VOLUME 4 GEOTECHNICS AND DRAINAGE
SECTION 1 EARTHWORKS

PART 6

HA 74/07

TREATMENT OF FILL AND CAPPING MATERIALS USING EITHER LIME OR CEMENT OR BOTH

SUMMARY

This Advice Note provides guidance on the use of lime and cement to stabilise capping materials for highway works and slope repairs. The guidance covers site investigation, design and construction

INSTRUCTIONS FOR USE

1. This document supersedes HA 74/00, which is now withdrawn.
2. Remove HA 74/00, which is superseded by HA 74/07 and archive as appropriate.
3. Insert HA 74/07 in Volume 4, Section 1, Part 6.
4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

May 2007

Volume 4 home page

DESIGN MANUAL FOR ROADS AND BRIDGES

HA 74/07
Volume 4, Section 1,
Part 6

THE HIGHWAYS AGENCY

TRANSPORT SCOTLAND

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

Treatment of Fill and Capping Materials Using Either Lime or Cement or Both

Summary: This Advice Note provides guidance on the use of lime and cement to stabilise capping materials for highway works and slope repairs. The guidance covers site investigation, design and construction

Volume 4 home page

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

Volume 4 home page

VOLUME 4 GEOTECHNICS AND DRAINAGE
SECTION 1 EARTHWORKS

PART 6

HA 74/07

TREATMENT OF FILL AND CAPPING MATERIALS USING EITHER LIME OR CEMENT OR BOTH

Contents

Chapter

Volume 4 home page

1. INTRODUCTION

General

1.1 This Advice Note provides guidance on the use of either lime or cement or both to treat materials. It considers aspects of investigation, design and construction for capping, general fill and slope repairs.

1.2 The use of lime or cement to form capping is given in the Specification for Highway Works (MCHW 1). General guidance is provided in the Notes for Guidance on the Specification for Highway Works (MCHW 2). This Advice Note contains more detailed information and guidance on stabilised capping, improved materials for general fills and slope repairs.

1.3 The economic and environmental advantages of the use of lime and cement have led to its successful use on a number of civil engineering projects and this Advice Note includes this experience as well as knowledge gained from the few cases where problems have arisen.

Scope

1.4 This Advice Note is issued for guidance on the design of capping, the improvement in general fills and for slope repair design. It therefore covers projects requiring specialist plant for spreading and mixing lime and cement with large volumes of material to much smaller projects where lime and cement may be spread by hand from bags and mixed with agricultural ploughs or conventional construction plant. It advises on the site investigation requirements for lime or cement improvement, to complement existing MCHW and DMRB documents. Guidance is given on ground investigation strategy and testing to enable designers and contractors to consider lime or cement improvement as an option for new and maintenance works.

1.5 Ground granulated blastfurnace slag (GGBS) and Pulverised Fel Ash (PFA), are discussed in the Advice Note to encourage their further consideration. There is increasing use of these materials which needs to be considered on a project-specific basis.

1.6 Attention is given to the specification of the works and testing methods for compliance of earthworks materials. The experience gained from on-site monitoring is included to assist site staff in understanding the process and to provide information on site queries.

1.7 The guidance given is applicable to roads and motorways within the jurisdiction of the Overseeing Organisation and may also be considered good practice on other earthworks projects.

1.8 This Advice Note covers the specific design aspects of capping materials and general fill treated with either lime or cement or both in order to improve their engineering characteristics.

1.9 The investigation, design and construction of slope repairs using stabilised materials are included in the Advice Note. Although the quantities of material are smaller than for general fill and capping, the advantages are similar and the application more readily appropriate given the need for efficient maintenance methods.

1.10 Site control and methods of working are described in order to facilitate the use of the method in locations where economic and environmental advantages can be achieved.

Definitions and Abbreviations

1.11 Site investigation (SI) encompasses preliminary sources study, planning and supervision of the ground investigation contract and interpretation of factual data for design of a project.

1.12 Ground investigation (GI) is the examination of a site required to provide geotechnical data which are representative of the ground conditions and relevant to the project considered. This includes surface and subsurface investigation, laboratory work and factual reporting.

1.13 Improvement is the spreading of lime on a layer of deposited or intact granular or cohesive material, and the subsequent process of mixing followed by appropriate compaction to form the whole or a constituent layer of a capping or general fill. Improvement is a means of rendering unacceptable materials U1A acceptable.

1.14 This Advice Note considers the chemical and physical effects improvement may have on cohesive

Volume 4 home page

and granular soil. These effects are realised in a shorter time period, when compared to stabilisation and generally require less lime.

1.15 In MCHW 1, sub-Clause 601.11, lime and cement stabilisation is defined as a construction process:

> 'Stabilisation shall mean the spreading of either cement or lime or both on a layer of deposited or intact granular or cohesive material, and the subsequent process of pulverising and mixing followed by appropriate compaction to form the whole or a constituent layer of a capping.'

1.16 This Advice Note uses this definition in terms of lime or cement stabilisation of on-site cohesive and granular material for capping. It also considers the chemical and geotechnical effects stabilisation may have on cohesive and granular soil. These effects are realised in a longer time period where lime only is used, and generally require a greater amount of lime, when compared to lime improvement.

1.17 Improvement involves the almost immediate chemical and physical effects lime has on cohesive and granular materials. It can be part of the stabilisation process associated with the spreading of lime and initial mixing.

1.18 Mellowing is the period of time when a cohesive material and lime mixture is left undisturbed after light compaction to allow the migration of lime through the material clods created during mixing and for improvement processes to take place. This period precedes the remixing and final compaction of the stabilised capping.

1.19 Curing is the period of time when a soil and lime or cement mixture is left undisturbed after final compaction of the capping to allow stabilisation processes to continue.

1.20 Formation is the top surface of capping. (If capping is not required, the top surface of the earthworks at the underside of the sub-base is taken as formation.)

1.21 Sub-formation is the top surface of earthworks at the underside of capping.

1.22 The Geotechnical Certification procedures referred to in this Advice Note are those defined in HD 22 (DMRB 4.1.2).

Implementation

1.23 This Advice Note should be used forthwith for all projects currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay. The Designer should confirm its application to particular projects with the Overseeing Organisation.

Mutual Recognition Clause

1.24 It is intended that the processes and procedures in this Advice Note are procured through contracts incorporating the Specification of Highway Works, Clauses 104 and 105. Any contract not containing these Clauses must contain a suitable clause of mutual recognition having the same effect.

2. APPLICATIONS AND FUNDAMENTALS

General

2.1 The use of lime, for cohesive materials, or cement, for granular materials, for stabilisation of capping is well established and has been included in MCHW 1 since 1986. The principal use of these materials has been with cohesive and granular soils. However, a two stage process of mixing lime then cement has become more prevalent on recent projects. This process has the advantage of increasing the range of acceptability of material properties. Table 2/1 shows the main applications of material treatment within an MCHW 1 context.

2.2 Lime is also used to reduce the moisture content or plasticity index of unacceptable cohesive materials to render them acceptable for general fill, slope repairs and capping use and to reduce the moisture content of granular materials.

2.3 Cement is primarily used to increase bearing ratio (CBR) although the moisture content will reduce due to hydration of the cement. Cement is generally applied to granular materials.

2.4 Some cohesive materials do not achieve the required long term bearing ratio when only lime is added, or they may contain a high percentage of granular material, so cement is added as a second process to achieve the required strength. In this two stage process the initial addition of lime is primarily to make the cohesive material friable so that the cement can be added. Guidance when a two stage approach is needed depends on the results of laboratory testing and is covered in Section 3.41.

Lime

2.5 For engineering purposes, there are two types of lime; quicklime and hydrated lime.

(a) Quicklime (CaO) is required in MCHW 1 (sub-Clause 615.3) to comply with BS EN 459-1 and to have a grading of 100% passing a BS 10 mm sieve and at least 95% by mass passing a 5 mm size test sieve. Compared to hydrated lime its advantages are that it has a higher available lime content and a very fast drying action on wet soils. The disadvantage is that it requires considerable amounts of water to hydrate, which although an advantage for wet soils, can be a problem in dry soils. Quicklime is also available in granular form which has the advantage of having less dust particles but the disadvantage of a less well distributed mix. Granulated quicklime is particularly useful on works next to live carriageways or where drifting dust is a sensitive issue. It does not, however, distribute as well as powder which is used for stabilisation in new works.

(b) Hydrated lime ($Ca(OH)_2$), or slaked lime, is also permitted in MCHW 1 provided it complies with BS EN 459-1. It comes in the form of a fine, dry powder. Hydrated lime is quicklime with sufficient water added to it to hydrate the lime. The main advantage is that it requires less water to react and so may be desirable for drier sites. However, this may be counteracted by the cost of transporting water, albeit chemically bonded to the quicklime, with the lime. It may be cheaper to transport quicklime, with its higher available lime content, and add water on site.

Available lime is the amount of reactive lime in the constituent. For quicklime this is likely to be almost 100% whereas for hydrated lime it would be lower. Manufacturers should be consulted for the exact figures.

Lime Improvement

2.6 When lime is mixed with cohesive material, the cohesive material is first improved before further chemical reactions occur, if sufficient lime is present, which in most soils lead to stabilisation. Not all cohesive materials can be stabilised but all can be improved. The improvement of a cohesive material using lime changes the soil properties in two ways if quicklime is used, or in one way if hydrated lime is used. Improvement alone is generally only applied in rendering U1A unacceptable materials acceptable. Mixing quicklime with a wet soil immediately causes the lime to hydrate via an exothermic reaction as water is absorbed from the soil into the lime. The heat produced is sufficient to drive off some of the moisture within the soil as vapour and hence further reduce the moisture content. The second effect is a reduction in plasticity as the clay particles flocculate. Figure 2/1,

Volume 4 home page

from Sherwood (1967), illustrates the effect of lime on plasticity.

A soil at a moisture content of 35% with no lime added will be above its plastic limit of 25%. The addition of 2% of lime will increase the plastic limit to 40% and the soil will be 5% below the plastic limit, dimensions ‘y’ in the figure, rather than 10% above, dimension ‘x’ in the figure even if there is no change in the moisture content of the soil. The effect of lime on liquid limit is much less marked. This improvement in plasticity also occurs with hydrated lime, or slaked lime as it is sometimes called, but since the lime is already hydrated, no exothermic reaction occurs. These effects are immediate, little affected by temperature providing the material is above freezing and are complete within 24 to 72 hours. They have been used to gain access to and work materials on a number of water logged sites (Sherwood, 1992).

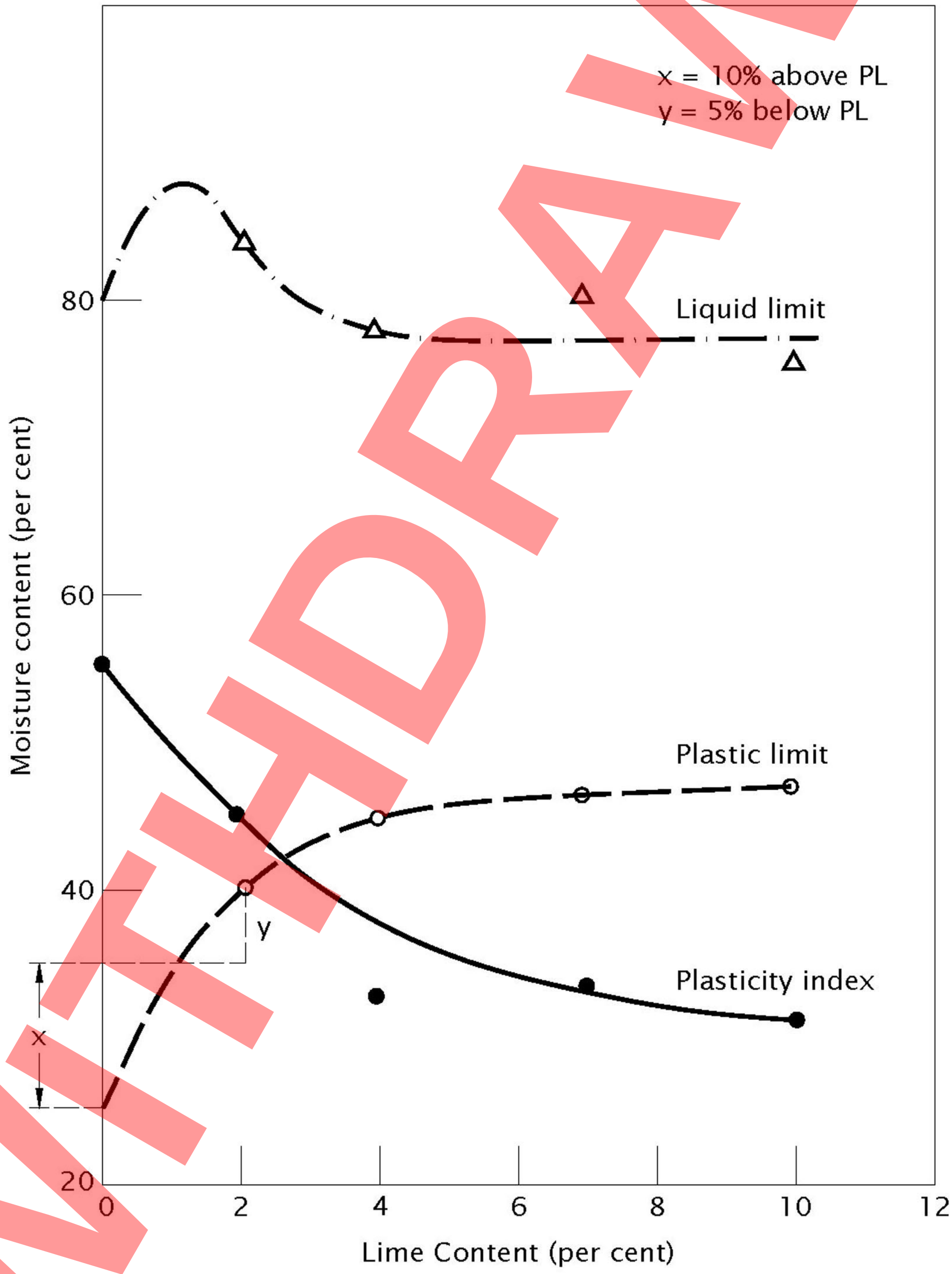

Figure 2/1 Effect of the Addition of Lime on the Plasticity Properties of London Clay (Sherwood, 1967)

Volume 4 home page

Lime Stabilisation

2.7 Lime improvement of clay soils has an almost immediate effect with significant improvement on mixing and with some remaining improvement occurring up to 72 hours later. In the longer term, the lime reacts with the silica and alumina in clay particles to produce cementitious products which then bind the soil together if sufficient lime above that required for full improvement (termed the fixation level) is present in the mix. This is termed stabilisation.

2.8 The MCHW 1, sub-Clause 615.8 allows stabilisation to be carried out between March and September inclusive and when the shade temperature is not below 7°C. Appendix 6/7 allows the use of site specific alternatives.

2.9 Sulfates, although not affecting the reduction in plasticity, can, because of lime addition, cause excessive swelling. Where used in capping, this can be detrimental to the pavement's strength and cause deformations of the road surface. It can be particularly rapid during construction or in the short-term immediately following pavement construction. The reactions are fully described in Sherwood (1993) and TRL Report 447. The sulfates may be present either within the soil already, be produced by the oxidation of sulfides, or be introduced by groundwater. High sulfate levels are a risk to the success of the process and the pavement and must be explored. Details are given in the following sections and an example is given in Snedker and Temporal, 1990. Swelling in fills and slope repairs is usually not detrimental provided there is not a significant drop in shear strength and the materials are a sufficient distance from sensitive surfaces such as the carriageway or drainage runs.

2.10 Organic materials may also prevent the stabilisation process occurring unless sufficient lime is added. Lime stabilisation relies on an increase in the pH of the soil which may not be possible in organic (acid) soils unless large and, possibly uneconomic, amounts of lime are added. The change in pH depends on the type and amount of organic materials (Sherwood, 1992).

2.11 Lime stabilisation requires the soil and constituent to be thoroughly pulverised and mixed on site using mobile stabilising machines.

