereof shall be submitted to the Engineer for approval prior to commencing the constructional works.

2. The following conditions shall apply to the construction of cofferdams :-

General

(i) Their internal dimensions shall be the minimum that is necessary for the execution of the works.

(ii) Cofferdams shall be constructed in such a manner so as not to adversely affect either the stability of river banks or the newly constructed works. In this connection temporary protective measures may be required to any exposed parts of the river banks or new works and the Contractor should include details of such when submitting his cofferdamming proposals.

3.21 **Material for Embankments**

1. Excavated material used as filling for embankments shall be free from clods and lumps and shall be approved by the Engineer. No frozen material shall be placed as filling and the Contractor shall not place filling in freezing conditions.

2. Should the material being placed as filling, while acceptable at the time of selection, become unacceptable to the Engineer due to exposure to weather conditions or due to flooding or have become puddled soft or segregated during the progress of the Works, the Contractor shall remove such damaged, softened or segregated material and replace it with fresh approved material.

3.22 **Construction of embankments**

1. All embankments shall be constructed in accordance with the drawings with approved materials obtained from the excavations.

2. The approved materials shall be placed in layers, not exceeding 250 mm in depth before compaction and shall be compacted to a dry density not less than ninety-five per cent of the maximum dry density obtained in the B.S. Compaction Test as described in B.S. 1377, Test 11 or to such higher density as is specified hereinafter or shown on the Drawings. During compaction the fill shall have a uniform moisture content equal to or a little above the optimum moisture content recorded in the B.S. Compaction Test. Where necessary the Contractor shall adjust the moisture content of the fill either by drying out or by adding water. After such drying out or adding of water the fill shall be thoroughly mixed until the moisture content is unifrom.

3. The Contractor shall when placing the filling make due allowance for any subsequent placing of Topsoil and, if so required by the Engineer, he shall make an additional allowance of two per cent of height over and above the levels on the Drawings to allow for settlement.

4. The Contractor shall arrange the timing and rate of placing fill material around or upon any completed or partially completed structure in such a way that no part of the Works is over-stressed, weakened, damaged or endangered. The

3.22 cont'd

materials shall be placed so as to exert a uniform pressure around the walls of a structure and each layer shall be placed with a fall away from the walls of the structure to prevent the accumulation of water, adequate drainage being provided.

5. Where the Contract requires the placing of different types of fill material in separate layers the Contractor shall carry out the work so as to avoid mixing the different types of material. Should there, in the opinion of the Engineer, be any mixing of materials, such mixed materials shall be removed from the Site and replaced with separate materials. The requirements of this sub-clause will be applied rigidly in the case of surface filling to the seaward batters of new embankments.

3.23 Over excavation to be made good

All material resulting from Over-excavation shall be disposed of in the manner specified for the adjoining Excavation and the Contractor shall make good the additional void so formed as may be required by the Engineer having regard to the nature of the adjoining work. No additional payment will be made for Over-excavation or for any consequential back-filling and their costs shall be deemed to be covered by the Contract rates.

3.24 Spoil Tips on the Site

1. Temporary spoil tips may be used to store excavated material as required and shall be arranged by the Contractor subject to the Engineer's approval having regard to any particular requirements of the Contract.

2. Only material which is approved by the Engineer shall be placed in the various spoil tips. No unsuitable material as defined in Clause 3.17.1 of the Specification or rubbish of any kind shall be placed in spoil tips.

3. Temporary spoil tips shall be so shaped as to maintain stability and good drainage at all times.

3.25 Field Drains in General Excavation

Should any existing sub-soil, field drains or surface water drains be uncovered or damaged during general excavation, the Contractor shall carefully replace them when back filling or, if this is impracticable shall divert them or otherwise relay them as the Engineer may direct, and all work in this connection shall be ordered by the Engineer as additional work.

3.26 Turfing

1. All turf, shall be of a minimum thickness of 50 millimetres and shall be used within one week of cutting. Any turves not used within this period shall be discarded and in the case of such rejected material no payment will be made for cutting,handling or supply.

2. Surfaces to receive turf shall be comprenesively raked and screeded to remove irregularities and gypsum shall be applied at an even distribution of 200 grammes per square metre.

3. Turfing shall be undertaken in such a manner as to ensure that all turves are well bonded; they shall be lightly beaten and shall be laid diagonally across embankment slopes.

4. All newly turfed areas on seaward facing slopes shall be pegged down using galvanised sheep netting secured by galvanised plain wires running from top to bottom of slopes at 0.8 metre centres and firmly stapled to timber anchor posts 0.50 metres long driven into the slope at 1.50 metre staggered centres, so that the head of each post is flush with the top of the turf. Reinforcement is not required on the embankment crest nor on landward slopes.

5. Netting reinforcement shall be laid flush with the surface of the turf and shall extend for a distance of 500mm beyond the toe of the embankment, before being buried vertically to a minimum depth of 500mm. It shall extend over the complete area of seaward facing slopes and shall extend across the embankment crest for a minimum of 200mm A continuous line of timber anchor posts shall be provided at crest level (0.80 metre spacings) and the netting reinforcement shall be firmly anchored along the top extremity by means of a galvanised line wire lacing, firmly stapled to each anchor post. The line wire lacing shall be attached to the reinforcement along this top edge at minimum 200mm centres.

3.26 Continued.

6. All laps in netting reinforcement shall be a minimum of 150 mm. The finished reinforcement should form a sound protective cover to the turf and should be free from flapping edges and gaps of any kind other than mesh holes and should be reasonably taut in all directions.

WITH COMPLIMENTS 16/4/96

ENVIRONMENT AGENCY

To: Alex Purcell

Re: Earth Embankment Forming (NRA 30)

Copy of specification for most recently ~~constructed flood defence~~ embankment as requested.

Regards David Murphy

BINNIE BLACK & VEATCH
Redhill
RECEIVED
Job 18 APR 1996 File
Reply
Date

Environment Agency - Thames Region
North East Area Office, Gade House, London Road, Rickmansworth, Hertfordshire WD3 1RS. Tel: (01992) 635566 Fax: (01992) 645468

1.19 Forming of Reed Beds and Planting

Not required

1.20 Removal of Undesirable Plant Material

The areas of designated undesirable Plant Material as indicated on the plans to be excavated and as directed by the Engineer shall be carefully excavated and all the ensuing material is to be removed off-site and disposed to an approved tip in a manner such that the risk of further infestation is kept to a minimum. The majority of the undesirable plant material consists of Japanese Knotweed and Giant Hogweed - refer to safety statement.

The Contractor shall allow in his rates of excavation and disposal off site for the work and additional care to comply with the requirements of this clause.

1.21 Removal of Contaminated Excavated Material to approved Sites

It is brought to the Contractor's attention that the river channel to be excavated has been subjected to flows from contaminated water, and the soil sample tests results (at Appendix 2) show the levels of the various determinants measured in the silt to be excavated.

Much of the spoil arising from this site is considered unsuitable for normal disposal tip sites and will require disposal to sites that have been specifically licensed for the contaminated spoil. The Contractor shall ensure he has made appropriate enquiries and allowances in his rates (including tip licence, etc.) for disposal to approved licensed tips. Details of the tipping sites are to be provided to the Engineer at least 7 days before commencement of tipping.

1.22 Compacted Clay Fill to Embankment

The material to be used in the construction of the embankment shall be selected clay derived from bulk excavations to the approval of the Engineer. Preferably freshly excavated material shall be used for the construction.

If the material is stored prior to use it shall be properly protected during storage. Material which has become dried or damaged by rain or frost shall not be used.

The material shall be spread in uniform layers with a compacted thickness of not more than 150 mm and shall be excavated or prepared in such manner as to produce a material of a size suitable for such a layer and the means of compaction selected. The fill shall be adequately and uniformly compacted throughout its entire volume to produce a material of uniform consistency and quality.