2.12 A period of not less than 24 hours and not greater than 72 hours is allowed in MCHW 1 sub-Clause 615.11 for the material to mellow. This period, if sufficient water is available, allows the lime to slake, if quicklime is used, provides time for the lime to migrate through the material clods and, as a result of the plasticity changes, makes mixing of the material before final compaction easier. It also assists compliance with the requirement for 95% of the material to pass a 28 mm size test sieve and a lower pulverisation limit of 30%. The soil is principally undergoing improvement during this time although some cement bonds are forming. The layer is sealed by one pass of a smooth wheeled roller prior to mellowing. The purpose of the sealing is to reduce carbonation of the lime. Carbonation occurs when the lime reacts with carbon dioxide in the air and reverts to calcium carbonate on long-term exposure. Clearly any carbonation that occurs before the lime has reacted with the soil reduces the amount of lime available. Sealing the layer reduces the air content and prevents significant carbonation. In practice, no problems have been reported with carbonation in the United Kingdom.

Cement

2.13 The type of cement permitted in MCHW 1 is Portland cement complying with Clause 1001.

Cement Stabilisation

2.14 The mixtures of cement with granular materials do not go through an improvement process. Since cement is an hydraulic binder, no reactions with the material are required and cementing takes place with hydration.

2.15 The other main difference to lime stabilisation is that compaction must be undertaken within two hours of mixing due to the rapid setting of the cement and material mixture. If left for longer, the bonds formed will be broken during compaction and some degree of strength will be lost.

2.16 The reaction between cement and sulfates is a concern as described in Section 2.9.

Lime and Cement Stabilisation

2.17 This two stage process is principally used in capping where either the cohesive material does not achieve the required strength or mixtures of cohesive and granular materials occur and it is not feasible to use lime only or cement only stabilisation. Lime is mixed first with the material to improve it and then cement is added and mixed to provide the strength required. The testing requirements to prove suitability are similar to lime or cement stabilisation.

Volume 4 home page

Lime and Ground Granulated Blastfurnace Slag Stabilisation

2.18 Ground granulated blastfurnace slag (GGBS) is readily available throughout the UK where its main use is in concrete. On its own, GGBS has only slow cementitious properties and Portland cement normally provides the alkalinity to activate and accelerate these properties. Lime can also be used to provide the necessary alkali for activation. It has been shown that GGBS and lime combinations are practical and effective options for soil stabilisation, and provide technical benefits. In particular the incorporation of GGBS, is known to be effective at combating the expansion associated with the presence of sulfate or sulfide in soil. Following extensive research and site trials, lime and GGBS stabilisation is now becoming a more widely established technique in the UK and may be a preferred option where there are significant levels of sulfates or sulfides present in the soil.

This Advice Note provides guidance for the MCHW1 and does not cover lime and GGBS in any detail. For further information see Wild, Kinuthia, Jones and Higgins (1999); Higgins, Kinuthia and Wild (1998); Higgins, Thomas and Kinuthia (2002); Kennedy (1996); **www.ukcsma.co.uk** and Higgins and Kennedy J (1999).

Pulverised Fuel Ash in Stabilisation

2.19 Pulverised Fuel Ash (PFA) (a pozzolan) has some cementitious properties but this is greatly increased when mixed with lime. Hence lime and PFA can be used to mix with soils to treat them for use in capping. PFA is collected from the boilers of coal-fired electricity generating stations. PFA is usually mixed with lime in the proportions of 1 of lime to 3 or 4 of PFA but ratios of 1 to 2 up to 1 to 10 are used. The proportion depends on the reactivity of the particular fly ash which may vary. Lime and PFA treated layers have a similar performance to cement treated layers.

This Advice Note provides guidance for the MCHW1 and does not cover lime and PFA stabilisation in any detail. For further information see Sherwood (1993) and **www.britishlime.org/publications/14775_BLA_techdata_3.pdf**.

Constituent	**Process**	**Application**	**Initial Class**	**Primary purposes of constituent**	**Resultant Class**
Lime	Improvement	General granular fill	Class U1A	Reduction in mc (or increase in MCV)	Class 1A Class 1B Class 1C
Lime	Improvement	General cohesive fill	Class U1A	Increase in MCV (or reduction in mc); reduction in PI	Class 2A Class 2B Class 2C Class 2D Class 2E
Lime	Improvement	General chalk fill	Class U1A	Reduction in mc	Class 3
Lime	Stabilisation	Selected cohesive fill – capping	Class 7E	Increase in MCV (or reduction in mc); increase in bearing ratio; reduction in PI	Class 9D
Cement	Stabilisation	Selected granular fill – capping	Class 6E	Increase in bearing ratio	Class 9A
Cement	Stabilisation	Selected cohesive fill – capping	Class 7F Class 7G	Increase in bearing ratio	Class 9B Class 9C
Lime and cement	Stabilisation	Selected cohesive material – capping	Class 7I	Increase in MCV (or reduction in mc); increase in bearing ratio; reduction in PI	Class 9E
Lime and cement	Stabilisation	Selected granular fill – capping	Class 6R	Reduction in mc (or increase in MCV); increase in bearing ratio	Class 9F

Note:
1. Improvement – rendering unacceptable material acceptable
2. Stabilisation – change in use of acceptable material
3. mc = moisture content
4. MCV = Moisture Condition Value
5. PI = Plasticity Index
6. Bearing ratio = California Bearing Ratio

Table 2/1 Applications of Lime and Cement Treatment for General Fill and Capping

3. CAPPING

General

3.1 The use of cement stabilisation for capping in highway works is specified in Clause 614 of the Specification for Highway Works (MCHW1). The use of lime stabilisation for capping in highway works is specified in Clause 615 and the use of lime and cement is specified in Clause 643.

3.2 Capping is a higher strength and higher stiffness layer placed and compacted on weak fills and cutting foundations. Material used in the capping must be of sufficient strength and stiffness to provide a working platform for construction of the pavement layers and act as a structural layer in the longer term. The formation should not be operated on unless adequate protection is provided in addition to that required for weather (MCHW 1 Clauses 617 and 704). The Pavement foundations for long-term performance are designed using the 'equilibrium' CBR derived from the Plasticity Index of the material, construction quality and watertable level as given in HD25 (DMRB 7.2.2.).

Varying subgrade CBR values will require a design with either a thicker sub-base or the use of capping of differing thickness depending on the value of CBR obtained and the type of pavements being considered. Details are given in HD 25 (DMRB 7.2.2) which also provides guidance on the assessment of CBR values for construction and in the longer term. The requirement to have an adequate CBR can be achieved by using either granular materials or materials stabilised with either lime or cement or both to the requirements of MCHW 1. The varying circumstances on different sites will make the use of either granular capping or stabilised capping more appropriate. Availability of granular material and the impact of importing this material is one consideration. On-site materials may not have properties suitable for stabilisation, in which cases granular material may be the only option. However, stabilisation may produce substantial benefits. These include the maximum use of on-site materials with less haulage off-site and reduced need for spoil tips, the saving of scarce resources and reduced impact of the construction on the surrounding environment.

3.3 In many cases stabilisation is a cost-effective procedure which minimises the amount of haulage of unsuitable material off the highway site. The majority of applications have been successful (Sherwood 1992) although there have been a few well publicised failures (Snedker and Temporal 1990).

3.4 Lime 'stabilisation' is a long-term effect on cohesive materials, but initially the material will pass through the 'improvement' process. The capping design will rely upon the lime stabilisation process to improve the properties of the formation level to an acceptable level. With cement stabilisation and lime and cement stabilisation, the capping design relies on the stabilising effect of the cement.

Stabilising Materials for Use in Capping

3.5 The MCHW 1 uses a classification system where materials are given a Class number and usually a letter subclass. (In some cases a third level may be used eg Class 6F1.) Figure 3/1 illustrates how the Classes relate to each other for improvement and stabilisation to form capping. Some cohesive and silty cohesive materials may require rendering to acceptable Classes 7E, 7F, 7G or 7I using lime before they may be considered for stabilisation. Granular materials, when acceptable (Class 6E), can be cement stabilised without improvement. Wet granular materials require the two stage process of lime and cement stabilisation; improvement is not necessary as the material can be successfully treated as a stabilised material for capping.

3.6 Stabilised materials Classes 9A, 9B, 9D, 9E and 9F will require final compaction according to a method specification (either Method 6 or 7). Class 9C requires compaction to an end-product specification (95% of maximum dry density: 2.5 kg rammer method). For all stabilised materials, considerable amounts of water may need to be added during mixing in order to achieve adequate compaction and to hydrate the quicklime where used. The water should be introduced in the hood of the rotary mixer. It is essential that the moisture content of lime stabilised materials is wet of optimum moisture content, although below the high moisture content limit, otherwise inadequate compaction will occur.

3.7 No material is allowed to be deposited on the compacted layer nor construction plant allowed to traffic the layer until the bearing ratio (ie the CBR result obtained during construction) obtained from the laboratory testing and given in Appendix 6/1 of the Specification (see MCHW 2, NG 600) has been achieved.

Volume 4 home page

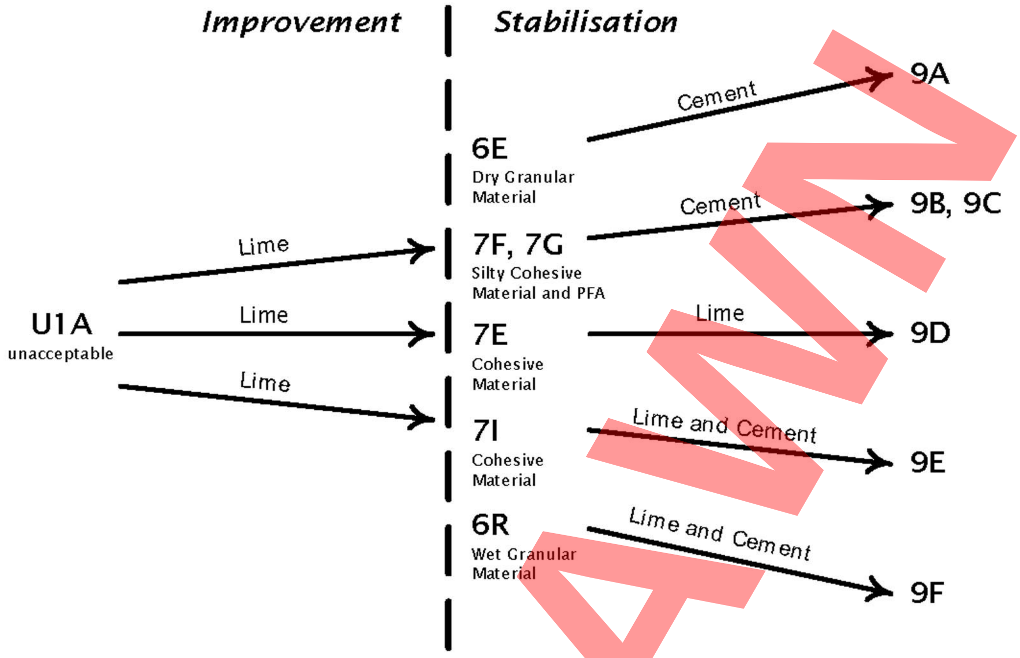

Figure 3/1 Derivation of Classes of Material for Stabilised Capping

3.8 MCHW 1 Clause 615.5 requires that the amount of lime added for lime only stabilisation of capping should be subject to a minimum of 2.5% by weight of available lime expressed as a percentage of the dry weight of the Class 7E material. During the design stage, it should be ascertained if higher percentages of lime are required to achieve an adequate bearing ratio.

3.9 For cement stabilisation, MCHW 1 Clause 614.3 requires that the amount of cement added should be subject to a minimum of 2% by weight expressed as a percentage of the dry weight of the Class 6E, 7F or 7G material. Higher percentages of cement may be ascertained during the design stage to be necessary to achieve an adequate bearing ratio. Similarly for lime and cement stabilisation a minimum addition of 1% lime and 2% cement is required subject to testing during the design stage.

Preliminary Sources Study

3.10 The information that is available for the preliminary sources study (PSS) stage of the site investigation is reviewed in this chapter. Appendix B of Part 2 of HD 22 Ground investigation and earthworks procedure for geotechnical certification (DMRB 4.1.2) provides an example of contents for the PSS Report and this forms the framework for Paragraphs 3.12 to 3.21.

3.11 It is not intended that this Advice Note should reproduce the requirements and guidance for the PSS given in HD 22 (DMRB 4.1.2. The advice given here is in addition to that given in HD22 and should be consulted at the same time as part of normal site investigation procedures. The purpose is to ensure that the possibility of treatment of materials using lime or cement or both is considered from the outset of the SI and earthworks procedures.

Information to be Given in the Preliminary Sources Study

3.12 The following guidance is structured within the headings of the PSS report recommended in HD 22 (DMRB 4.1.2).

INTRODUCTION

3.13 The PSS report should include an assessment of local geology and geotechnical features associated with the route.

SOURCES OF INFORMATION AND DESK STUDY

3.14 The list of all sources scrutinised for geotechnical data and other relevant general information should include those sources relevant to

Volume 4 home page

lime and cement stabilisation. Such sources of information include the following:

(a) TRL Contractor Report 151, Stabilized capping layers using either lime, or cement, or lime and cement (Sherwood, 1992).

(b) British Lime Association, Lime stabilisation manual (British Lime Association, 1990a).

(c) British Lime Association, The Benefits of lime treatment (1998). A one day seminar considered the use of lime for railways, buildings, housing and contaminated land.

(d) British Aggregate and Construction Materials Institution (1988) and British Lime Association (1990b). These two volumes on lime stabilisation bring together a number of papers which cover highway applications and include case histories.

(e) Snedker and Temporal (1990) highlight the importance of sulfate control and adequate compaction.

(f) Longworth (2004) provides a critique of sulphate and sulphide testing at the time of publication.

(g) Bessey and Lea (1953). This reference considers the distribution of sulfates in clay soils and groundwater. Although not exhaustive in a geographical sense, the document contains detailed information on the distribution of sulfates with depth.

(h) Rogers, Glendinning and Dixon (1996) is a very useful state of the art assessment of lime stabilisation and provides an indication of future developments. Rogers, Glendinning and Roff (1997) and Holt and Freer-Hewish (1998) also provide details of the considerable advance made in the understanding of stabilisation.

(i) Cripps and Taylor (1986 and 1987) brought together a lot of information available at the time of publication on the engineering properties of overconsolidated clays and mudrocks. These two publications cover Mesozoic and Tertiary deposits, which are the deposits for which lime stabilisation is most likely to be used. A useful overview of clays and mudstones is given in De Freitas (1981).

(j) The British Geological Survey (BGS) have extensive databases of geological information. These have been brought together and the regional distribution of sulfates in Britain examined. This provides a valuable source on the concentrations of sulfates within a large number of geologies. The British Geological Survey's regional geologist can give advice on whether clays, shales or mudstones are likely to contain sulfate or sulfide minerals. In Northern Ireland geological information and publications can be obtained from the Geological Survey of Northern Ireland.

(k) Publications of the BGS. These comprise handbooks, memoirs and special publications. These include descriptions of soils and rocks and make reference to the presence of sulfate and organic materials. The geologies identified on geological maps will also give an initial general indication of the suitability of the materials for lime stabilisation in association with the other sources of information given here.

(l) Examination of previous site investigation reports where available either for the highway itself, adjacent highways or any adjacent construction project. It is likely that these reports did not consider lime or cement treatment, due to its relatively recent introduction, and therefore are unlikely to have information on the swelling characteristics of stabilised soil. However, the reports may still contain geotechnical data which could be used as additional information in assessing the feasibility of stabilisation.

(m) Records of any problems in the vicinity, not only with material improvement, but also where swell has occurred of buildings or highways. These problems may be the result of other sources of calcium carbonate, limestone for example, being placed with argillaceous rocks and clay soils and where natural reactions associated with pyrite oxidation cause expansive minerals to form.

(n) Visit **www.ukcsma.co.uk**. In particular 'Soil stabilisation with GGBS: summary report by Cementitious Slag Makers Association, May 2006.

(o) The Proceedings of the TREMTI International Conference in 2005 provides a useful collection of international papers on treatment and recycling of materials. These are wide ranging and illustrate different national practices.

Volume 4 home page

(p) Visit **www.soilstabilisation.org.uk** which is the site developed by Britpave. Useful publications include Stabilised Soils, Soil Stabilisation – Guidelines for Best Practice and Stabilisation of Sulfate-Bearing Soils.

FIELD STUDIES

3.15 When carrying out walkovers, and investigating materials at exposures and in exploratory holes, it is important that sulfide and sulfate minerals are recognised (see Appendix A). These minerals can be seen commonly in hand specimens using the naked eye or hand lens. Evidence of organic material should also be sought.

SITE DESCRIPTION

3.16 Where materials are known or predicted to be suitable for treatment, the plans and overlays should be cross referenced with the description in the section on ground conditions.

GROUND CONDITIONS

3.17 In this section, early indications can be given of the soils likely to be encountered in the project, together with preliminary comments on those which have been treated successfully before and those that have not.

PRELIMINARY ENGINEERING ASSESSMENT

3.18 Experience of sites where stabilisation has been used for capping is given in Sherwood (1992). The materials stabilised included:

- Estuarine Clay;
- Alluvial Clay;
- Brickearth;
- Boulder Clay;
- Glacial Till;
- London Clay;
- Lower Lias;
- Mercia Mudstone (Keuper Marl).

Many other materials have been successfully stabilised in other civil engineering applications and these are also discussed. However, Sherwood describes how some problems have occurred with the stabilisation of Lower Lias, Boulder Clay and London Clay. These problems have since been addressed and solutions have now been found which are included in this Advice Note.

Dumbleton (1962) showed that the Weald Clay when mixed with lime did not increase in strength with time as did other clays, such as London Clay and Lower Lias clay. Although the plasticity of the Weald Clay was reduced, long-term stabilisation did not occur. This effect has been noted also by Heath (1992). Wood (1988) considered that the poor reaction with lime was due to the presence of kaolinite in the Weald Clay but Sherwood (1992) points out that kaolinite is present in most British clays including those that react well with lime. Other workers have also found that kaolinitic clays can stabilise well with lime (Ingles and Metcalf, 1972; Lees *et al*, 1982; Anon, 1986). To identify whether materials will stabilise with lime, a testing regime is suggested in this Chapter which will remove any ambiguity relating to the presence of kaolin. Should a material not stabilise with lime, cement can be added and the two stage lime and cement stabilisation process carried out.

PROPOSALS FOR GROUND INVESTIGATION

3.19 This section should outline the strategy for the GI, highlighting the need to locate exploratory holes at the most appropriate position to identify the strength, description and chemical properties. Details of a suitable strategy are given in this Chapter.

DRAWINGS

3.20 The suitability of materials expected on site for material treatment should be noted on the drawings. This will allow an initial and very broad assessment to be made of the quantities of materials likely to be available for stabilisation.

Ground Investigation Strategy

General

3.21 The following points should be given careful consideration for ground investigations which specifically include improvement and stabilisation of highway earthworks materials.

3.22 The purpose of the ground investigation is to provide information with which to decide whether improvement and stabilisation are viable and to provide sufficient material to carry out testing to ascertain an

Volume 4 home page

adequate mix design. The strategy should be to obtain the maximum amount of representative data for the minimum cost in a reasonable period of time. These aims can be difficult to satisfy without proper supervision and technical input.

3.23 The preliminary sources study will provide a broad and essential understanding of the site conditions. To plan the ground investigation, these data and the probable location of cuttings and embankments should be used to establish the most efficient position for exploratory holes and depth of sampling.

Ground Investigation

3.24 During the Ground Investigation, the amount of boring, drilling or probing may need to be extended or increased in frequency. This is appropriate in materials to be excavated from cuttings and used in embankments. Many of these materials will have the potential for use as stabilised capping for embankments. Also the materials at or below formation level may be suitable for stabilisation in situ as a capping layer at the base of cuttings.

3.25 The ground investigation should be planned to provide sufficient information to enable the potential use of stabilisation to be assessed.

3.26 A geologist should be employed to carry out soil descriptions who, in addition to being able to describe soils according to BS 5930: 1999, has an awareness of the distribution and appearance of sulfate and sulfide minerals. This Advice Note assists in their identification by providing information on the appearance of sulfate and sulfide minerals (Appendix A and C), their likely location (Appendix B) and the problems that can be associated with them.

3.27 The plasticity of some materials, for example Mercia Mudstone, varies depending on the degree of weathering and material properties (Chandler, 1969). The suitability for stabilisation can also be related to the zoning or layering used to describe these variations. As clay particles are required for the lime stabilisation process, the suitability of weathered mudstone for lime stabilisation may well be governed by the degree of weathering.

3.28 Trial pits and trenches are particularly useful for obtaining information on the uniformity, extent and composition of soils. Deep trial pits, around 6 m deep, can provide a more accurate picture of the nature of the material in bulk compared to borehole observations and give a more accurate profile of weathering, particularly in mudstones such as Mercia Mudstone and Lias Clay. Trial pits can also reveal the variability of the weathering profile in much more detail than boreholes This has important implications for stabilisation in terms of identifying those less weathered materials that do not meet the plasticity requirements for lime stabilisation but which can be cement stabilised.

3.29 In order to observe the occurrence of sulfate minerals (gypsum for example), use should be made of trial pits and trenches at the expected transition zone between cutting and embankment. The transition zone is one area where sulfate minerals are likely to occur at or near to formation. The lower levels of the weathering zone of soils with high sulfur contents commonly contain sulfates resulting from oxidation of sulfide minerals (pyrite for example).The positioning of a trial pit or trench in the transition zone increases the likelihood of locating any sulfate minerals that may be present at the level where lime stabilisation may be used. Trial pits can therefore be used for identifying sulfate and sulfide minerals both near the surface and at the formation level in cuttings. Localised concentrations of these minerals could result in significant swell. In order to locate sulfur minerals at formation in deep cuttings, boreholes are necessary. Although sulfate minerals can be present, sulfide minerals may predominate at greater depths where oxidation has not occurred. However, both sulfate and sulfide minerals must be considered because during the lime stabilisation process, sulfide minerals will oxidise to sulfate minerals as the material is exposed and processed for capping in cuttings or during excavation, transportation, deposition and processing for capping on embankments.

3.30 The sampling and testing should reflect the intended use of the soil, as a fill capping material or as capping in a cutting. In terms of stabilisation, sampling in cutting areas from formation to at least 1 m below is essential to include material which is most likely to be used in stabilisation. Less frequent sampling of the rest of the cutting area may only be possible as more material is involved. However, sampling of materials for use in fills can be less critical because mixing of material during excavation and deposition is likely. This has the advantage of mixing areas of soil with properties detrimental to stabilisation, such as concentrations of high sulfur and organic contents, with more suitable areas and diluting the detrimental effect. Testing is necessary but, at a general level, much information on the feasibility of lime stabilisation can be obtained from the soil descriptions of the exploratory holes in the Factual Report.

Volume 4 home page

3.31 The first step in the assessment is to describe soils in and from trial pits, trenches and boreholes using the naked eye and hand lens. The description of in situ soils with trial pits and trenches where personnel are required to enter the pit, will generally require pit supports depending on the depth and risk. In particular, sulfide and sulfate minerals tend to occur in discontinuous nodules or are finely disseminated making the macro-description crucial to obtaining an overview of the soil. In the later laboratory testing, close examination using a microscope would be followed by sulfur tests, thus providing detailed and necessary information on sulfur minerals but on a very small sample. Nodules of sulfur minerals are clearly visible by eye and this must be taken as the primary step in the identification of sulfates and sulfides.

3.32 There is little point undertaking detailed laboratory testing if significant quantities of sulfate minerals were visually identified during the ground investigation. It is, therefore, important that account is taken of descriptions and testing for soils at various powers of magnification, and that the effect of the size of sample is understood. Tests for sulfates at the location of structures alone are not sufficient for accurate extrapolation along the route for assessing the suitability of soils for stabilisation. Although they are, of course, another potential source of information. Figure 3/2 illustrates the process of intelligence gathering through design and execution of the works. It is important to realise that this is an ongoing process and information will need to be collected and scrutinized by the Design Organisation.

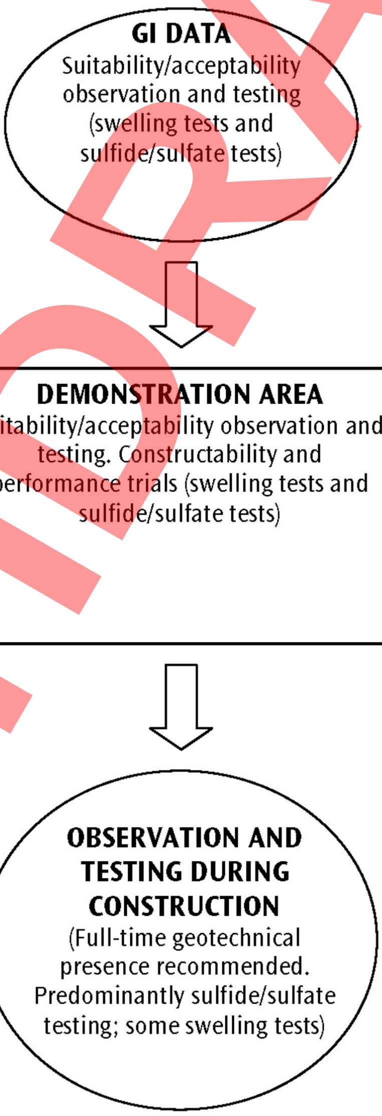

Figure 3/2 Flow of Information for Suitability/Acceptability of Material for Stabilisation

Volume 4 home page

Groundwater

3.33 Information on groundwater is essential to determine groundwater regimes which may affect the design of the earthworks. In particular, careful consideration needs to be given to:

(a) subgrade softening due to wetting;

(b) design of drainage to maintain capping strength by avoiding further softening: the reduction in available water, with or without sulfates, will also reduce the severity of sulfate reactions with lime;

(c) ensuring the sulfate content of the groundwater is below the specified upper limit. The laboratory tests will ultimately reveal how much sulfate affects the mixed soil.

3.34 If a source of surface water can be identified which is likely to be used in stabilisation, tests should be carried out to identify high sulfate contents and low pH values. Their effect can then be assessed in laboratory testing.

Execution Of The Ground Investigation

General

3.35 The Design Organisation should provide an experienced engineering geologist who is familiar with the identification of sulfur minerals and organic materials, and is aware of the importance of soil composition in stabilisation to direct and supervise the ground investigation. This person must have the authority to vary or extend the exploration plan if necessary during the investigation as a result of information gained, within prearranged limits set by the Design Organisation.

3.36 Most of the work on site to allow consideration of stabilisation is similar to conventional ground investigations and guidance is given in BS EN 1997-2 and BS 5930: 1999. However, sampling requires particularly careful attention if stabilisation is to be carried out successfully.

Sampling

3.37 The oxidation of sulfide minerals, principally pyrite, and the associated formation of sulfuric acid and sulfates takes time (Hawkins and Pinches, 1987; Hawkins and Wilson, 1990; Sandover and Norbury, 1993). Therefore, laboratory tests for sulfates will tend to show higher values than occur in situ, the longer the testing is delayed. Also the pH will decrease, that is the sample will become more acidic, the longer the testing is left. These changes will affect the interpretation of the acceptability of materials as higher total and water soluble sulfate contents will be recorded in the laboratory tests than in the undisturbed soil. This can lead to an inaccurate assessment of total and water soluble sulfate contents of the material for lime stabilisation. The inaccuracy depends not only on the time interval prior to testing, but also on the potential for sulfate formation as a result of oxidation. Laboratory assessment using total sulfate testing only is therefore considered inappropriate and unreliable. Additional testing for the total sulfur content, which measures sulfates indigenous to the material and sulfates produced by oxidation of sulfides, provides a better assessment of the potential effect of sulfates on stabilisation.

3.38 It is, therefore, recommended that testing is carried out for both total sulfate and total sulfur. In order to reduce the effect of oxidation on samples to be used for sulfate testing, such samples should be kept in well sealed and full containers, thus limiting the amount of oxygen available for oxidation. In order to reduce the rate of oxidation, Mitchell (1986) recommends storing the samples at low temperature (4°C). BS 5930:1999 should be consulted on time expediency.

3.39 It is critical that the site staff are fully aware of sulfur mineral identification during the ground investigation and that the occurrence of sulfates and sulfides is understood (Appendix B) when proposing exploratory hole positions and sample depths. Sulfate and organic content determinations should not be confined to exploratory holes located at structural foundations only. Testing should also be carried out on samples taken from the layers at or near sub-formation and formation, as well as in the layers above, for lengths of highway in cutting. The frequency of testing should not be standardized but should reflect the ground conditions observed and test results. Also more testing for Plasticity Index and, if necessary, more information on moisture content is required to assess which stabilisation method is feasible. It is important that the Design Organisation ensures that this information is obtained and recorded in a coherent manner, firstly to assess the feasibility of stabilisation and the quantities involved, and secondly to allow an accurate estimate of costs.

Volume 4 home page

Laboratory Testing

General

3.40 It is essential to set limits on the material properties required for acceptability for materials for stabilisation and stabilised materials, both to allow the selection of suitable material and to give assurance of good long term performance of the pavement structure. Laboratory tests for design purposes and relating to untreated material are carried out in accordance with BS 1377: 1990 (and DMRB 4.1.4 SH7/83 in Scotland) and TRL Report 447. A summary of laboratory tests for suitability of soils for stabilisation and design requirements for Appendices 6/1 and 6/7 of MCHW 1 is given in Table 3/1 of this Advice Note. A suggested test procedure is shown in Figure 3/3 and the results would be expected to be reported in a Factual Report. The laboratory testing should only be undertaken if there is no clear observed presence of sulfates and sulfides as described in the ground investigation and seen in the laboratory (Appendix C).

3.41 Tests for suitability determine whether or not the material is able to be stabilised and include tests such as initial consumption of lime and soaked California Bearing Ratio. Tests for acceptability are for determining whether the soil meets the requirements of the Classes in MCHW 1 Table 6/1 or for providing values for inclusion as limits in Appendix 6/1. The property requirements are designed to produce a stabilised capping that when compacted to Method 6 or Method 7 (MCHW 1 Table 6/4) will have a CBR of not less than 15%, an air voids content of 5% or less and will not be susceptible to swelling. Figure 3/3 provides a means of achieving this and should be consulted throughout this chapter. Fewer acceptability tests are required than suitability tests as they have been derived to ensure the material meets the design requirements based on the suitability testing. The amount of testing required will lead to an extra volume of material being required from the ground investigation.

3.42 Test results should not be combined to produce an average figure otherwise important extremes in material properties will be overlooked.

3.43 It is possible that the Design Organisation is able, from the material description in the GI, to see that lime and cement will be necessary (for example where clay and beds of sand are frequently interbedded). In this case, the Design Organisation should carry out the initial plasticity, grading and chemical testing in Figure 3/3 but may then progress straight to the CBR testing for cement and lime.

Soil Tests for Suitability and Acceptability of Material for Stabilisation (Classes 6E, 6R, 7E, 7F, 7G and 7I)

Plasticity Index

3.44 For lime stabilisation, it is necessary to ensure that there are enough clay minerals present in the untreated material to enable the soil to react with the lime and allow the pozzolanic reaction to occur. The lower limit of 10% for the plasticity index (I_p) in MCHW 1 Table 6/1 should ensure the suitability of the soil so that this reaction can take place. Also to allow cement to be mixed into granular materials it is important to know the granular material's fines content.

Moisture Condition Value and Moisture Content

3.45 A calibration line for moisture content versus Moisture Condition Value (MCV) is needed to assess the suitability of the material for handling and trafficking. This is used to set the maximum moisture content, or minimum MCV, and is related to the bearing capacity of the soil for the construction plant and shear strength of the soil. An upper value of MCV or lower moisture content for untreated materials is not normally specified for compaction purposes as water will be added when mixing with lime. However, it is necessary once the material is treated and immediately prior to final compaction.