The embankment shall be formed by placing fill in gently sloping layers so as to shed rainwater. The placing of any fill shall not be carried out during periods of rain or frost.

The greatest care shall be taken to ensure that no unsafe load is imposed on any part of the embankment by the Contractor's operations.

Where compacted clay is placed against an existing clay face, the two materials shall be moulded together at the interface. The method(s) of compaction shall be such that the surface of a compacted layer is not smooth before placing the next layer.

1.23 Moisture Content of Compacted Clay

The moisture content of the compacted clay shall fall within the following limits:

The moisture content shall not be less than the moisture content of the material at the plastic limit.

The moisture content shall not be less than the moisture content of the as dug material by more than 3% of the dry weight.

Moisture content and plastic limit shall be defined and determined according to BS1377.

The clay shall be watered as necessary to bring the moisture content of the compacted clay within the limits specified. Especially during dry weather watering may be necessary to replace evaporation losses during handling, etc. The water shall be applied by means of a spray and so applied that the moisture is uniformly distributed in the mass of the clay in the compacted state.

1.24 Volume of Air Voids in Compacted Clay

The volume of air in the voids of the compacted clay shall not be more than 3% of the total volume of the clay.

The volume of air voids in the clay shall be calculated from direct measurement of the bulk density and moisture content of the clay and the relationship between the various quantities shall be as given in the following equation:

$$\frac{(1 - Va)}{100} = 97\%$$

$$Yd = \frac{YW}{\frac{1}{GS} + \frac{m}{100}}$$

Where
Yd = dry density of clay in Mg/cu.m
Yw = density of water (1.0 Mg/cu.m)
Gs = specific gravity of clay particles
m = moisture content per cent
VA = volume of air voids expressed as a percentage of the total volume of the clay

The dry density and moisture content shall be defined and determined in accordance with BS1377.

The specific gravity of the clay particles shall be assumed to be 2.75.

1.25 Contractor designed box culverts

The 2 No. sections of box culvert to be provided between the existing culvert under the A13 and the new sluice structure are to be designed to the requirements of the

Department of Transport. Approval in principle (AIP) has been obtained and is included at Appendix 4. The units are to be designed to comply with the requirements of the AIP. The Contractor shall supply design calculations, drawings and design certificate which should be submitted to the Engineer for approval at least four weeks prior to the casting of the units. Copies of the design certificate and (AIP) which sets out the criteria for the design of the units is attached at Appendix 4. Sufficient as-built details/records in accordance with "Road 277" proforma (copy also attached at Appendix 4) are to be provided prior to the end of the contract.

1.26 Grass Seeding

The grass seeding of the embankments and the inclined surfaces of the River Ingrebourne channel shall be carried out using JF 41 General Purpose grass seed from Johnson Seeds, Boston, Lincolnshire (tel.:
0205 36502).

The seed is to be evenly applied at 3 gms/m^2 throughout.

ENVIRONMENT AGENCY

Our ref: PM/FD/9612
Your ref:

Date: 16 April 1996

Alex Purcell
Binnie Black & Veatch
Grosvenor House
69 London Road
Redhill.
Surrey RH1 1LQ

BINNIE BLACK & VEATCH
Redhill
RECEIVED
Job 18 APR 1996 File
Reply Date

Dear Ms Purcell

EARTH EMBANKMENT FISSURING

I enclose copies of specifications used by the Agency and its predecessors for supply of material and construction of earth embankments for flood defences.

Please contact this office if you require any further information.

Yours sincerely

P.H. Monk

PHIL MONK
Flood Defence Engineer (Devon)

Please ask for: Phil Monk, extn: 2336

The Environment Agency
Manley House Kestrel Way Exeter EX2 7LQ Tel: (01392) 444000 Fax (01392) 444238

Test Results

Strength, classification, compaction and chemical tests were carried out on various soils taken from the test holes. The results of these tests are shown in the attached tables. In addition, in-situ vane tests were carried out in the fine grained soils. The results of these tests are shown in the remarks section of each test hole along with the test depth.

Due to difficulties experienced with reliable undisturbed sampling of the soft clays many strength tests had to be carried out on remoulded specimens.

Conclusions

This section has been divided into two sub-headings:

A. Excavated soils for fill purposes.
B. Embankments and foundation soils.

General Notes

The soils to be used for fill are in the main to be taken from existing flood banks, adjoining ditches and borrow pits. To ensure good compaction for clayey earth embankments the moisture content should ideally lie close to the plastic limit. If the moisture is much lower, voids may remain in the bank, or if it is much higher it is difficult to handle and compact using normal mechanical methods. Also the strength of soil may be too low to ensure stability of the bank. Before placing the fill, the surface of the existing embankment slope should be lightly benched, as a series of steps to provide a key for the new fill. The initial placing of the fill should be at a gentle slope of around 4:1 forming a rough profile behind the existing embankment. At a later date it should be recompacted and shaped to its final profile. To protect and help stabilize the earth slopes after construction turf or grassing may be used.

The critical condition of a clay fill embankment is normally immediately after construction when excess pore water pressures are present within the embankment and foundation soils, before the soft saturated soils have consolidated and strengthened under the embankment's loading. Therefore stability calculations have been based on the undrained shear strength.

1. River Taw Section
A. Excavated Soils for Fill Purposes

Below an initial thin layer of firm clay the soils from the flood banks are naturally soft and wet. Similar soil conditions also exist in T.P.15 behind the banks. The natural moisture contents are close to or above the liquid limit. The strength of these soils when recompacted is very low, around 10 kN/m^2. Without allowing these soils to dry they are unlikely to be suitable for handling or placing in the new flood banks. However the initial layer of firm clay, to around 0.5 - 1.0m depth, is thought to be suitable as excavated.

B. Embankments and Foundation Soils

At present the existing banks appear reasonably stable. In general calculations suggest the proposed increase in height of around 1 to 2 metres of the flood banks should not overstress the foundation soils. However, isolated local areas of instability may occur initially, requiring individual treatment, but these should not prove to be too troublesome.

NKA Civil Engineering Contract Administration Manual Vol 21
current spec for 'New Works'

3.13 FILLING ABOVE GROUND

Note to Designers and Specifiers (not part of the Specification)

The objective of these clauses is to produce earthworks which are both fit for purpose and economical. These clauses do not constitute a design in themselves and will require an element of tailoring.

The design may therefore propose use of imported or locally available material, however, the Specification should, whenever possible, be written to allow the tenderer to offer alternative sources of materials. The Engineer will need to keep an open mind on the matter and be prepared to evaluate tenders against alternatives, including some redesign, recalculation of quantities and amendments to the specification.

It is expected that cut and fill lines will be identified on the Drawings.

* *Items marked with an asterisk require appropriate deletion or amendment to suit the job.*

This section replaces 3.13 clauses 1 and 2.

Materials

1. The basis for the design of the earthworks is *imported/locally won/*Clay/*Hoggin/*granular material* with properties as shown in the table below.

   The tender shall be based on use of this material, however should the tenderer propose an alternative material in an alternative tender he shall also submit an outline design, proposed modifications to this part of the Specification and a modified bill of quantities.

Location	Undrained Shear Strength	Dry Density	Moisture Content	Grading
eg, Embankment	*100 kN/m²*		*Optimum +1% to Optimum +4%*	

2. All imported materials used in the works shall be free from leachates which are harmful to the natural environment of the site. Fill materials shall be free from Rhizomania and other diseases and also from unwanted plant species. The Contractor shall provide, for the Engineer's approval, a leachate analysis of all material required for the works. The Contractor shall obtain this analysis from an approved independent testing laboratory.

Topsoil Stripping and Storage

3. Topsoil shall be stripped over the areas prescribed in the Contract. The depth of topsoil to be stripped shall be the top layer of soil that can support vegetation and will generally be between 150mm and 400mm in depth. Topsoil from areas with differing plant communities shall be stored separately.