Material property	**Defined and tested in accordance with:**	**6E/9A**		**7F/9B**		**7G/9C**		**7E/9D**		**7I/9E**		**6R/9F**	
		S	**D**	**S**	**D**	**S**	**D**	**S**	**D**	**S**	**D**	**S**	**D**
Plastic limit	BS1377:Part 2	x		x				x		x		x	
Liquid limit	BS1377: Part 2	x		x				x		x		x	
Plasticity index	BS1377: Part 2	x		x				x		x		x	
Particle size distribution	BS1377: Part 2	x		x				x		x		x	
Uniformity coefficient	Note 1			x									
Organic matter	BS1377: Part 3	x	x	x	x			x	x	x	x	x	x
Water soluble (WS) sulfate content	TRL Report 447, Test No. 1	x	x	x	x	x	x	x	x	x	x	x	x
Oxidisable sulfides (OS) content	TRL Report 447, Test No. 2 and 4	x	x	x	x	x	x	x	x	x	x	x	x
Total potential sulfate (TPS) content	TRL Report 447, Test No. 4	x	x	x	x	x	x	x	x	x	x	x	x
Initial consumption of lime	BS 1924: Part 2							x					
CBR	BS EN 13286-47	x	x	x	x	x	x	x	x	x	x	x	x
Swelling	BS EN 13286-47	x		x		x		x		x		x	
MCV for untreated material	BS 1377 Part 4 (In Scotland, DMRB 4.1.4 SH7/83)				x				x		x		
MCV for stabilised material	BS EN 13286-46				x				x		x		
MC for untreated material	BS1377: Part 2		x				x						x
MC for stabilised material	BS EN 13286-2		x				x						x
Optimum moisture content for stabilised material (2.5kg test)	BS EN 13286-2				x		x		x		x		
Optimum moisture content for stabilised material (4.5kg test)	BS EN 13286-2		x										x
Frost Susceptibility	BS1924: Part 2	x		x		x		x		x		x	
IDD of chalk	Clause 634 MCHW1	x	x									x	x

S tests for suitability
D tests for design
x indicates test is applicable

Note 1: Uniformity coefficient is defined as the ratio of the particle diameters D60 to D10 on the particle size distribution curve where:
D10 = particle diameter at which 10% of the soil by weight is finer
D60 = particle diameter at which 60% of the soil by weight is finer

Table 3/1 Soil Tests for Suitability and Design

Volume 4 home page

Plasticity Index (Except Class 7G) .... BS 1377: Part 2
Grading (To MCHW 1 Table 6/2) .... BS 1377: Part 2

Within MCHW 1 requirements?

The Plasticity Index and grading will determine if lime only or cement only is to be used.

Establish Initial Consumption of Lime (ICL) .... BS 1924: Part 2
(For lime stabilisation only)

Is ICL established?

IF YES CONTINUE, IF NO REJECT,

Measure Water soluble (WS) sulfate content .... TRL Report 447, Test No 1
Measure Oxidisable sulfides (OS) content ....TRL Report 447, Test No 2 and 4
Measure Total potential sulfate (TPS) content .... TRL Report 447, Test No 4
Measure Organic Matter .... BS 1377:Part 3 (see Note 1)

For lime only and cement only stabilisation:
Carry out CBR Tests .... BS EN 13286-47

For lime stabilisation	For cement stabilisation
(i) mellow before compacting	(i) 3 days curing
(ii) 3 days curing	(ii) followed by 28 days soaking
(iii) followed by 28 days soaking	(iii) then test
(iv) then test	

Swelling, monitor to day 28 .... BS EN 13286-47

Repeat tests at a range of moisture contents and (a) lime addition from ICL in 0.5% stages or (b) cement additions from 2% in 0.5% stages. Determine design lime and cement addition value.

Is 31 day average CBR>15% (no individual specimen less than 8%)?
Is average swelling < 5 mm (no individual specimen more than 10 mm)
and approaching an asymptotic value?

IF YES, THEN MATERIAL IS SUITABLE FOR STABILISATION WITH LIME ONLY OR CEMENT ONLY
[subject to satisfactory water soluble sulfates in surrounding materials]
[Classify as Class 6E, 7E, 7F or 7G]
IF NO, CONSIDER LIME AND CEMENT STABILISATION

Figure 3/3 Tests for Soil Suitability

For lime and cement stabilisation:
Carry out CBR Test .... BS EN 13286-47
(i) 3 days curing (conditioning)
(ii) followed by 28 days soaking
(iii) then test
Swelling, monitor to day 28 .... BS EN 13286-47

Repeat tests at a range of moisture contents and lime additions from 1% to 2% in 0.5% stages and cement additions from 2% to 5% in 1.0% stages. For guidance the following combinations are recommended.

Lime	Cement
1%	2%
1%	3%
1.5%	4%
2%	5%

Determine design addition values.

Is 31 day average CBR > 15% (no individual specimen less than 8%)?
Is average swelling < 5mm (no individual specimen more than 10 mm) and approaching an asymptotic value?

IF YES, THEN MATERIAL IS SUITABLE FOR STABILISATION WITH LIME AND CEMENT
[subject to satisfactory water soluble sulfates in surrounding materials]
[Classify as Class 6R or 7I]

IF NO, THEN REJECT MATERIAL

ADDITIONAL LABORATORY TESTS AND CALIBRATIONS REQUIRED:

Test for frost susceptibility .... BS 1924: Part 2
(see Note 2)
Establish MCV/mc calibration for Class 7E, 7F or 7I material .... BS 1377: Part 4 (In Scotland, DMRB 4.1.4 SH7/83)
Establish MCV/mc calibration for Class 9B, 9D or 9E material at design addition value(s)........... BS EN 13286-46
(see Note 3)
Determine OMC for stabilised material at design lime addition value(s) .... BS EN 13286-2
(see Note 3)

Note 1. Some materials with greater than 2% organic matter are capable of being satisfactorily stabilised. Acceptance for suitability will depend upon establishing a CBR performance. The value for maximum organic matter, based on this performance, should then be entered in Appendix 6/1.

Note 2. The test for frost susceptibility should be included to identify stabilised materials which require protection against frost damage during construction.

Note 3. It is essential that any calibrations and design values/limits for lime stabilisation relating to moisture content requirements, such as MCV and OMC, are carried out at a time that is representative of site practice, that is after the mellowing period.

Figure 3/3 Tests for Soil Suitability (continued)

Sulfate and Sulfide Content

3.46 The tests used in determining sulfate and sulfide contents of capping and their purpose are given in Table 3/2.

Test requirement in MCHW1	Test method	Purpose	Units
Water soluble (WS) sulfate content	TRL Report 447, Test No 1	Mobility of sulfates in groundwater	g/l SO_4
Measure Oxidisable sulfides (OS) content	By calculation – subtracting the total sulfates present (from TRL Report 447 Test 2) from the total sulfur available (from TRL Report 447 Test 4) thus leaving the sulfides	Sulfides that will oxidise to sulfates	$\%SO_4$
Measure Total potential sulfate (TPS) content	TRL Report 447, Test No 4	Total sulfates available, both as sulphate and as potential sulfates from sulfides	$\%SO_4$

In their natural state, sulfates occur as SO_4 and this is the standard unit used. For conversion purposes:

$$SO_3\% = SO_4\%/1.2 \quad \text{and} \quad S\% \times 80/32 = SO_3\% \quad \text{hence} \quad S\% \times 3 = SO_4\%$$

Table 3/2 Test Methods for Sulfate and Sulfide Contents in Stabilised Capping

3.47 Table 3/3 shows the process involved in determining the three contents required in MCHW1.

3.48 WS, OS and TPS contents are required near concrete structures to be in accordance with MCHW 1 sub-Clause 601.14. They must also be determined for untreated materials within 500 mm of the stabilised capping, as sulfates in solution can migrate into the capping or be in direct contact with the capping, causing similar reactions to sulfates present in the capping itself. At least five samples of each material shall be tested for WS, OS and TPS, the exact figure depending on the confidence and ground model developed in the desk study and from observations of the material from exploratory holes. Similar to sub-Clause 601.14, the mean of the highest two values should be used for determining acceptability. This also applies if six to nine results are taken. If ten or more results are available, the mean of the highest 20% of the results should be used for determining acceptability.

3.49 Sulfates can result from the oxidation of sulfides. It is therefore important that the sulfates converted from sulfides be measured as well. The test for acid soluble sulfate content provides a measure of the sulfates already in the soil and the test for total potential sulfate provides a measure of the sulfates already in the soil and the sulfates from oxiding sulfides. The difference between the two is the sulfides that may oxidize to sulfates.

3.50 Although not part of soil suitability testing, tests for sulfates in groundwater and standing water using TRL Report 447 Test No. 1 will also be required as they will influence the feasibility of lime or cement stabilisation or both and requirements for drainage.

Organic Matter

3.51 Testing for organic matter is required as it can interfere with the normal reaction between the lime or cement and the soil.

Soil Tests for Suitability and Acceptability of Stabilised Material (Classes 9A, 9B, 9C, 9D, 9E and 9F)

General

3.52 In order to establish the suitability of the stabilised material, a series of laboratory tests is needed to ensure that certain design criteria relating to bearing capacity, swelling and compaction are met.

Volume 4 home page

Test requirement in MCHW1	**Test and method of calculation**				
Water soluble (WS) sulfate content	Water soluble sulfur (WSS) – 2:1 (water : soil) extract analysed by ICP – AES [TRL Report 447 Test No 1]	⇨ WSS (%S)	⇨ 15 x WSS	⇨ Water soluble sulfate WS (g/l SO_4)	
Oxidisable sulfides (OS) content	Acid soluble sulfur (ASS) – Acid digestion analysed by ICP – AES [TRL Report 447 Test No 2]	⇨ ASS (%S)	⇨ 3 x ASS	⇨ Acid soluble sulfate **AS** (% SO_4)	⇨ Oxidisable sulfides content (% SO_4) **OS = TPS - AS**
	Total sulfur (TS) – Microwave digestion using ICP – AES quantification [TRL Report 447 Test No 4]	⇨ TS (%S)	⇨ 3 x TS	⇨ Total potential sulfate **TPS** (% SO_4)	
Total potential sulfate (TPS) content	Total sulfur (TS) – Microwave digestion using ICP – AES quantification [TRL Report 447 Test No 4]	⇨ TS (%S)	⇨ 3 x TS	⇨ Total potential sulfate TPS (% SO_4)	

Note: ICP-AES = Inductively Coupled Plasma – Atomic Emission Spectroscopy

Table 3/3 Process Involved in Determining the Three Contents Required in MCHW1 for Stabilised Capping

Volume 4 home page

Initial Consumption of Lime

3.53 For adequate stabilisation with lime, sufficient lime needs to be added to allow the reaction with the clay to occur. The minimum value of available lime required to enable reaction with Class 7E material to be achieved must, therefore, be determined. This value is known as the initial consumption of lime (ICL) and is defined as the amount of available lime required to achieve a pH of 12.4 (although there is some debate on this issue (Rogers, Glendinning and Roff, 1997)) at a temperature of 25°C. This pH value is required to maintain reaction between the lime and any reactive components in the material to be stabilised. The presence of organic materials in acid soils will increase the amount of lime required for stabilisation. The BS 1924 test is based upon the test developed by Eades and Grim (1966).

Available Lime Content

3.54 Available lime content is determined as the percentage of calcium oxide (CaO) using the test method in BS 6463 amended according to MCHW 1, Clause 641.

California Bearing Ratio (CBR) and Lime and Cement Addition

3.55 For stabilised material the laboratory CBR tests are carried out as given in BS EN 13286-47. In previous editions of the standard this test was called the bearing ratio, the name used in MCHW 1. Any reference to CBR in this Advice Note means laboratory CBR unless otherwise stated. The purpose of the CBR testing is to:

(a) ascertain the lowest MCV, or highest moisture content, and minimum lime addition which produces a CBR value, based on laboratory CBR testing, adequate for supporting the next construction layer during compaction and carrying the plant necessary to construct it;

(b) ensure the structural integrity of the capping;

(c) to find the percentage or percentages of constituent which produce(s) a satisfactory CBR and degree of swelling.

3.56 Prior to testing for lime stabilisation it is recommended that the material samples are mellowed, in sealed containers to prevent carbonation, for a period of 24 to 72 hours to allow the lime to react with the soil and represent the site procedure given in MCHW 1 sub-Clause 615.11.

3.57 There is an option within BS EN 13286-47 for CBR tests to be carried out either soaked or unsoaked after a period for curing. Sherwood (1992) has reviewed this subject and proposed a test procedure which is recommended in this Advice Note. After allowing the test sample to cure (referred to as conditioning in BS EN 14227-11:2006) in the sealed CBR mould for a 3 day period at 20 ± 2°C, the sample is soaked for 28 days, at the same temperature, after which the CBR is measured. The sample should be fully immersed. The soaked CBR test was introduced to replicate very wet conditions in-situ. It is supported by testing undertaken by TRL and fitted with the design and construction processes used in the UK.

The unconfined volumetric test, where the material is not contained in a vessel and is completely immersed is in BS EN 13286-49 as a test method and BS EN 14227-11:2006 as a specification. A volumetric change is measured rather than a linear one in the CBR mould test. The volumetric test is undertaken at 40°C and accelerates certain reactions; it does not however replicate certain chemical reactions which occur at lower temperatures. In the UK the soaked CBR test is used as a design tool in the site investigation and demonstration area. It is not intended as a site control tool where reliance would be on sulfur testing (for concentrations at a location) and observation (for both distribution and observable high sulfur concentration minerals). In BS EN 14227-11 (Specification) both tests (BS EN 13286-47 (CBR) and BS EN 13286-49 (volumetric)) are given with no preference. It is considered that the volumetric test may be too harsh and unnecessarily preclude the use of stabilised materials for capping in the UK although available evidence is limited at present. The use of unconfined MCV samples for volumetric changes is one approach which has been used in the UK although an agreed test method has yet to be standardised.

3.58 The test samples should be prepared with a range of moisture contents that enables the limit for acceptability to be determined. Dependent on the type of soil, this should cover moisture contents from about MCV 13 to MCV 8, that is from optimum moisture content through to wet of the plastic limit. It is necessary to establish the lower limit for the MCV, or equivalent moisture content, which gives a minimum CBR value (usually 15%) at 28 days, for the minimum lime content.

3.59 CBR tests should be carried out on a range of sample mixes that will produce an average CBR of greater than 15% at 28 days with no individual test specimen having a CBR of less than 8% (Wood, 1988).

The number of test samples prepared should also allow CBR tests to be carried out at 28 days and the degree of swell to be monitored.

3.60 The amount of swell that occurs during the soaking period is critical in determining the suitability of the stabilised material. It is important, therefore, that measurements are recorded for up to 28 days to ensure that all swelling has ceased. This usually occurs by the fourteenth day with most materials. It is currently recommended that the average degree of swelling should be less than 5 mm (measured on the standard 127 mm high CBR mould sample), with no individual test specimen swelling more than 10 mm. If swelling is still occurring after 28 days but is still below this limit, some subjective assessment of changes in the rate of swell may be necessary: alternatively the swelling test period could be extended to 56 days provided the rate of swell was declining.

Moisture Condition Values and Moisture Content

3.61 It is recommended that MCV is used for stabilised cohesive materials and moisture content is used for stabilised granular materials. It is essential that the operator is aware that Class 9B, 9D and 9E materials are likely to produce an MCV/moisture content calibration with 'wet' and 'dry' legs. Figure 3/4 shows a typical MCV calibration exhibiting this type of behaviour. The calibration leg which must be used is the 'wet' leg, which shows reducing MCVs with increasing moisture content values (that is a negative slope). This provides the correct range of MCV for use as the criterion for acceptability.

3.62 The timing of laboratory tests must be related to the likely time-scale of construction activities and the MCV/moisture content calibration should be made after the specified mellowing period, thus relating to the condition of the material at the anticipated time of compaction. MCHW 1 requires a mellowing period immediately prior to compaction of between 24 and 72 hours.

Laboratory Compaction

3.63 In this Advice Note 'optimum moisture content' is the moisture content either at the maximum dry density or at 5 per cent air voids whichever is the wetter. Due to the rather flat dry density/moisture content curve that may result for some stabilised materials, some difficulty may occur in accurately defining the optimum moisture content. In such cases, it is recommended that the moisture content value at which the compaction curve crosses the 5 per cent air void line is taken as the optimum moisture content; this value will approximate to the moisture content in the field that should ensure an acceptable state of compaction to be achieved. For granular materials 5 per cent air voids are unlikely to be met but the moisture content at the maximum dry density will be better defined and this should be used.

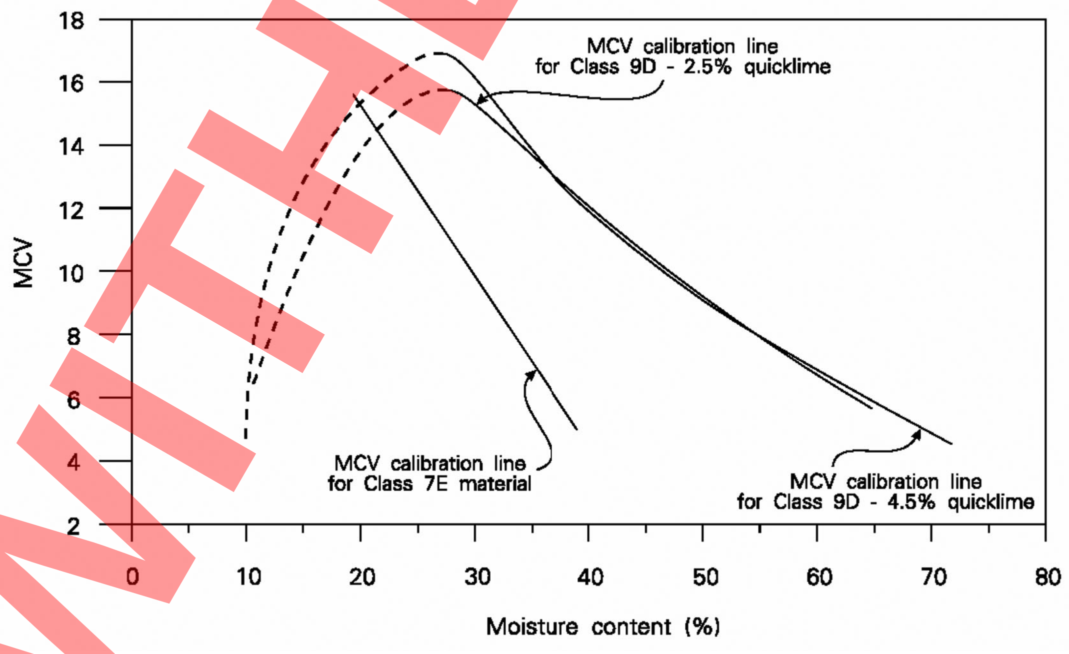

Figure 3/4 Typical MCV Calibrations for Class 7E and 9D materials

Volume 4 home page

3.64 It is important that the laboratory compaction test method selected reflects the ability of compaction plant to achieve similar dry densities in the field. Whilst there is a wide range of compaction plant available, some of which are capable of producing high compactive effort, their effectiveness in producing well compacted soils is not only governed by the compactive energy produced but also by the type of material being compacted. Experience has shown that, for cohesive soils, only the 2.5 kg rammer method produces realistic results which relate to densities achieved on site. The test methods which use higher compactive effort, such as the 4.5 kg rammer and vibrating hammer, are primarily for use on coarser grained and granular soils. Therefore, the dry density and moisture content relations of the Class 9B, 9C, 9D and 9E materials are determined using the 2.5 kg rammer compaction method. Class 9A and 9F dry density and moisture content relations are determined using the 4.5 kg rammer method.

3.65 The plasticity characteristics and the optimum moisture content of lime stabilised materials changes with time and so the preparation of the stabilised samples for the laboratory compaction test should reflect the time-scale of construction events: MCHW 1 requires a mellowing period immediately prior to compaction of between 24 and 72 hours. It is recommended, therefore, that the laboratory samples are allowed to mellow before compaction for the same period as anticipated on site. This is particularly important if a moisture content value is to be used for the material acceptability criterion on site because the optimum moisture content of the mellowing soil will alter significantly with time. The actual period of time between the sample preparation and time of testing should be reported.

3.66 For lime stabilisation, it must be appreciated how important it is to carry out the optimum moisture content testing at the same time as the MCV/moisture content calibration and at a similar time interval to that expected after mellowing on site. MCV is able to reflect the changes in plasticity and is less dependent on time of testing than optimum moisture content. Figure 3/5 illustrates this point for a stabilised heavy clay. In the figure, day 0 occurs at the time of compaction following the mellowing period. The shift to the right reflects the changing plastic limit of the material. Although the optimum moisture content has changed as the material becomes more granular in behaviour the MCV still stays around 13.5.

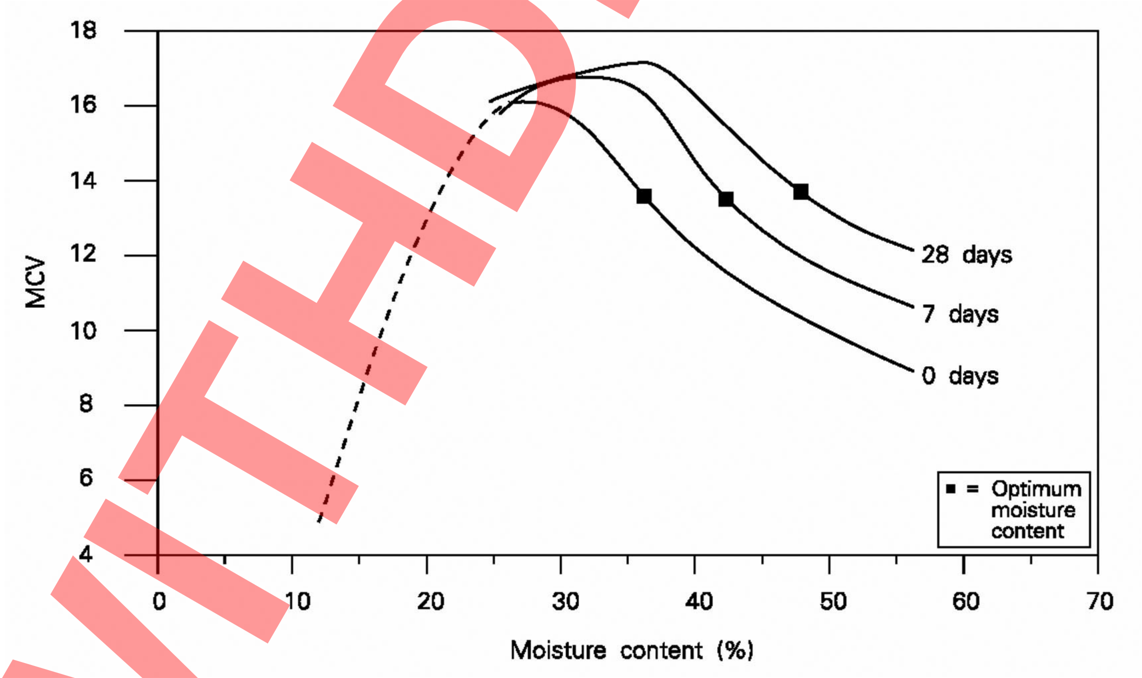

Figure 3/5 Effect of Time on MCV and Moisture Content for a Stabilised Heavy Clay

Volume 4 home page

3.67 The addition of cement for testing for cement only stabilisation and lime and cement stabilisation will cause cementation within 2 hours. It is therefore important that testing is carried out within this period.

Frost Susceptibility

3.68 The test specified in sub-Clause 602.19 of MCHW 1 is an amended BS 812: Part 124 test, and hence BS 1924: Part 2 test, which should be carried out on stabilised specimens of the materials proposed for the lime stabilisation during the ground investigation. Further tests should also be carried out on specimens cured for at least 28 days after mixing with lime.

(Note BS EN 14227-11 relates to provisions valid in the place of use and hence reference should be made to BS 1924: Part 2 frost susceptibility testing.)

Test Interpretation And Specification Limits

General

3.69 Following the laboratory testing of the material, to determine its suitability for stabilisation, the designer should extract the relevant limiting values for material acceptability and details of the addition of lime or cement or both for inclusion in Appendices 6/1 and 6/7 of the MCHW 1.

3.70 It is advisable to consider trials to demonstrate the materials' suitability, method of working and equipment before commencing with the main works.

Initial Consumption of Lime

3.71 The establishment of an ICL will identify whether the Class 7E material is suitable for stabilisation and will also provide the starting value for lime addition during the CBR tests. The ICL will depend upon the mineralogy of the unstabilised material, with typical ICLs ranging from 1.5% to 3.5%. If an ICL is not achieved the Class 7E material must be rejected as being unsuitable for lime stabilisation and lime and cement stabilisation considered.

California Bearing Ratio

3.72 If the swell and strength criteria have not been met then the material is deemed to be unsuitable for stabilisation and should be rejected. From the results of CBR tests carried out over a range of available lime and cement additions and moisture contents, the moisture content value and the MCV can be identified at which the minimum CBR strength requirement is achieved. This value should be entered in Appendix 6/1 as the lower limit for the MCV, or the upper limit for the moisture content for acceptability.

Lime Addition

3.73 The minimum amount of available lime required to achieve a CBR greater than 15% will have been identified during the CBR tests. For the actual design mix value, it is recommended that an additional 0.5% is included to allow for variations in the available lime content of the bulk lime supplied to site, local variations in material mineralogy and inefficient site mixing. An overall minimum available lime content of 2.5% by weight of available lime expressed as a percentage of the dry weight of the Class 7E material is specified in MCHW 1 sub-Clause 615.5. This is a typical value, representative of materials tested to date. However, it must be replaced by any higher value of lime addition indicated by CBR testing. The value should be included in Appendix 6/7. The amount of available lime varies with the type of lime manufactured. In quicklime the available lime content is about 90% to 95%, but in hydrated lime it is only about 60% of the total mass. The amount of lime added for the design will obviously have an influence on whether the process will be economical or not.

3.74 Appendix 6/7 should also state whether quicklime, hydrated lime or any other form of lime is to be used for the lime stabilisation works, or whether the choice is to be left to the Contractor.

Cement Addition

3.75 Similarly, the amount of cement required to achieve a CBR greater than 15% will have been identified during the CBR tests. Again 0.5% should be added to this figure to allow for any variations. MCHW 1 sub-Clause 614.3 specifies a minimum of 2% but this must be replaced if a higher value is indicated in the CBR testing.

Lime and Cement Addition

3.76 The percentage lime addition in the two stage process is likely to be much less than that of the cement as its purpose is primarily to make the cohesive material friable for the cement mixing or to reduce the moisture content of the granular material. The percentage of cement indicated from the CBR testing should be increased by 0.5% for variations on-site. The lime addition figure is less critical and should be the same on-site as that found in the laboratory testing.

Volume 4 home page

Moisture Condition Value and Moisture Content

3.77 Limiting values for MCV, or moisture content, for acceptability of both untreated and stabilised materials are required for Appendix 6/1 MCHW 1. For the untreated material the limits on MCV, or moisture content, only need to reflect the limits on earthmoving plant operation and hence only a lower limit is required. The value entered in Appendix 6/1 would typically be around MCV 7, or the equivalent moisture content, although some stabilisation plant can cope with sites wetter than this. The lower and upper limiting values for the stabilised material are based upon compaction requirements and the laboratory CBR.

Laboratory Compaction

3.78 The optimum moisture content for the design mix should be used to set either the upper limit for the MCV, or the lower limit for moisture content, for acceptability of the stabilised material in Appendix 6/1 of MCHW 1. Any material placed at a higher MCV, or lower moisture content, will probably have an excessive air void content and will be highly susceptible to wetting up and, in the case of cohesive material, swelling in the longer term.

3.79 It must be appreciated how important it is, for lime stabilisation, to carry out the optimum moisture content testing at the same time as the MCV/moisture content calibration and at a similar time interval to that expected after mellowing on site. Figure 3/5 illustrates this point for a stabilised heavy clay. Although the optimum moisture content has changed as the material becomes more granular in behaviour the MCV still stays around 13.5; consequently a specified limit of an MCV of 12.5 for a stabilised heavy clay would be wet of optimum moisture content.

3.80 Figure 3/6 (based on Parsons, 1992) shows the variation between dry density and MCV for soils ranging from lime stabilised glacial till and heavy clay to gravel-sand-clay. For the different stabilised materials, the MCV at optimum moisture content varies between about 12 and 14 and these values should be used as a guide to the upper MCV limit. These MCVs are considered an absolute maximum for the stabilised materials given and it is essential for compaction purposes to be at lower MCVs, that is to be 'wet' of optimum moisture content. The relation between MCV and optimum moisture content is the key to why the MCV is such a useful test for lime stabilisation; although the plasticity properties of a cohesive material vary with time, the MCV remains relatively constant.

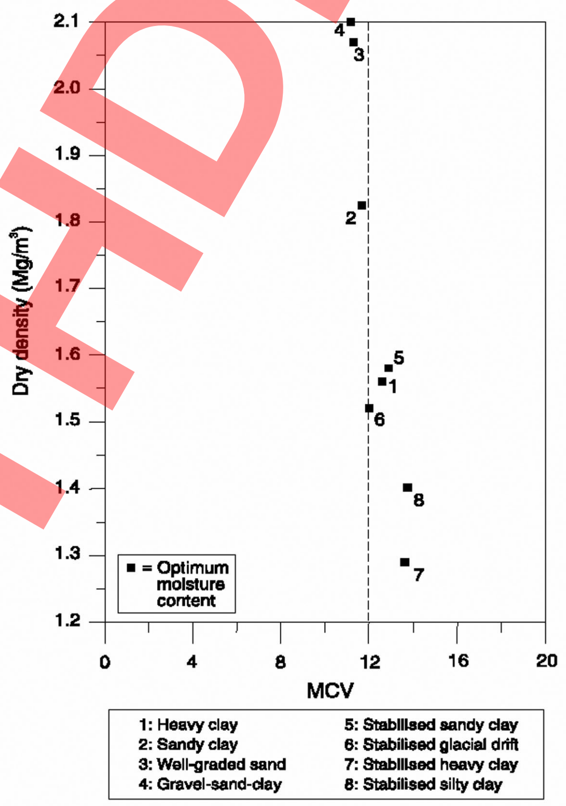

Figure 3/6 MCV/Dry Density (2.5 kg Rammer)

Volume 4 home page

Sulfates and Sulfide Content

3.81 Limits for acceptability for WS, OS and TPS of untreated material will primarily depend upon the swell measured during the CBR tests meeting the criteria given, provided that sulfate and sulfide minerals have not already been seen in the GI and the process discounted. Values of WS, OS and TPS, along with the amount of swelling measured in the soaked CBR tests, should be assessed to fix the limit for WS, OS and TPS. The upper limits to be entered in Appendix 6/1 for acceptability should be based on those measured on the material before carrying out the swell tests. The testing regime described in this Advice Note will provide sufficient information to set a limit on a site specific basis. The frequency and location of sampling will depend on the information from the GI, from the trial area and observations during construction. It is critical that the sampling frequency and location is governed by interpretation of the ground and not standardized methods such as a standard grid or uniform spacing. It is also important that the sampling is representative and again should reflect the ground conditions. The trial area should be in an area which has been identified during the GI as representing those areas where swelling is a risk.

3.82 An upper limit for the WS sulfate content in groundwater is required. This limit is set at 1500 mg/L and is based on the limits for material containing water soluble sulfate within 500 mm of cementitious materials (MCHW 1, sub-Clause 601.14).

Organic Matter

3.83 An upper limit of 2% organic content for acceptability of the untreated material is a useful guide, although there is some evidence to suggest that it is the type rather than the amount of organic matter which affects stabilisation (Sherwood, 1993). If the material under investigation has an organic matter content greater than the 2% value, but has been successfully stabilised in terms of reaching acceptable CBR and swell values, then consideration should be given to increasing the upper limit to accommodate the actual value measured. Soils containing higher percentages of organic material can be successfully stabilised and the upper limit for organic matter should be entered in Appendix 6/1.