4. Unless otherwise specified, topsoil should not be stripped from any area lying directly beneath the canopy of any tree which is to be retained. Topsoil shall preferably not be stored beneath the canopy or within 3m of the trunk of any tree whichever to the grater. Topsoil shall not be unnecessarily trafficked either before stripping or when in a stockpile.

5. Topsoil shall wherever practicable, be used immediately after its stripping or, if not, stored in stockpiles and used within six months of stripping.

6. Stockpiles shall not be surcharged or otherwise loaded and multiple handling shall be kept to a minimum. Weed growth occurring on stockpiles shall be cut down before seed dispersal can take place.

7. After removal of topsoil stockpiles from areas where original topsoil remains undisturbed reinstatement of the stockpiles sites shall include cultivation of the original topsoil to a depth of 300mm. or the full depth of topsoil, whichever is the lesser.

Two-Stage Vegetation Stripping and Storage

8. A two stage strip will take place with topsoil stripping being preceded by the removal of the topmost vegetative strip to a maximum depth of 100mm. The vegetation, roots and seeds must be stockpiled separately from topsoil and reused at the completion of the earthworks to re-establish flora/fauna. The storage restrictions for topsoil apply to this type of stripping work.

urrent spec for
maintenance
work

Materials for Embankments

'Clay'

9. The Contractor shall submit to the Engineer for approval, samples of the clay material he proposes to use for the construction of the works and the source of that material.

10. All clay material subsequently delivered to the Works shall conform with the approved samples.

11. The material shall not have less than a 30% true clay fraction (as defined in BS 5930 Site Investigations) and shall have a liquid limit greater than 60%. Not more than 10% of the material by weight shall be inclusions having a dimension greater than 10mm. Both the clay fraction and the granular content shall be evenly distributed through the fill material.

12. Materials with a water soluble sulphate content exceeding 1.9 grams of sulphate (expressed as SO_3) per litre when tested in accordance with BS1377: Part 3 shall not be deposited within 500mm of concrete, cement, bound materials or other cementitious materials forming part of the Permanent Works.

13. Materials with a water soluble sulphate content exceeding 0.25 grams of sulphate (expressed as SO_3) per litre when tested in accordance with BS 1377: Part 3 shall not be deposited within 500mm of metallic items form part of the Permanent Works.

14. The Contractor shall employ only plant and working methods which are suited to the materials to be handled and traversed. He shall be responsible for maintaining the nature of the suitable material so that when it is placed and compacted it remains acceptable in accordance with the Contract.

`Hoggin'

15. Hoggin shall be obtained from an approved source and shall be free from large rocks, organic matter and excessive clay and moisture.

Construction of Embankments

16. All embankments shall be constructed to the levels shown on the Drawings using suitable approved material.

17. When the topsoil has been stripped the Engineer shall inspect and approve each section of the formation, prior to the placing of the first layer of fill. As soon as the Engineer has approved a section of formation, the Contractor shall immediately cover the exposed areas by placing fill. No material shall be placed when the formation is frozen.

18. Fill material shall be placed in layers, not exceeding 250mm in depth before compaction, to a dry density of not less than 95% of the maximum dry density obtained from BS 1377: Part 4. During compaction, the fill shall have a uniform moisture content, determined in accordance with BS 1377: Part 2 within 2% of the optimum moisture content determined from BS 1377: Part 4 Where necessary the Contractor shall adjust the moisture content of the fill, either by drying out or by adding water. Before incorporation in the Works, the fill shall then be thoroughly mixed until the moisture content is uniform.

19. Fill material shall not be placed onto standing or running water and the Contractor shall form embankments with appropriate falls and gradient to shed water.

20. Whenever fill is to be deposited against the face of a natural slope, or sloping earthworks face including embankments, cuttings, other fills and excavations, such faces shall be benched, immediately before placing the subsequent fill. Unless otherwise stated in the Contract, benching shall apply to all slopes steeper than one vertical to ten horizontal.

Stockpiling

21. Stockpiling of any material shall be to the Engineer's approval and shall in no case exceed 4.0 metres in height above existing ground levels.

Tolerances in Surface Profiles

22. Surfaces to embankments to receive turf or topsoil shall comply with the tolerances shown hereunder:-

(a) Gradual irregularity: + or - 50 millimetres
(b) Abrupt irregularities: not permitted

Gradual irregularities shall be tested by means of a taut string-line or straight template over a measured distance of 10 metres in any direction.

22. In the case of patching works to existing defences, the profile shall blend to the original line and levels so that the final surface profile matches that of the existing defence.

Topsoiling and Seeding

23. Following the approval of the profile of the embankments by the Engineer, the topsoil, previously set aside, shall be evenly spread over the embankment crest and landward slope to a minimum depth of 150mm for grassed areas and 400mm for planted areas.

24. Topsoil shall not, unless the Engineer permits otherwise, be excavated from stockpiles:

(a) Which have been exposed to a cumulative rainfall exceeding 100mm, over the preceding 28 days measured at a point approved by the Engineer; or

(b) When heavy rain is falling.

Attention of
Alex Purcell.
re/ NRA /26.

ENVIRONMENT AGENCY

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Redhill
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3/34 151

with compliments NR

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Project 29 APR 1996 File

The Environment Agency
Rivers House, East Quay, Bridgwater, Somerset TA6 4YS
Tel 01278 457333 Fax 01278 452985

Ref NRA/26.

HALCROW

Sir William Halcrow & Partners Ltd
Consulting Engineers
Bass House, Ambassador Drive
Exeter Business Park, Honiton Road
Exeter EX1 3QN

Tel (UK) 01392 444252
Fax (UK) 01392 444301

Environment Agency South West
Rivers House
East Quay
Bridgwater
TA6 4YS

For the attention of Mr N W Stevens

19 April 1996 Our Ref: SJW/SSD/21 Your Ref:

Dear Sirs

STOLFORD TO STEART SEA DEFENCES
Compaction of embankments

As requested please find enclosed the relevant pages from the specification for the above. The method of compaction actually used on site was, preliminary compaction of spread layers by tracked excavator and then further compaction by the running of the large dump trucks along the top of the bank.

Yours faithfully

S J Webster

S J WEBSTER
Section Engineer

0.11 Material for embankments shall be spread and compacted in accordance with the Department of transport Specification for Highway Works 1991 Table 6/4 Method 2. Earthworks

Table 6/4 is reproduced in Appendix A for convenience.

0.12 The Contractor should note that the site is contained within Bridgwater Bay Site of Special Scientific Interest (SSSI). On no account shall the Contractor permit any labour, plant or materials to stray onto, or cause damage to, the SSSI. Any breach of this will cause the Employer to request the immediate removal from site of the guilty party and may leave the Contractor liable to prosecution. Working in SSSI

0.13 The following grass seed mix shall be used in the SSSI for landscaping the permanent works and reinstatement:- Grass seeding

Creeping red fescue	40%
Hard fescue	15%
Smooth stalked meadow grass	20%
Brown top bent	10%
Crested dogs-tail	15%

It shall be sown at the rate 10g/m^2. Fertiliser and sowing to be in accordance with clause 3.133 and 3.9.

The seed shall be of native provenance and sowing shall take place between mid-September and early October during suitable weather conditions.