Bearing Ratio

3.84 The designer would normally be expected to set the lower limiting value for the average construction bearing ratio in MCHW 1 Appendix 6/1 at 15%.

3.85 The CBR will increase considerably in the short term immediately following compaction and then reduce in the long term In order to ensure the lime stabilised mix design is sufficiently robust to cope with the short and long term changes, the mix design is based upon a curing period of three days in sealed CBR moulds and 28 days soaked. This will tend to produce conservative CBR values which will ensure sufficient lime is added for an appropriate design.

Frost Susceptibility

3.86 If the design indicates that the stabilised capping will occur within 450 mm of the designed road surface, or 350 mm if the annual frost index of the site is less than 50 (MCHW 1 sub-Clause 602.19), and the results of the amended BS 812 test, and hence BS 1924: Part 2 test, show it to be frost-susceptible at 28 days, then the option of stabilisation in the Contract should be restricted to a lower layer of capping or deleted altogether. Where there has been a reduction in frost susceptibility after 28 days cure but the results still fail the test, consideration should be given to carrying out further tests after 56 days curing.

3.87 Stabilised capping can be damaged either by the freezing of water entering the surface of the unprotected material before the pavement is constructed, or by frost heave when water is drawn from below in freezing conditions. The BS 1924 test will establish the susceptibility of the material to the latter type of damage.

3.88 The reaction of lime with clay soils initially produces a flocculated structure that is granular in appearance and is more frost susceptible than the original clay. However, the pozzolanic reaction, which occurs later, and is similar to that of the cement stabilisation reaction, leads to the progressive growth of cementitious compounds, a resulting reduction in permeability and an increase in tensile strength. This may make the material non-frost-susceptible after 28 days curing, or longer, depending on the percentage of lime added. But some stabilised materials may remain frost-susceptible even after considerable curing periods.

3.89 Stabilised capping, like all other capping, should be covered during the period October to February by a weather protection layer at least 300 mm thick if the overlaying pavement has not been constructed, unless the result of the amended BS 1924 tests demonstrate that the stabilised material is non frost-susceptible. This needs to be established at the ground investigation stage so that if weather protection is required it can be included in the Contract. The purpose of the protection

Volume 4 home page

is to prevent frost attack and softening of the material. The sub-base is not sufficient as weather protection if it is less than 300 mm thick.

Monitoring During the Trial in the Demonstration Area and Construction For Compliance

General

3.90 Monitoring requires both observations on site and testing as testing alone is not sufficient. This is true for both the trial and the construction. The demonstration area should be chosen to include material of highest risk as deduced from the site investigation. Properties required for acceptability are given in the MCHW 1 Table 6/1 and Appendix 6/1. A summary of the tests required for acceptable material is presented in Figure 3/7. In addition, great reliance should also be put on observation of the materials at excavation, in the subformation and in the trial area. In order to do this there should be a qualified and experienced engineering geologist/geotechnical engineer on site full time. If sulfur minerals are identified by observation, either in-situ, in fills/stock piles or hand specimen then an assessment should be made as to whether stabilisation is appropriate and further testing is necessary. Alternatively if the areas of concern can be clearly identified then these areas can be avoided and selected granular capping used instead. Given that sulfur minerals occur in concentrations in their distribution, it seems highly unlikely that stabilisation would be suitable if this is observed. Success during the trial does not mean that the construction should not be monitored. Given the concentrated presence of sulfur minerals and their variable location in certain strata, it is possible that only at construction will their full presence become apparent.

A useful checklist based on a document produced by the Soil Stabilisation Task Group who form part of Britpave is provided in Appendix E.

3.91 The Class 9B, 9D and 9E material property requirements for acceptability given in the MCHW 1 Table 6/1, and Appendix 6/1, are designed to produce a stabilised capping layer that, when compacted to Method 7 Table 6/4, will have a laboratory CBR of at least 15%, an air void content of 5% or less, and will not be susceptible to swelling if wetted after compaction. During the compaction process strict supervision of moisture content is crucial if an acceptable state of compaction is to be achieved. Because of the changing plasticity of the cohesive material with time, the use of MCV is preferred as it provides a more reliable method of on-site control of moisture, as opposed to direct moisture content measurements. The Class 9C material property requirements for acceptability are based on an end product specification that requires the achievement of 95% of maximum dry density. Classes 9A and 9F may not achieve the 5% air voids requirement due to their granular nature but Method 6 will achieve 95% of laboratory maximum dry density for a wide range of moisture contents.

3.92 When material is being excavated and placed, an engineering geologist or geotechnical engineer should be on site to ensure the material is as expected from the site investigation. For example, an engineering geologist will be able to assist in identifying sulfide and sulfate minerals, and identify weathering zones of different plasticity within a material type. However, it must be emphasised that the SI should be thorough, as it should be for earthworks in any case. Any potential economic benefit from the use of improvement or stabilisation will be lost if the SI, does not correctly assess the acceptability of the soils for stabilisation.

Monitoring of Untreated Material

Moisture Condition Value and Moisture Content

3.93 Requirements for untreated material acceptability in terms of either MCV or moisture content are given in MCHW 1 Appendix 6/1. The limits will have been established to allow ease of handling of the material during the earthworking phase of the stabilisation process. MCV is the preferred method for moisture content control for cohesive materials due to speed of test on site.

Sulfates and Total Sulfur Content

3.94 Observation to see if testing is representative and testing to establish the WS, OS and TPS contents is required in the MCHW 1 Appendix 6/1. It is important that the test upper limits for acceptability are not exceeded, as the limits will have been established on the swelling performance of the design mix. At the time of the trial and construction, confirmation of the ground investigation findings should be made by visual examination of the material as well as by appropriate testing.. The testing should be carried out as early as possible to allow alternative work processes to be arranged if necessary.

UNTREATED MATERIAL

Grading	BS 1377: Part 2
Uniformity coefficient	D60 to D10 ratio
Moisture Content (see Note 1)	BS 1377: Part 2
MCV (see Note 1)	BS EN 13286-46 (In Scotland DMRB 4.1.4 SH7/83)
Plasticity Index	BS 1377: Part 2
Organic Matter	BS 1377: Part 3
Measure Water soluble (WS) sulfate content	TRL Report 447, Test No 1
Measure Oxidisable sulfides (OS) content	TRL Report 447, Test No 2 and 4
Measure Total potential sulfate (TPS) content	TRL Report 447, Test No 4
Measure Organic Matter	BS 1377:Part 3 (see Note 1)

IDD of chalk	Clause 634 MCHW 1

STABILISED MATERIAL

Pulverisation	BS EN 13286-48
MCV immediately before compaction (see Note 3)	MCHW 1 Clause 632 (In Scotland, MCHW 1 Clause 632SO)
Bearing Ratio	BS EN 13286-47
Moisture Content (see Note 4)	BS EN 13286-2

Note 1. Limits on moisture content, or MCV, are applied primarily to ensure ease of handling of the untreated material.

Note 2. Additional sulfate and sulfur testing may be required on exposure of formation level in cuttings. Any such requirement should be given in Appendix 6/1.

Note 3. MCV is the preferred method of moisture control for cohesive materials. The MCV limits will ensure that an adequate state of compaction is achieved, and are independent of changes of plasticity with time. The operator must ensure that the MCVs recorded are on the correct calibration leg, that is the 'wet' leg.

Note 4. Moisture content is the preferred method of moisture control for granular materials. If moisture content is to be used as the alternative to MCV for cohesive materials then the mc values required for acceptability must be directly related to the material properties at the time of compaction.

Figure 3/7 Testing for MCHW 1 Acceptability

Volume 4 home page

Monitoring of Stabilised Materials

Pulverisation

3.95 A pulverising machine is used to ensure thorough mixing of the constituent and water additions to the soil. This is an essential part of the stabilisation process which provides a well mixed material for lime stabilisation. It allows an effective reaction between the lime and the clay during the mellowing period. A further mixing, after mellowing, is required prior to compaction. For all stabilised materials, there is a requirement in MCHW 1 sub-Clauses 614.7 and 615.9 that 95% of the processed material passes a BS 28 mm sieve and that the pulverisation complies with the lower limit of the degree of pulverisation for acceptability of 60% for Class 9A, 9C and 9F, 30% for Class 9D and 9E, given in MCHW 1 Table 6/1 and a value for Class 9B based on the demonstration area and past experience. The normal figure would be expected to be 30%. The degree of pulverisation is based on the ratio of material passing a BS 5 mm sieve before and after being broken down.

Moisture Condition Value and Moisture Content

3.96 The MCV is the preferred test method for checking the acceptability of the Class 9B, 9D and 9E material immediately prior to compaction. Moisture content is the preferred test for Class 9A, 9C and 9F. It is essential to the stabilisation process that the moisture condition of the material will enable an acceptable state of compaction to be achieved when compacted. The limits for acceptability given in Appendix 6/1 and the required compaction procedures must be adhered to. If they are not an acceptable state of compaction will not be achieved and the susceptibility of the layer to swell will be increased if sufficient sulfates are present.

3.97 Any variation in the time-scale of events will result in changes in the plasticity characteristics of lime stabilised cohesive material Class 9D material and, therefore, change the compaction requirements. For any increase in time, due to site delays etc, the material will probably require additional water to be added. If the upper MCV limit, the dry value, is exceeded, it is likely that an adequate state of compaction will not be achieved (ie it is likely that the air void content will be too high).

3.98 The use of the MCV for acceptability of Class 9B, 9D and 9E will effectively overcome problems associated with changes in plasticity with time. The MCV is a compaction related test and changes with changes in plastic limit: it is thus self-compensating as illustrated in Figure 3/5.

3.99 The MCV operator should be made aware that the MCVs measured must be on the correct ‘wet’ leg of the calibration. If there is any reason to suspect the MCV reading, or that there is evidence that the Class 9B, 9D or 9E material is too dry, then an additional MCV test on a slightly wetter sample of in situ material should be carried out. If the resulting MCV decreases for the wetter sample, then the result would indicate that the MCV is on the correct calibration leg (ie the ‘wet’ leg).

3.100 It is recommended that moisture content is not used for acceptability of Class 9B and 9D materials for the following reasons. If moisture content is specified as the criterion for acceptability, then it must be understood that the limits inserted in Appendix 6/1 should have been determined at a time that reflects the anticipated time of compaction on site, that is related to the mellowing period. Any variation between the laboratory determination time and the corresponding site timing could significantly alter the state of compaction achieved, and could possibly result in inadequate compaction. Moisture content control for Class 9E is not recommended as MCV gives a quicker and more reliable result.

3.101 Note that sufficient water needs to be added to quicklime during the stabilisation process to allow it to hydrate otherwise even very wet untreated material may become too dry relative to optimum moisture content.

Bearing Ratio

3.102 The lower limit on bearing ratio (unsoaked CBR) given in MCHW 1 Appendix 6/1 has to be met to ensure that the stabilised material can support other material deposited or compacted above it, as required in MCHW 1. This value may be reached at the completion of the compaction process or may take a number of days to be achieved. Samples of the stabilised material should be taken at the time of compaction to enable the laboratory CBR (unsoaked) to be determined for comparison with the lower limit for acceptability given in MCHW 1 Appendix 6/1.

Frequency of Testing

3.103 Advice is given in MCHW 2 NG100 Table NG 1/1 on the frequency for testing, which should be regarded as a minimum value required for material acceptability. For the Class 7 materials the suggested frequency in MCHW 2 is one test per 400 tonnes for grading and MCV or moisture content, daily for

Volume 4 home page

Plasticity Index and twice weekly (or perhaps daily where sulfates are suspected) for organic matter, total sulfate content and total sulfur content. The suggested frequency for the Class 9 materials is for one test per lane width per 200 m length for pulverisation, MCV or moisture content and bearing ratio. This approximates to an equivalent of one test per 500 m2. MCHW1 sub-Clause 601.14 requires that at least five samples of each material shall be tested for WS, OS and TPS. The mean of the highest two values shall be used for comparison with the limiting values. This also applies if six to none results are available. If ten or more results are available, the mean of the highest 20% of the results shall be used for comparison with the limiting values. The location of sampling is critical and should rely on the experience gained from the investigations with the involvement of a geotechnical engineer with knowledge of sulfur minerals. See also Para 3.90.

3.104 MCHW 1 sub-Clauses 614.4 and 615.6 state that the Contractor shall check the rate of spread by weight, once for every 500 m2 of lime or cement spread or for lime a different rate of testing for the rate of spread given in Appendix 6/7. Table NG 1/1, MCHW 2 recommends a weekly test for the available lime content, from each source of lime and MCHW 1 requires the ‘source’ to be the sample tray for the spread of lime, not the lime processing plant.

Demonstration Area

3.105 Trials in areas representative of the proposed material for stabilisation (see Para 3.91 and Appendix A, B and C), using the appropriate binders, will be implemented by the contractor prior to commencement of the main stabilisation works. The demonstration area should not be less than 700 m2 and to a thickness as required in the Permanent Works and is included in Appendix 6/7.

The methods of construction of stabilised capping are specified in Clause 614 (for cement), Clause 615 (for lime) and Clause 643 (for lime and cement) of MCHW. It is strongly recommended that a maximum layer depth of 250 mm be used however in some circumstances it may be specified in Appendix 6/7 that capping up to 350 mm thick be stabilised in a single layer and that capping 600 mm thick be stabilised in two layers, each 300 mm thick. Field trials will be necessary to demonstrate the ability to achieve adequate end product compaction of the thicker layers. It will be necessary to show that 5% or less air voids (average throughout the layer) for cohesive materials, or 95% of maximum dry density (average throughout the layer) for granular materials, are achieved and that a laboratory CBR (tested and soaked in accordance with Figure 3/3) of 15% is exceeded at formation level and on the lower layer of a two layer capping before placement of the upper layer.

Preparation of Formation

3.106 In situ stabilisation is generally carried out in the material’s final location, either on a cut formation or on material deposited for fill. In these instances, as all the processing is carried out in one area, quality is easier to control and there is less risk of material falling outside the specification limits.

Prior to stabilisation, the formation should be trimmed and compacted to achieve a level of final treated layer within the specified formation tolerance (e.g. +20 to –30 mm), with allowance made for up to 10% bulking due to the effect of the lime on the maximum dry density of a cohesive material.

In preparing the formation, it is important to remember that the level and density of the soil prior to treatment will determine the accuracy of the mixing depth, final thickness and overall strength and the consistency of the layer.

To reduce the potential for standing water on the stabilised layer which may soften the top surface, the formation should be shaped to falls where possible, and sufficient drainage, either temporary or permanent, should be provided to remove surface water once stabilisation is complete.

In road cuttings where side drainage has not yet been constructed, it is normal to provide temporary grips to collect water from cutting sides.

In the past, incorrect setting out has meant that stabilised material has been placed in areas where drainage is specified. Due to the high strength of the stabilised material, it was necessary to use a breaker, and a circular saw on larger lengths, to install drainage. Setting out should therefore be a point of care. During the demonstration, the Contractor should show accuracy in control of the setting out of the edge of stabilised areas.

3.107 In sub-Clause 613.3 of MCHW 1, Class 9D or Class 9E stabilised cohesive material is not permitted to be placed above Classes 6F1, 6F2 or 6F3 granular capping materials. This is because:

Volume 4 home page

(a) it is much simpler and more effective to mix the material with lime in situ wherever possible and use granular materials for higher levels in the capping;

(b) the spreading and mixing on a granular layer would be difficult;

(c) contamination of the granular layer can occur if it is overlain with a stabilised clay layer.

4. GENERAL FILL

General

4.1 This chapter considers the use of quicklime to improve both cohesive and granular materials. The addition of lime can render unacceptable materials to a state of being acceptable as Class 1, Class 2 or Class 3 materials. Research shows that cohesive materials are unlikely to alter to a granular state with lime improvement and that the MCV limits for the untreated Class 2A can still be used as they will fall within the limits for modified materials (ie be conservative). Occasionally it may be possible for cohesive materials to be transformed into well graded granular material with compaction characteristics of Class 1A. This could mean an increase in compactive effort from Method 1 to Method 2 but this can be observed and controlled on site, using compliance testing which requires measurement of compaction, for this occasional occurrence.

4.2 The use of lime for general fill improvement does not lend itself to a prescriptive approach, as it is a method of 'achieving' the material requirements in MCHW 1. The addition of lime to cohesive materials causes some reduction in moisture content due to the exothermic hydration reaction, but of more significance is the improvement in engineering characteristics as indicated by changes in compaction curves, MCV calibrations, plastic limit and bearing capacity. However, the changes are unlikely to alter the materials from Class 2. For granular materials, water is more easily available for the quicklime, and moisture contents tend to reduce more than cohesive materials although there is no plasticity behaviour to change.

Preliminary Sources Study

4.3 No special requirements are needed during the PSS to accommodate the use of lime improvement other than the need to be aware of the possible expansion of sulfate and sulfide bearing materials (see Appendix B) especially if the material is to be used near formation or subformation. However, the list of sources of information given in Paragraph 3.14 provides useful background reading to the use of lime in general fill.

Ground Investigation Strategy, Execution and Testing

4.4 The ground investigation should follow existing guidance given in BS EN 1997-2, BS 5930:1999 and in Paragraphs 3.21 to 3.39. There are no special additional requirements.

Construction process

4.5 The ground investigation and interpretation will give an indication of the quantities of unacceptable materials, their moisture content and plasticity. The Contractor may intend to use the improved material when bidding or use improvement as a site expedient.

4.6 Past experience, particularly in France, Germany, Italy and America, has highlighted the benefits of the Contractor adopting a flexible approach to the use of lime. The Contractor will require ready access to lime stores, either on site or by tanker. The unacceptable material is likely to be exposed in a cutting where material handling and trafficking is a problem. The use of lime to remove small amounts of standing water, and reduce moisture content and plasticity, will improve handling and render the material acceptable ready for transportation and placement.

4.7 The spreading of the lime is by tractor based spreaders or, for small projects, by hand from bags. The vehicles obviously have to be able to cope with adverse ground conditions. It is possible to spread lime by shovel from bags but for most projects this is inefficient and raises health and safety issues. It is important that the quicklime is fresh and delivered to site in sealed tankers or bags to remove almost any chance of slaking.

4.8 Mixing the lime does not have to be as thorough as for capping materials and the techniques used for mixing capping materials would be inappropriate for the quantities of material used for general fill. Generally rotovators are used to mix the lime but disc harrows or ploughs or a combination of both may be employed. Ploughs are effective for turning the soil, especially the larger ploughs mounted on large crawler tractors. The harrow is more appropriate for breaking up soil clods.

4.9 The amount of quicklime required to be added is difficult to specify due to the expedient nature of the process but normally only 1% to 2% by dry weight of available lime is required for all general fill material types requiring rendering. The amount of lime required for general fill is therefore much less than for capping.

4.10 Once the material is mixed at the cutting site, it can be excavated, transported and deposited at the fill site. During this period the material will mellow and become more friable making deposition easier. The material will still need to meet the compaction and moisture content requirements of the general fill Classes and the testing for this should be undertaken at the place of deposition. It is important to beware of changing a too wet fill problem to one where the material is too dry for compaction.

4.11 The lime improved material is likely to fall into one of the following Classes: Class 1A, 1B, 2A, 2B, 2C, 2D and 2E.

4.12 It is recommended that cohesive general fills, except Class 2E, use MCV to control moisture content, bearing ratio and shear strength. As explained in Paragraph 3.66 for capping, MCV is a constant measure as the optimum moisture content changes with time after lime mixing due to the change in the materials' engineering properties. As the time after mixing, and before compacting, general fills is likely to be greater than for capping, the MCV is even more appropriate There is little point in doing any Plastic Limit testing as this varies with time and lime addition. Moisture content is the preferred control for granular general fills and cohesive fill Class 2E.

4.13 An unacceptable material when improved with lime can then be classified as a class of acceptable. Due to the continuing change in nature of the fill material, MCV testing at placement shortly before compaction is necessary so that the correct compactive method is used and the material meets the property criteria limits for a Class of specified acceptable material.

4.14 The rigorous sulfate and sulfide requirements and swell testing for capping are considered unnecessary for general fill materials, unless specifically identified in the PSS or ground investigation.

4.15 Materials such as pyritic clays and sulfate bearing strata (see Tables B/1 and B/2) will be particularly susceptible to expansion and a similar approach to that given in the laboratory testing for suitability of capping will be necessary especially within two metres of the formation or sub-formation. Pyritic argillaceous materials, such as colliery shales, will not be suitable for lime improvement. Other forms of rendering such as stockpiling or spreading are better ways of improving these and any other wet materials unsuitable for lime improvement.

4.16 The change in compaction curve for cohesive materials is to increase the optimum moisture content as plastic limit increases and to produce a flatter compaction curve. Hence a maximum dry density can be achieved at wetter moisture contents. For granular materials, the compaction curve remains unchanged but the reduction in moisture content from wet of optimum moisture content moves the improved material's state of compaction nearer to the maximum dry density.

Volume 4 home page

5. SLOPE REPAIRS

General

5.1 This Chapter deals with maintenance issues rather than the construction stage described in the previous chapters. It describes the use of quicklime in treating failed cohesive materials for reuse in the slipped area. The technique uses lime improvement with a degree of stabilisation.

5.2 In parts of the United Kingdom, slopes of highways are particularly prone to instability (Perry, 1989). The slopes are usually composed of cohesive materials in embankments. Failures usually occur at a depth of 1m to 2 m and the length of slope that has failed is typically 20 m. Although not large, the high frequency has led to high costs. In addition, failures of this type are becoming an increasing maintenance commitment.

5.3 Traditionally this type of failure has been repaired by either (a) excavating the failed material and replacing with granular material or (b) using geosynthetics in combination with the failed material.

Preliminary Sources Study

5.4 Records of an earthwork's past performance should be available from the HA and its Agents. These will indicate whether a slip has occurred in the past and may give details of soil type and extent of failure.

5.5 The records may also provide information on the success or otherwise of past remedial measures.

5.6 If the area is prone to instability preventative measures and a ground investigation may have already been undertaken and should be referred to.

Ground Investigation

5.7 The size and extent of investigation will depend on the extent and severity of failure. It is therefore only possible to give guidance on types and frequency of test, but the works should follow the ground investigation specification in MCHW 5.3.4. In most circumstances it is advisable to take: a number of window samples with moisture content (at 0.25 m intervals) and Atterberg limit tests (at 1m intervals); and a fewer in number of trial pits for Atterberg limit tests, material description, grading, moisture content and extent of slip plane. These will give indications of material type, conditions and an initial assessment of suitability for lime treatment.

5.8 Bulk samples from the trial pits will provide soil samples for testing the effect of lime addition and its suitability.

Design Approach

5.9 The cause and extent of failure may be identified from interpretation of the ground investigation and PSS. Usually slope failures during the operation of a highway are due to increased pore water pressures on the outer surface of the slope and at the toe (Crabb, West and O'Reilly, 1987). Guidance on soil strength parameters for analysis is given in Crabb and Atkinson (1991).

5.10 The addition of quicklime will cause a reduction in pore water pressure, increased suctions and bind together a block of soil which will have a buttressing effect on the embankment. It is therefore important that each compacted layer binds with the ones above and below it.

5.11 In order to prevent softening of the material beneath the stabilised material and to ensure a drainage path for soils deeper in the slope, a drainage layer needs to be provided beneath the stabilised material. For the horizontal surfaces, free draining materials are suitable which should be thicker at the toe in areas prone to flooding. Figure D/1 in Appendix D shows a typical design for a repair of an embankment constructed of overconsolidated clay in a low lying flat topography.

5.12 The design soil parameters will depend on the results from stability analyses of the failed embankment and will require integration with the test results.

5.13 A berm may be needed to ensure stability and to deposit surplus stabilised materials.

5.14 The drainage at the top and toe of the embankment or cutting must be maintained. Reinstatement of an open ditch or filter drain or pavement drainage may be necessary. Where a berm extends over an open ditch, provision must be made to install a combined filter/carrier drain to carry water

Volume 4 home page

longitudinally along the toe to drain the slope and the subsoil.

Testing and Material Specification

5.15 Table 5/1 lists the tests required. It is necessary to know the plasticity of the material in order to assess whether there is sufficient clay for the treatment effects to occur. Appendix D includes a specification and Table D/1 shows the material requirements. Similar to capping, a minimum plasticity index of 10% is considered appropriate.

Material Property	Defined and tested in accordance with:
Untreated material:	
Plastic limit	BS 1377: Part 2
Liquid limit	BS 1377: Part 2
Plasticity index	BS 1377: Part 2
Particle size distribution	BS 1377: Part 2
Treated material:	
MCV/mc calibration for stabilised material	BS EN 13286-46
Optimum moisture content for stabilised material (2.5 kg test)	BS EN 13286-2
Effective angle of internal friction (Ø’) and effective cohesion c’:	
Consolidated drained triaxial test	BS 1377: Part 8
Shear box	BS 1377: Part 7

Table 5/1 Soil Tests for Suitability and Design

5.16 An constituent amount of 2% by dry weight of available lime in granulated form is considered, from experience, to be sufficient in most cases to ensure a stable slope using the existing material and should be used as an initial value for testing. If sufficient shear strength is not achieved, the lime addition can be increased in 0.5% steps to ensure full improvement of the soil. Lime additions greater than 6% are likely to be uneconomic and may make the material too dry for compaction. Granulated quicklime is used to reduce any lime dust drifting onto the adjacent highway or onto adjacent land.

5.17 Particle size distributions are required to ensure that cohesive materials are used. Class 7E grading has been used for slope repairs as well as capping.

5.18 Reliance is placed on the MCV and its relation to mc, compaction and shear strength. It is an ideal test for on-site control and for consistent results with stabilised material (see Paragraphs 3.61 to 3.67). Compaction tests using the 2.5 kg rammer are recommended to establish the lower limit for moisture content at 10% air voids. The upper limit of moisture content relates to the drained shear strength parameters obtained from the slope design and found from the material testing. The MCV/mc calibration is then used to convert moisture content to Moisture Condition Value so that the MCV can be used on site as a site control.

5.19 The effect of quicklime on drained shear strength is dramatic. Littleton, Strevens and Livesey (1988) show an increase in drained cohesion from 8 kN/m^2 for untreated Oxford Clay to 140 kN/m^2 for the same clay mixed with 3% quicklime. The drained friction angle remains almost unchanged.

Construction Process

5.20 Appendix D, Table D/1 and Figure D/1 include the specification and details of the method of construction.

5.21 The establishment of space to mix the lime is an important logistical consideration. In some cases it may be preferable for the contractor to mix excavated slipped material off the slope on an adjacent flat area to the side or at the base of the slope rather than mixing it in place.

5.22 As a guide in order to achieve a 2% lime addition, a 5 kg bag of granulated quicklime will be sufficient for a metre square of soil, 200 mm deep (so as to achieve a 150 mm deep compacted layer).

5.23 The stabilising machine, i.e. the mixing plant, is likely to be an agricultural tractor mounted rotovator. There is no requirement for water addition under the hood but the specified MCV values must be met. However, more sophisticated machines, which achieve greater pulverisation, and improved water addition are not excluded.

5.24 The compaction requirement for a tamping roller is to ensure a good bond is achieved between each layer.

5.25 The treated material will be more alkaline than before the repair and the vegetation used in the topsoil and slope will need to be more alkaline tolerant.

5.26 There should be an awareness of the health and safety issues and environmental considerations when working with lime. Chapters 6 and 7 cover these in some detail. The use of granulated lime alleviates the problems with dust, which is why it is specified. Not only does it make a safer environment to work in but there is less dust to drift onto the carriageway or adjacent land. Experience has shown that the use of bags for such small sites is likely to produce less dust than a bulk delivery. (On a large construction site where bulk delivery is employed, there is greater control of spreading as specialised spreaders can be used.)

5.27 The specification requires the use of a stabilising machine. However, for small failures where there is little room for mixing consideration can be given to batch mixing off-site, although this may be uneconomic, or a method of working achieved where lime is adequately mixed during the excavation and deposition stages of repair. Using the latter method, fifty per cent of the lime could be placed on the failed material before excavation and mixed during the process of excavation. The remaining fifty per cent of the lime could then be added on the surface of the stock pile and mixed in again as the material is placed back on the prepared bench ready for compaction. Mixing is obviously not going to be as thorough as for a soil and lime mixture produced from a stabilising machine but for less critical sites where space is a premium this method may be suitable.

Monitoring

5.28 It is recommended that for large sites consideration should be given for installation of a modest system of monitoring. Inclinometers and piezometers installed after completion of the works and located where they would be most beneficial would help monitor the performance of the repair and provide valuable feedback. Monitoring may be necessary for about two years.

5.29 In addition, it would be beneficial to take samples of the stabilized materials at suitable time intervals after construction and test for shear strength in order to clearly identify improvement with time.

6. ENVIRONMENTAL CONSIDERATIONS

General

6.1 Both lime and cement powders and granulated lime are used in the in situ improvement of cohesive and granular soils using purpose built spreaders and rotovators. As strong alkalis, lime and cement require that operators working with them have adequate personal protection (dust masks, gloves, goggles, etc) which is described in Chapter 7.

6.2 The possibility of lime or cement leachate or run off is unlikely as far as is currently known, because they are effectively consumed within the improved soil layer to form a cemented material with cementitious gels. If leaching were to occur from the stabilised soil, then the lime or cement leachate would be quickly consumed within the surrounding ground due to its reaction with the soil minerals. Recent studies (Rogers and Glendinning, 1993) of the potential for quicklime to migrate through clay soils have found that migration is negligible, i.e. less than 50 mm.

6.3 Measures are adopted in the process of in situ improvement to reduce airborne dust to a level which will not present a risk either to health or the environment outside the confines of the construction area.

6.4 Specific measures to minimise dust are given in the following information and guidance:

(a) lime or cement for bulk use is delivered by road tanker which discharges via a hose into purpose built spreaders. During filling, air in the spreader is expelled through filter apparatus to minimise dust. Delivery for small projects (eg slope repairs) is usually by sealed bags;

(b) spreaders are used on large projects which apply the product through slots at the rear of the plant, which are surrounded by rubber skirts that reach the ground and greatly reduce levels of dust. For small projects spreading is undertaken by hand;

(c) spreading for large and small projects should not be undertaken in strong winds. A water supply to spray on the dust may need to be available to wet down the surface;

(d) plant should not be allowed to drive over the spread lime or cement prior to mixing with the soil;

(e) mixing is carried out under the hood of a rotovator, which pulverises the soil with the lime or cement;

(f) mixing should be carried out close behind the spreader, or shortly after spreading for small projects, to reduce the time available for wind to pick up the dust;

(g) care in workmanship is necessary to ensure minimal lime or cement dust is produced;

(h) for works adjacent to the live carriageway, for example slope repairs, or environmentally sensitive areas dust production is an important consideration and granulated quicklime should be used (see Paragraph 5.26) to minimise this effect.

6.5 Consideration should be given as to whether the Environment Agency, in England and Wales, Scottish Environmental Protection Agency, in Scotland, or Environment and Heritage Service – Environment Protection, in Northern Ireland, and the local authority environmental department should be informed of the operation and the Overseeing Organisation’s Horticulturist advised.

7. HEALTH AND SAFETY ASPECTS OF THE USE OF LIME AND CEMENT

General

7.1 Lime and cement products should be handled with care. However, a few precautions can minimise risks and lime and cement can be used safely provided the producers' safety advice is followed.

7.2 Works near the area of treatment will need to be programmed so that the lime or cement dust is not blown on to workers. Care in workmanship is necessary to ensure minimal lime or cement dust is produced.