The Contractors attention is drawn to the cutting requirement of clause 3.9.4

SECTION 3 - EXCAVATION, BACKFILLING AND RESTORATION

3.1 EXCAVATION

3.1.11 If the Final Surface is damaged or allowed to become puddled through neglect of the Contractor he shall, at his own expense, remove any material which in the opinion of the Engineer's Representative is rendered unsuitable and replace it in accordance with Clause 3.7.6. *Excavation Generally*

3.3 TOPSOIL FOR RE-USE

3.3.3 a) In the course of excavation all topsoil shall be kept separate by the Contractor and be replaced carefully after completion of the works. If so ordered, cultivated lawn turf shall be carefully cut, rolled, stacked, watered as necessary and carefully replaced. If, after placing, any turf is not in the opinion of the Engineer satisfactory, then the Contractor shall at his own expense immediately replace the turf with new turf to the satisfaction of the Engineer. *Topsoil*

b) The Contractor shall replace any topsoil which is lost, removed or temporarily stacked elsewhere with new topsoil equal in quality and quantity to that excavated, and shall carry out the reinstatement with such new topsoil to the entire satisfaction of the Engineer.

3.4 DEALING WITH WATER

3.4.4 The Contractor shall inform the Engineer's Representative of the discovery of any spring in the course of excavation. Where a spring occurs behind or beneath a proposed structure the Contractor will be required to construct a weephole through the structure as directed by the Engineer and flap the outfall if so instructed. *Springs*

3.7 BACKFILLING

3.7.6 Soft spots existing below the bottom of the excavation shall be removed as directed by the Engineer. Beneath the foundations of structures, the resulting voids shall be replaced with Grade C7.5P concrete. Elsewhere, the voids shall be backfilled with well compacted suitable material. *Unsuitable Soft Material*

3.7.7 Any excavation carried out by the Contractor beyond the net plan dimensions required in the Contract for the purposes of providing working space shall be backfilled as specified at the Contractor's expense using only material which in the opinion of the Engineer's Representative is suitable. Unsuitable material shall be removed from the site and replaced with imported fill as specified in the Clause 2.148, unless otherwise specified. Beneath the base-slab of any wall all such backfill material shall comprise Grade C7.5P concrete. — Backfilling of working space

3.7.8 Where excavation is carried out beyond that indicated on the Drawings and the Specification, the void so formed shall be filled to the satisfaction of the Engineer's Representative at the Contractor's expense. — Excessive Excavation

3.8 REINSTATEMENT OF HIGHWAYS

3.8.25 *Reinstatement of Highway and Footpaths*

a) Items are included in the Bill of Quantities where necessary for backfilling above the final surface with stated materials other than the excavated materials where required.

b) The Contractor shall carry out the permanent reinstatement of carriageways and footpaths as detailed on the drawings and in Section 2 of the Specification to the approval of the Highway Authority.

c) Grass verges shall be reinstated as specified in Clause 3.9.4 and the rates shall include for grass seeding using mixture 1 as specified in Clause 2.132.

3.9 REINSTATEMENT OF UNPAVED LAND

3.9.4 *Reinstatement of Unpaved Working Area*

a) Where directed, and before topsoiling within the working area, the Contractor is to carry out subsoiling in an approved manner and in accordance with good agricultural practice. Subsoiling will be carried out to give maximum lift and shatter of the soil, normally 90° to existing lateral drains. The exact direction of the lines of subsoiling is to be agreed with the Engineer's Representative before work is carried out.

b) On completion of subsoiling, the topsoil, which may have been removed, is to be replaced, levelled and then consolidated by light rolling.

c) When the working area within the site is able to be reinstated, ground preparation shall be completed and grass seeding shall take place within the earliest growing season.

d) Where Grass Seed Mix Type 1, Type 2 or Type 3 is specified, the seed is to be drilled, or broadcast and raked, into the prepared area at the application rates shown in Specification Clause 2.132. The specified fertilizer shall be applied either in separate drilled rows with the grass or immediately after the seeding as a surface dressing. The seeded area shall then be rolled.

e) Where Grass Seed Mix Type 4 is specified, topsoil is to be prepared 4 to 6 weeks before sowing in accordance with Clause 3.9.4.b above. Immediately before sowing the topsoil shall be sprayed with a contact herbicide and rolled to firm. The seed shall be well mixed then sown at a rate of 50 kg per hectare by broadcasting and incorporated into the soil by light raking and firming. No fertilizer shall be used.

f) All seeded areas shall remain fenced and the Contractor shall not enter the areas with his plant except to cut the grass. The areas shall be maintained by the Contractor following seeding until the end of the Period of Maintenance.

g) During the Period of Maintenance the Contractor's duties shall include the cutting of the grass, and the Bill of Quantities includes a given number of mowings. Since it is not possible to predict accurately the precise number of mowings which may be required on any site in any one year, the Contractor will be paid according to his rates for more or less than this number, dependant upon the prevailing weather conditions throughout the growing season. Following each operation the cut grass shall be collected and taken to the Contractor's tip.

h) For Grass Seed Mix Types 1, 2 and 3, the seeded area is to be sprayed with a selective hormone weed killer at the earliest susceptible stage of growth, usually at the beginning of May. For Grass Seed Mix Type 4, weeds shall be removed by treating with spot applications or herbicide.

i) The Engineer's Representative will only authorise payment for grass areas when germination has proved satisfactory and all weeds have been removed. The Contractor shall allow for re-seeding any bare patches with the specified mixture. In instances where establishment of re-seeding is unlikely to be satisfactory, the Engineer's Representative may instruct that the area be turfed at the Contractor's expense.

j) Where, in the opinion of the Engineer's Representative, excessive subsidence of seeded areas has occurred such subsidence shall be made good by the Contractor raising all depressions with similar quality topsoil. If, in the opinion of the Engineer's Representative, the subsidence is due to the Contractor's poor or negligent work then all making good shall be done at the Contractor's own expense.

3.11 **LAND DRAINS**

Replacement pipes shall be clayware field drain pipes to BS 1996, or similar approved, preferably in one continuous length without joints other than those connecting the replacement pipes to existing drains.

Reinstatement of land drains

Where it is not practical to replace land drains with one rigid length of clay pipe, and it is necessary to introduce joints, the pipes shall be adequately supported across the excavated area by a method approved by the Engineer's Representative.

3.12 **FILLING ABOVE GROUND**

3.12.3 Selected fill material derived from site shall be as specified in Clause 2.148.

Materials for Embankments

Fill material to be imported for the construction of the embankment is to conform with the requirements of the Department of Transport "Specification for Highways Work" 1991.
Fill to the embankment is to be either:
Class 2A : Wet cohesive material - General fill, or
Class 2B : Dry cohesive material - General fill, or
Class 2C : Stony cohesive material - General fill.

Earthworks Tolerances

Grading requirements as follows:

Sieve Size Percentage by mass passing the size shown

	Class 2A	Class 2B	Class 2C
300mm	-	-	-
125mm	100	100	100
2mm	80-100	80-100	15-80
63 microns	15-100	15-100	15-80

Compaction requirements as follows:

for Class 2A Table 6/4 method 1
for Class 2B Table 6/4 method 2
for Class 2C Table 6/4 method 2

3.12.4 a) In setting out, the tolerance on the line of the embankments shall be ± 300 mm, except where the embankment is shown as tying in to the floodwalls, where the line shall be exact.

b) The tolerance in flood protection level, ie top of embankment level, shall be + 75 mm, - O mm.

c) The embankment slopes shall be formed such that they are no steeper than the design slope unless directed otherwise by the Engineer's Representative.

3.14 a) Trees, shrubs, hedges, turf and grass seed shall be planted, laid or sown where shown on the drawings or detailed in Section O of the Specification. Preparation shall be as detailed below. — Landscaping to Newly Formed Earthworks

b) Where subsoil has been compacted to a hard pan then, prior to preparation of the topsoil, the procedure detailed in Clause 3.9.4 a) shall be carried out.

c) Topsoil shall be levelled or graded as appropriate and then consolidated by light rolling.

d) Grass seed shall be of the Mix Type shown on the drawings or in Section O of the Specification and the constituents of each type shall be as Clause 2.132 of the Specification.

e) Seeding, fertilizing, weedkilling and cutting of grass shall be in accordance with Clause 3.9.4 c) to h) of the Specification as appropriate.

f) Where turf is required this shall be supplied as Clause 2.5 and laid in accordance with Clause 3.9.3 with the additional requirement that on slopes the laid turf shall be covered in lightweight Netlon held in place by galvanised wire ties until the turf has taken.

g) Where trees are required, unless otherwise specified, these shall be whips one metre high with rabbit protection and planted as directed by the Engineer's Representative.

3.15 The Contractor shall make a daily record of all the strata encountered in excavations together with depths at which they occur, the depths at which water is found and the appropriate ground water rest level. A written copy of these records shall be handed to the Engineer's Representative on a weekly basis. — Records of Strata

3.16 Perforated concrete slabbing shall be constructed to slopes and surfaces as shown on the drawings. This is to be formed using Grasscrete GC2 formers, 600 x 600 x 150 deep. These are to be laid on 125 mm thick Zone 2 (BS 882) sand. Reinforcement shall comprise A252 mild steel mesh and concrete shall be Grade C30/10P placed flush with the top of the formers and after the initial set brushed to leave the tops of the formers exposed. After 48 hours the exposed tops of the formers are to be burned away. Voids are to be filled with topsoil and seeded with the grass-seed mix used on adjacent areas of reinstatement. Grasscrete

TABLE 6/4 : Method Compaction for Earthworks Materials : Plant and Methods (Method 1 to Method 6)
(This Table is to be read in conjunction with sub-Clause 612.10)

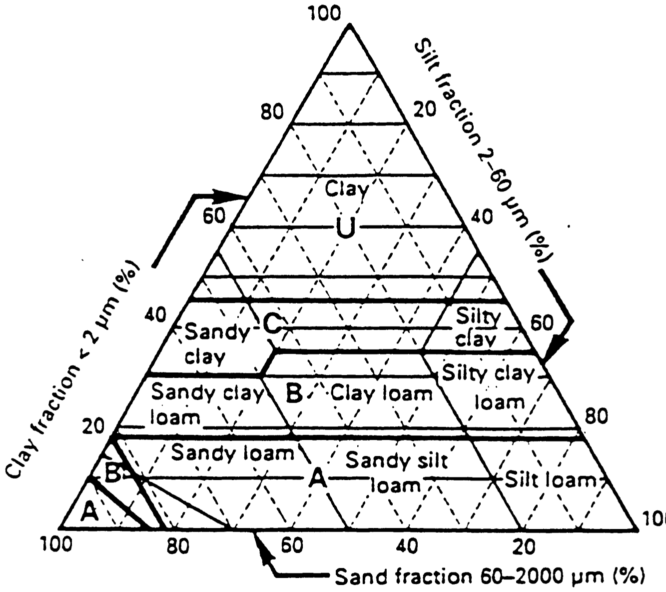
Type of Compaction Plant	Ref No.	Category	Method 1		Method 2		Method 3		Method 4		Method 5		Method 6		
			D	N#	D	N#	D	N#	D	N	D	N	N for D = 110 mm	N for D = 150 mm	N for D = 250 mm
Smooth wheeled roller (or vibratory roller operating without vibration)		Mass per metre width of roll:													
	1	over 2100 kg up to 2700 kg	125	8	125	10	125	10*	175	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 2700 up to 5400 kg	125	6	125	8	125	8*	200	4	unsuitable		16	unsuitable	unsuitable
	3	over 5400 kg	150	4	150	8	unsuitable		300	4	unsuitable		8	16	unsuitable
Grid roller		Mass per metre width of roll:													
	1	over 2700 kg up to 5400 kg	150	10	unsuitable		150	10	250	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 5400 kg up to 8000 kg	150	8	125	12	unsuitable		325	4	unsuitable		20	unsuitable	unsuitable
	3	over 8000 kg	150	4	150	12	unsuitable		400	4	unsuitable		12	20	unsuitable
Tamping roller		Mass per metre width of roll:													
	1	over 4000 kg	225	4	150	12	250	4	350	4	unsuitable		12	20	unsuitable
Pneumatic-tyred roller		Mass per wheel:													
	1	over 1000 kg up to 1500 kg	125	6	unsuitable		150	10*	240	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 1500 kg up to 2000 kg	150	5	unsuitable		unsuitable		300	4	unsuitable		unsuitable	unsuitable	unsuitable
	3	over 2000 kg up to 2500 kg	175	4	125	12	unsuitable		350	4	unsuitable		unsuitable	unsuitable	unsuitable
	4	over 2500 kg up to 4000 kg	225	4	125	10	unsuitable		400	4	unsuitable		unsuitable	unsuitable	unsuitable
	5	over 4000 kg up to 6000 kg	300	4	125	10	unsuitable		unsuitable		unsuitable		12	unsuitable	unsuitable
	6	over 6000 kg up to 8000 kg	350	4	150	8	unsuitable		unsuitable		unsuitable		12	unsuitable	unsuitable
	7	over 8000 kg up to 12000 kg	400	4	150	8	unsuitable		unsuitable		unsuitable		10	16	unsuitable
	8	over 12000 kg	450	4	175	6	unsuitable		unsuitable		unsuitable		8	12	unsuitable
Vibratory roller		Mass per metre width of a vibratory roll:													
	1	over 270 kg up to 1500 kg	unsuitable		75	16	150	16	unsuitable		unsuitable		unsuitable	unsuitable	unsuitable
	2	over 450 kg up to 700 kg	unsuitable		75	12	150	12	unsuitable		unsuitable		unsuitable	unsuitable	unsuitable
	3	over 700 kg up to 1300 kg	100	12	125	10	150	6	125	10	unsuitable		16	unsuitable	unsuitable
	4	over 1300 kg up to 1800 kg	125	8	150	8	200	10*	175	4	unsuitable		6	16	unsuitable
	5	over 1800 kg up to 2300 kg	150	4	150	4	225	12*	unsuitable		unsuitable		4	6	12
	6	over 2300 kg up to 2900 kg	175	4	175	4	250	10*	unsuitable		400	5	3	5	11
	7	over 2900 kg up to 3600 kg	200	4	200	4	275	8*	unsuitable		500	5	3	5	10
	8	over 3600 kg up to 4300 kg	225	4	225	4	300	8*	unsuitable		600	5	2	4	8
	9	over 4300 kg up to 5000 kg	250	4	250	4	300	6*	unsuitable		700	5	2	4	7
	10	over 5000 kg	275	4	275	4	300	4	unsuitable		800	5	2	3	6
Vibrating plate compactor		Mass per m^2 of base plate:													
	1	over 880 kg up to 1100 kg	unsuitable		unsuitable		75	6	unsuitable		unsuitable		unsuitable	unsuitable	unsuitable
	2	over 1100 kg up to 1200 kg	unsuitable		75	10	100	6	75	10	unsuitable		unsuitable	unsuitable	unsuitable
	3	over 1200 kg up to 1400 kg	unsuitable		75	6	150	6	150	8	unsuitable		unsuitable	unsuitable	unsuitable
	4	over 1400 kg up to 1800 kg	100	6	125	6	150	4	unsuitable		unsuitable		8	unsuitable	unsuitable
	5	over 1800 kg up to 2100 kg	150	6	150	5	200	4	unsuitable		unsuitable		5	8	unsuitable
	6	over 2100 kg	200	6	200	5	250	4	unsuitable		unsuitable		3	6	12

TABLE 6/4 : Method Compaction for Earthworks Materials : Plant and Methods (Method 1 to Method 6) (*continued*)
(This Table is to be read in conjunction with sub-Clause 612.10)

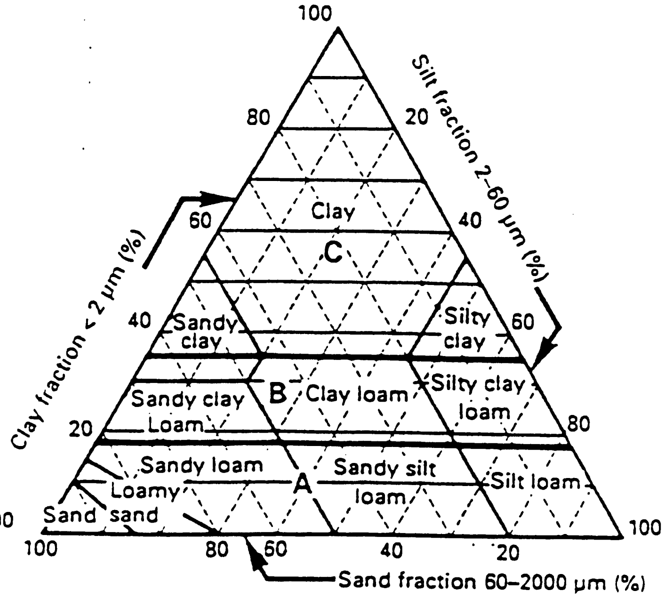
Type of Compaction Plant	Ref No.	Category	Method 1		Method 2		Method 3		Method 4		Method 5		Method 6		
			D	N#	D	N#	D	N#	D	N	D	N	N for D = 110 mm	N for D = 150 mm	N for D = 250 mm
Vibro-tamper		Mass:													
	1	over 50 kg up to 65 kg	100	3	100	3	150	3	125	3	unsuitable		4	8	unsuitable
	2	over 65 kg up to 75 kg	125	3	125	3	200	3	150	3	unsuitable		3	6	12
	3	over 75 kg up to 100 kg	150	3	150	3	225	3	175	3	unsuitable		2	4	10
	4	over 100 kg	225	3	200	3	225	3	250	3	unsuitable		2	4	10
Power rammer		Mass:													
	1	100 kg up to 500 kg	150	4	150	6	unsuitable		200	4	unsuitable		5	8	unsuitable
	2	over 500 kg	275	8	275	12	unsuitable		400	4	unsuitable		5	8	14
Dropping-weight compactor		Mass of rammer over 500kg height drop:													
	1	over 1m up to 2m	600	4	600	8	450	8	unsuitable		unsuitable		unsuitable	unsuitable	unsuitable
	2	over 2m	600	2	600	8	unsuitable		unsuitable		unsuitable		unsuitable	unsuitable	unsuitable

APPENDIX H
Soil Suitability for Specific Purposes

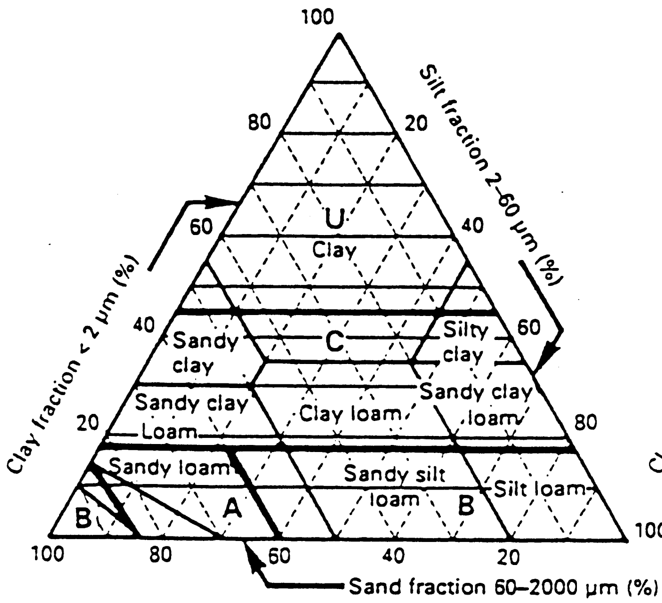
Box 4.3 Soil suitability for specific purposes based on texture



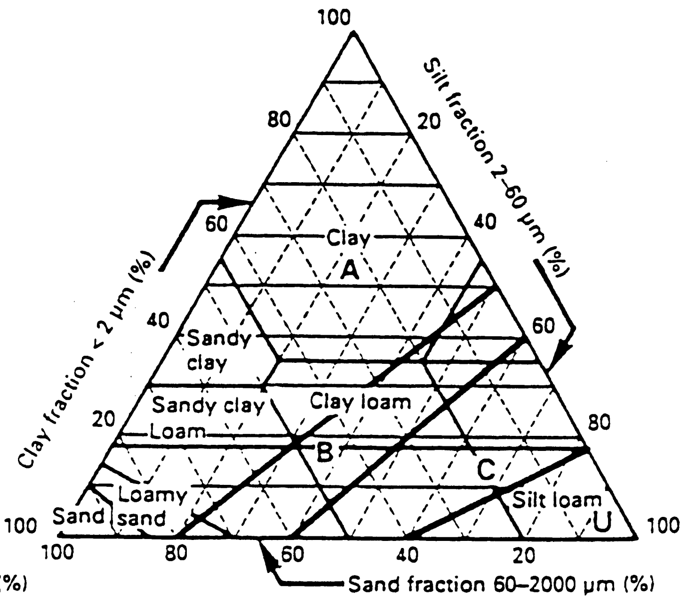
(a) Suitability classes given in Box 2.10



(b) Ease of cultivation and handling



(c) Heavily trampled and trafficked areas



(d) Erosion risk (erodibility)

Notes
A – most suitable/least susceptible
B – moderately suitable
C – just suitable/most susceptible
U – unsuitable

APPENDIX J
Glossary of Terms

Atterberg Limits: A collective term for the Liquid and the Plastic Limit.

Berm: The horizontal ledge formed in the side of an embankment or cutting.

Clay: A soil consisting of inorganic material, in which 35% of the grains by weight, have diameters smaller than 0.002mm.

Cohesive Soil: A soil which exhibits plasticity associated with the presence of a significant quantity of clay minerals.

Compaction: The process of packing soil particles more closely together, usually by rolling or mechanical means, thus increasing the dry density of the soil.

Crack: A physical discontinuity in a material induced by some form of stress.

Crest: The highest part of a flood defence embankment.

Delph Ditch: A ditch on the landward side of an embankment, in which overtopping or seepage is collected.

Estuary: The mouth of a river connected to the sea, where both fluvial and tidal effects occur.

Evaporation: The process by which water becomes a vapour.

Evapotranspiration: Water drawn form the soil by evaporation and/or plant transpiration.

Failure: A failure of a flood defence system is considered to be a failure of the system to perform as intended ie it is not capable of achieving the specified performance criteria during the design event.

Fissure: As *crack*

Flood Defence: Any protection measures made to manage flooding. For the purposes of this manual flood defence is considered to cover fluvial, estuarine and coastal situations.

Flood defence earth embankment: An earth bank built to prevent or control the extent of flooding.

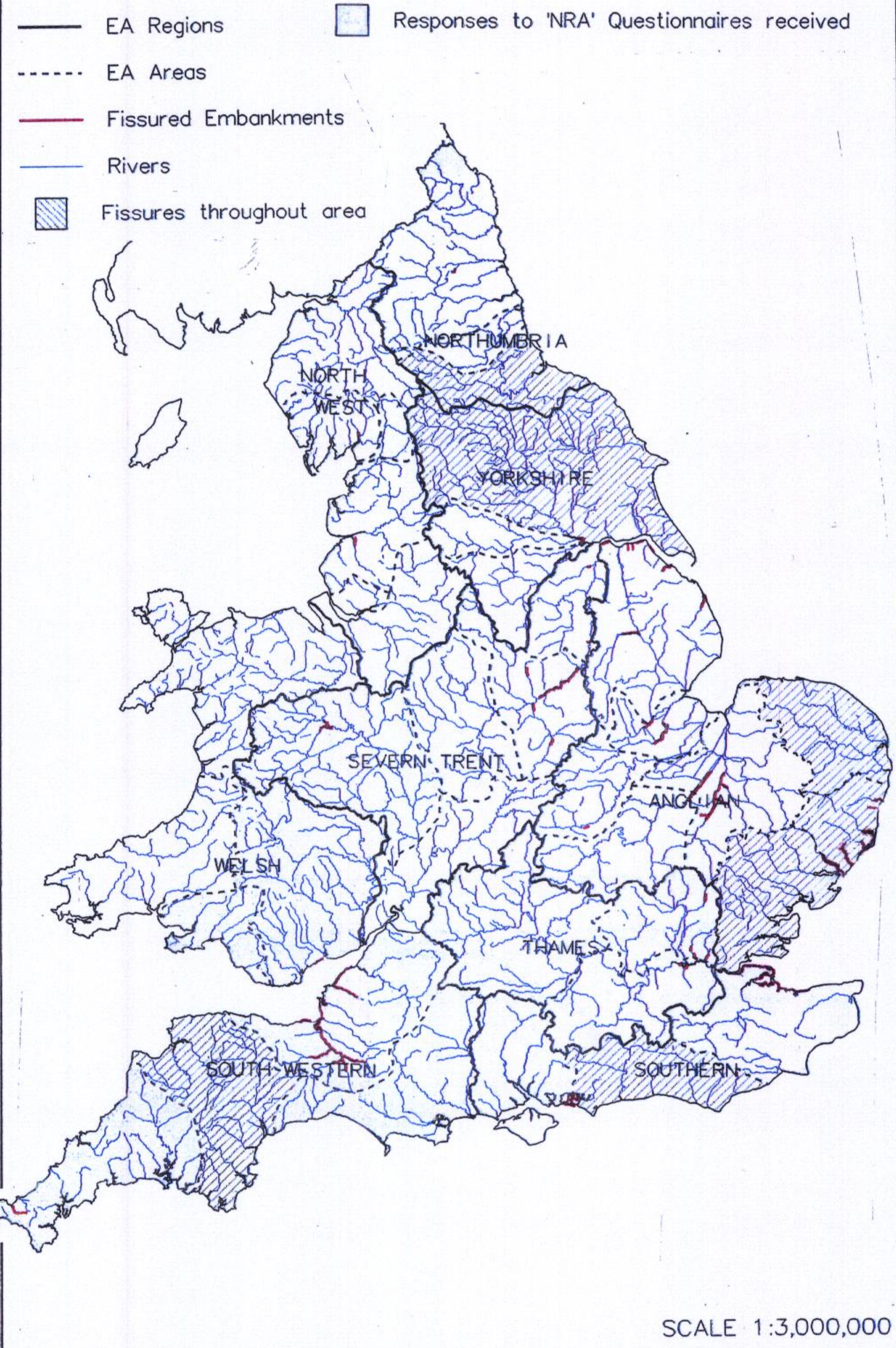
Flooding: The encroachment of land by water over areas that are not usually or are not intended to be inundated.

Fluvial: Relating to a river.

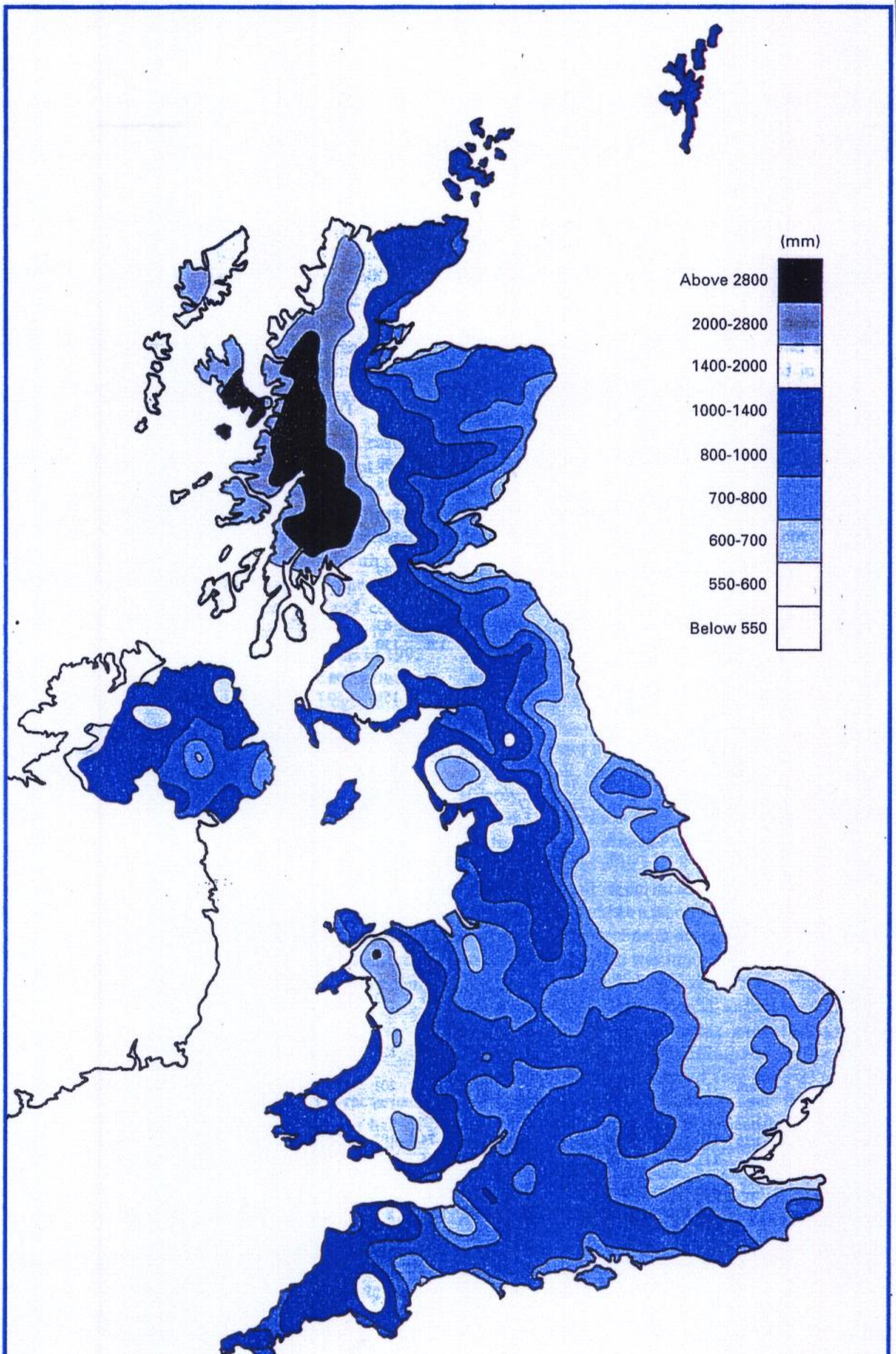
Freeboard: The height of the crest of and flood defence above the still water level.

Geotextile/Geogrid: Permeable synthetic material used in conjunction with soil for the function of filtration, separation, drainage, reinforcement and erosion protection.

Liquid Limit:	The moisture content at which soil passes from the plastic to the liquid state, as determined by the liquid limit test.
Maintenance:	All operations necessary to keep an asset in a defined state.
Moisture Content:	The mass of water which can be removed from the soil by heating at 105°C, expressed as percentage of the dry mass. (also referred to as the water content).
Optimum Moisture Content:	The moisture content of a soil at which a specified amount of compaction will produce the maximum dry density.
Overtopping:	The passage of water over a component such as a flood defence embankment due to high water levels or wave action.
Plastic Limit:	The moisture content at which the soil passes from a plastic state to the solid state, and becomes too dry to be in plastic condition, as determined by the plastic limit test.
Plasticity Index:	The numerical difference between the Liquid Limit and the Plastic Limit.
River:	Any natural water course carrying perennial flow.
Shrinkage limit:	The moisture at which the soil on being dried ceases to shrink.
Standard of Service:	The actual or required performance of a drainage or flood defence system, expressed as the return period of the event which can be withstood, or is required to be withstood.
Tidal:	Relating to tides.
Tides:	Periodic rising and falling of water resulting from the gravitational attraction of the moon, sun and other astronomical bodies, together with the effects of coasts and oceans.
Transpiration:	The process by which water vapour is lost to the atmosphere from living plants.



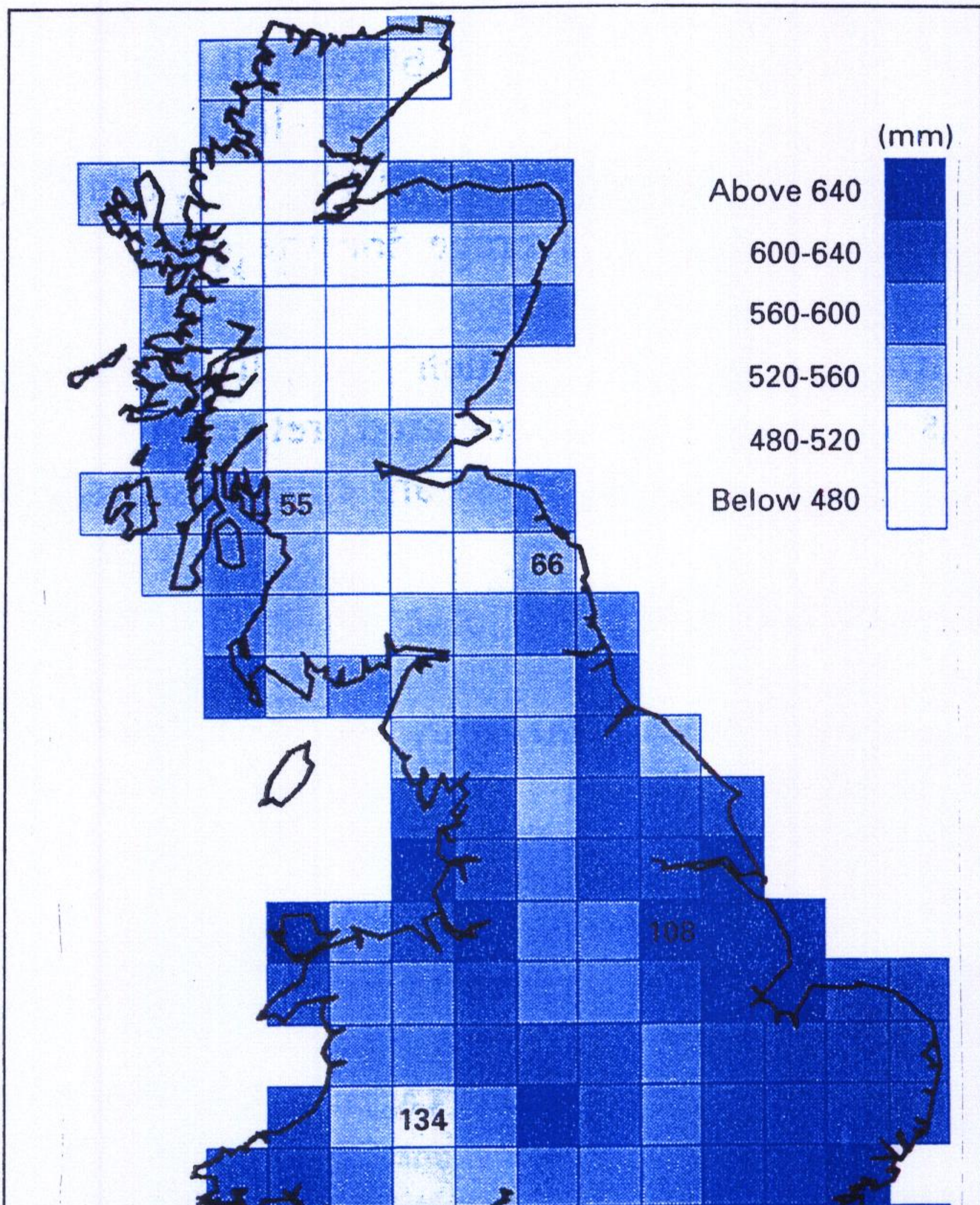
Geographical Extent of Reported Cracking and Fissuring | **Fig. 5**



Source: Meteorological Office

UK Rainfall 1992 (after Hydrological Year Book)

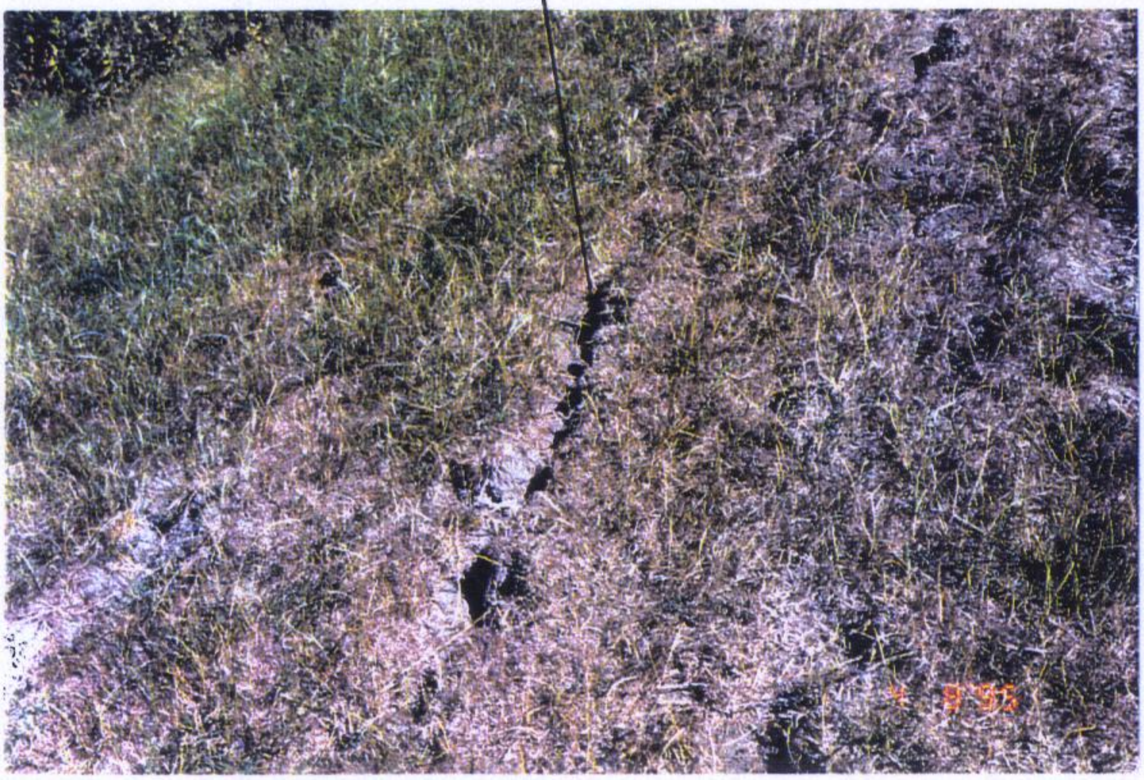
Fig. 9



Potential Evapotranspiration from Grass (after Hydrological Year Book)

Fig. 10

WIDE FISSURES



MAXEY CUT TALLINGTON

FINELY FISSURED ZONE

MILLBEACH TO GOLDHANGER