7.3 The environmental precautions in Chapter 6 will also assist in a safe method of working.

Health and Safety Procedures

7.4 Principally there are two effects which must be guarded against in order to protect the health and safety of personnel.

a) When quicklime comes into contact with water, considerable heat is produced as the quicklime hydrates; this can result in burns.

b) In the presence of water, hydrated lime produces a caustic alkali, which can cause chemical burns. Contact of hydrated lime with the skin can be sufficient to result in such burns.

The same effects can happen with cement, although to a lesser degree, due to the smaller quicklime content within cement.

Skin contact with lime and cement products should be avoided.

7.5 Due to the requirements of the Health and Safety Commission Chemicals (Hazard Information and Packaging) Regulations and the Health and Safety at Work Act, specific advice on handling lime and cement must be given by suppliers in the form of Chemical Safety Data Sheets. These safety data sheets cover the handling of both quicklime and hydrated lime as well as cement. It is a requirement that suppliers provide safety data sheets to all purchasers. The safety data sheets should then be included in the assessment for the Control of Substances Hazardous to Health (COSHH) Regulations or Control of Substances Hazardous to Health Regulations (Northern Ireland) 1995.

7.6 Safety information is also given on the labels attached to bags of lime and cement.

7.7 General guidance for lime stabilisation is given by the British Lime Association which should be consulted for more information.

7.8 The Construction (Design and Management) Regulations 1994 or Construction (Design and Management) Regulations (Northern Ireland) 1995 place additional statutory duties upon clients, designers and contractors to ensure that health and safety is taken into account throughout all stages of a construction project.

7.9 Adequate personal protection to guard against the risks outlined should be provided for personnel likely to come into contact with lime or cement.

Those personnel requiring the greater degree of protection will be those operating the spreading and mixing equipment. Personnel not actively involved in the operations should wear protective equipment also to guard against the effects of windborne dust.

No one should be allowed to approach an area whilst spreading and mixing is in operation without suitable eye protection.

Eye wash facilities at clearly marked stations should be provided in case of emergencies.

Specific protective equipment should be worn as indicated below.

Protective Equipment

7.10 a) Eye Protection. Goggles must be worn to prevent lime or cement dust entering the eye. Wide vision, full goggles with anti mist properties are preferred or an air stream helmet. Safety spectacles are less suitable.

Volume 4 home page

b) Respiratory Protection. An approved dust respirator should be worn as required. A dust mask consisting of gauze-covered cotton wool filter pads held in a wire frame with headband is effective for the mouth and nose.

c) Protective Clothing. Long sleeved (rolled down) shirt and trousers should be worn. Shorts and sleeveless shirts must be avoided. Gloves should also be worn, preferably with a knitted wristband.

d) Exposed Skin. Any exposed parts of the body, particularly those where perspiration is excessive or skin is sensitive such as shaven parts, may be protected by a barrier screen.

7.11 In the event of First Aid being necessary, procedures are recommended, reproduced below, by producers in their Chemical Data Sheets.

Emergency and First Air Procedures

7.12 a) Skin. Remove contaminated clothing. After contact with the skin wash immediately with plenty of water.

b) Eyes. SPEED IS ESSENTIAL. Particles should be removed with a cotton wool bud. Irrigate with eye wash solution or clean water for a least 10 minutes. Obtain immediate medical attention. Continue irrigation until medical attention can be obtained.

c) Inhalation. Remove patient from exposure, keep warm and rest. The nose and throat should be thoroughly irrigated with water for at least 20 minutes.

d) Ingestion. Do not induce vomiting wash out mouth with water and give copious quantities of water to drink.

Further Medical Advice Symptomatic treatment and supportive therapy is indicated in the Chemical Data Sheets.

Dust Control

7.13 Dust can be a problem and HA 44 (DMRB 4.1.1) gives advice on prevention and provides a case history. It is important that the skirt on the lime spreading machine is in good condition so as to reduce the amount of air-borne dust produced during spreading.

7.14 Precautions against dust, mud, dirt and other debris in MCHW Appendix 0/1 (Substitute, Additional and Cancelled Clauses) may already be in force at a general level but special recommendations may need to be given in environmentally sensitive and urban areas.

7.15 Spreading should be prohibited where dust is blown from the site onto adjacent land and property (MCHW 1, sub-Clause 615.8). Lime and cement are spread once for each soil layer and this is not a continual process. Therefore, the time interval when dust can be produced is fairly short.

Volume 4 home page

8. REFERENCES

ANON (1986). Cementitious stabilizers in road construction. Draft TRH13. National Institute for Transport and Road Research, Council for Scientific and Industrial Research, South Africa.

BAUER J (1975). A field guide in colour to minerals, rocks and precious stones. Octopus Books, London.

BESSEY G E and LEA F M (1953). The distribution of sulphates in clay soils and ground waters. Proceedings of the Institution of Civil Engineers, 2, (1), 159-181.

BRITISH AGGREGATE AND CONSTRUCTION MATERIALS INSTITUTION (1988). 'Lime Stabilisation '88'. BACMI, London.

BRITISH LIME ASSOCIATION (1990a). Lime stabilisation manual. 2nd Edition.

BRITISH LIME ASSOCIATION (1990b). 'Lime Stabilisation '90'. BLA, London.

BRITISH LIME ASSOCIATION (1998) The benefits of Lime. BLA, London.

BRITISH STANDARDS INSTITUTION (1981). BS 5930 Code of practice for site investigation. BSI London.

BRITISH STANDARDS INSTITUTION (1984). BS 6463 Quicklime, hydrated lime and natural calcium carbonate. BSI London.

BRITISH STANDARDS INSTITUTION (1989). BS 812: Part 124 Testing Aggregates. Method for the determination of frost-heave. BSI London.

BRITISH STANDARDS INSTITUTION (1990a). BS 1377 Methods of test for soils for civil engineering purposes. BSI London.

BRITISH STANDARDS INSTITUTION (1990b). BS 1924 Stabilised materials for civil engineering purposes. BSI London.

BRITISH STANDARDS INSTITUTION (1991). Special announcement: BS 1377. BSI News. January, 1991. BSI London. 30.

BRITISH STANDARDS INSTITUTION EN 459. Building lime. BSI London.

BRITISH STANDARDS INSTUTION EN 1997-2. Geological Design – Part 2: Ground investigation and testing. BSI London.

BRITISH STANDARDS INSTITUTION EN 13286-2. Unbound and hydraulically bound mixtures-Part 2: Test methods for the determination of the laboratory reference density and water content – proctor compaction. BSI London.

BRITISH STANDARDS INSTITUTION EN 13286-46. Unbound and hydraulically bound mixtures-Part 46: Test method for the determination of the moisture condition value. BSI London.

BRITISH STANDARDS INSTITUTION EN 13286-47. Unbound and hydraulically bound mixtures-Part 47: Test method for the determination of the California bearing ratio, immediate bearing index and linear swelling. BSI London.

BRITISH STANDARDS INSTITUTION EN 13286-48. Unbound and hydraulically bound mixtures-Part 48: Test method for the determination of the degree of pulverisation. BSI London.

BRITISH STANDARDS INSTITUTION EN 13286-49. Unbound and hydraulically bound mixtures-Part 49: Accelerated swelling test for soil treated by lime and/or hydraulic binder. BSI London.

BRITISH STANDARDS INSTITUTION EN 14227-11. Hydraulically bound mixtures-Specifications-Part 11: Soil treated by lime. BSI London.

BRITPAVE (2004) Stabilised Soils as subbase or base for roads and other pavements.

BRITPAVE (2005) Soil Stabilisation – Guidelines for Best Practice.

BRITPAVE (2005) Stabilisation of Sulfate-Bearing Soils.

BUILDING RESEARCH ESTABLISHMENT (1981). Concrete in sulfate-bearing soils and groundwaters. BRE Digest 250. Building Research Establishment, Watford.

BUILDING RESEARCH ESTABLISHMENT (1991). Sulfate and acid resistance of concrete in the ground. BRE Digest 363. Building Research Establishment, Watford.

CHANDLER R J (1969). The effect of weathering on the shear strength properties of Keuper Marl. Geotechnique, 19, (3), 321-334.

CRABB G I and ATKINSON J H (1991). Determination of soil strength parameters for the analysis of highway slope failures. Proceedings of the international conference on slope stability engineering. Institution of Civil Engineers, London pp 13 – 18.

CRABB G I, WEST G and O'REILLY M P (1987). Groundwater conditions in three highway embankment slopes. Proceedings of the ninth European conference on soil mechanics and foundation engineering. Dublin pp 401 – 406.

CRIPPS J C and TAYLOR R K (1986). Engineering characteristics of British over-consolidated clays and mudrocks: I Tertiary deposits. Engineering Geology, 22, 349-376.

CRIPPS J C and TAYLOR R K (1987). Engineering characteristics of British over-consolidated clays and mudrocks: II Mesozoic deposits. Engineering Geology, 23, 213-253.

DE FREITAS M H Editor (1981). Mudrocks of the United Kingdom. Quarterly Journal of Engineering Geology, 14, (4), 241-372.

DESIGN MANUAL FOR ROADS AND BRIDGES. The Stationery Office, London.

HD 22 – Ground Investigation And Earthworks Procedure For Geotechnical Certification (DMRB 4.1.2).

HD 25 – Foundations (DMRB 7.2.2).

SH 7 – Specification For Road And Bridge Works: Soil Suitability For Earthworking – Use Of The Moisture Condition Apparatus (DMRB 4.1.4).

DUMBLETON M J (1962). Investigations to assess the potentialities of lime for soil stabilisation in the United Kingdom. Road Research Technical Paper No.64. HMSO, London.

EADES J L and GRIM R E (1966). A quick test to determine lime requirements for lime stabilisation. Highway Research Record 139, Highways Research Board, Washington.

FORSTER A, CULSHAW M G and BELL F G (1995). The regional distribution of sulphate in rocks and soils of Britain. In: Eddleston M, Walthall S, Culshaw M G and Cripps J C (eds). The engineering geology of construction. Engineering Geology Special Publication No. 10. Geological Society, London. 95 – 104.

HAWKINS A B and PINCHES G M (1987). Cause and significance of heave at Llandough Hospital, Cardiff – a case history of ground floor heave due to gypsum growth. Quarterly Journal of Engineering Geology, 20, (1), 41-57.

HAWKINS A B and WILSON S L S (1990). Sulphate increase in laboratory prepared samples. Quarterly Journal of Engineering Geology, 23, (4), 383-386.

HEATH D C (1992). The application of lime and cement soil stabilization at BAA airports. Proceedings of the Institution of Civil Engineers (Transport), 95, February, 11-49.

HIGGINS D D and KENNEDY J (1999). Lime+ground granulated blastfurnace slag stabilisation of boulder clay on the A421 Tingewick Bypass", 3rd European Symposium on the performance and Durability of Bituminious Materials & Hydraulic Stabilised Composites. Leeds UK.

HIGGINS D D, KINUTHIA J M and WILD S(1998). Soil stabilisation using lime-activated GGBS Proc. 6th CANMET/ICI Int. Conf. on Fly ash, Silica fume, Slag & Natural pozzolans in Concrete. ACI Publication SP 178-55 pp 1057-1073. Editor: Malhotra V.M., Bangkok Thailand.

HIGGINS D D, THOMAS B and KINUTHIA J M (2002). Pyrite oxidation, expansion of stabilised clay and the effect of GGBS, 4th European Symp. on the Performance of Bituminous and Hydraulic Materials in Pavements, University of Nottingham UK

HOLT C C and FREER-HEWISH R J (1998). The use of lime treated British clays in pavement construction: Part 1 The effect of mellowing on the modification process and with GHATAORA G S :Part 2 The effect of mellowing on the stabilisation process. Transport Proceedings of the Institution of Civil Engineers. Thomas Telford, London.

INGLES O G and METCALF J B (1972). Soil Stabilization: Principles and Practice. Butterworths, Sydney.

KENNEDY J (1996). In situ stabilisation using GGBS. Highways & Transportation October p26.

LEES G, ABDELKATER M O and HAMDANI S K (1982). Effect of the clay fraction on some mechanical properties of lime-soil mixtures. Journal of the Institution of Highway Engineers. 1982, 11, 3-9.

LITTLEJOHN I, STREVENS G and LIVESEY I (1988). Some observations on the use of lime on Oxford Clay. Lime Stabilisation '88. British Aggregates Construction Materials Industries.

LONGWORTH I (2004). Assessment of sulfate-bearing ground for soil stabilization for built development: Technical Note. Ground Engineering May 2004.

MACNEIL D J and STEELE D P (2001). Swell test requirements for lime stabilised materials. Transport Research Laboratory Report 505. TRL, Crowthorne.

MANUAL OF CONTRACT DOCUMENTS FOR HIGHWAY WORKS. (MCHW) The Stationery Office.

Volume 0: Model Contract Document For Major Works And Implementation Requirements: (MCHW 0).

Section 3: Advice Notes. Part 3 SA3 Testing In Highway Construction Contracts (MCHW 0.3.3)

Volume 1: Specification For Highway Works: (MCHW 1)

Volume 2: Notes For Guidance On The Specification For Highway Works: (MCHW 2)

Volume 5: Contract Documents For Specialist Activities.

Section 3. Ground Investigation. Part 4 Specification For Ground Investigation (MCHW 5.3.4)

MITCHELL J K (1986). Practical problems from surprising soil behaviour. Journal of the Geotechnical Engineering Division, ASCE Geotechnical Journal, 112.

NIXON P J (1978). Floor heave in buildings due to the use of pyritic shales as fill material. Chemistry and Industry, 4 March 1978, 160-164.

OLIPHANT J L and WALKER D D (1992). Comparison of high calcium, soft burned Dolomitic and hard burned Dolomitic quicklimes for soil stabilisation use. Innovations and Uses for Lime, ASTM STP 1135.

PARSONS A W (1992). Compaction of soils and granular materials: a review of research performed at the Transport Research Laboratory. HMSO.

PERRY J (1989). A survey of slope conditions on motorway slopes in England and Wales, Research Report RR199, Transport Research Laboratory, Crowthorne, Berks.

ROGERS C D F and GLENDINNING S (1993). Stabilisation of embankment clay fills using lime piles, proceedings of the international conference on engineered fills, Newcastle upon Tyne, September, Thomas Telford, p226 – 238.

ROGERS C D F, GLENDINNING S and DIXON N (1996). Lime stabilisation, Thomas Telford, London.

ROGERS C D F, GLENDINNING S and ROFF T E J (1997). Lime modification of clay soils for construction expediency. Geotechnical Engineering, Proc Inst. Civ. Engs. Thomas Telford, London.

SANDOVER B R and NORBURY D R (1993). On an occurrence of abnormal acidity in granular soils. Quarterly Journal of Engineering Geology, 26, (2), 149-153.

SHERWOOD P T (1957). The stabilisation with cement of weathered and sulphate-bearing clays. Geotechnique, 7 (4) 179-191.

SHERWOOD P T (1967). Views of the Road Research Laboratory on soil stabilisation in the United Kingdom. Cement, Lime and Gravel, 42 (9), 277-280.

SHERWOOD P T (1992). Stabilized capping layers using either lime, or cement, or lime and cement. Contractor Report 151. Transport Research Laboratory, Crowthorne.

SHERWOOD P T (1993). Soil stabilisation with cement and lime. Transport Research Laboratory State of the Art Review. HMSO.

SITE INVESTIGATION STEERING GROUP (1993). Site investigation in construction Part 2 Planning, procurement and quality management. Thomas Telford, London.

Volume 4 home page

SNEDKER E A and TEMPORAL J (1990). M40 Motorway Banbury IV Contract – Lime Stabilisation. Highways and Transportation, December, 7-8.

THAUMASITE EXPERT GROUP (1999). The thaumasite form of sulfate attack: risks, diagnosis, remedial works and guidance in new construction. Department of the Environment, Transport and the Regions, London.

TREMTI (2005). Treatment and recycling of materials for transport infrastructure. Second International Symposium, Paris. October 24-26 2005.

WEST G (1991). Field description of soils and rocks. Professional Handbook Series. Geological Society, London.

WEST G and O'REILLY M P (1986). Evaluation of unburnt colliery shale as fill for reinforced earth structures. Research Report 97. Transport Research Laboratory, Crowthorne , Berks.

WILD S, KINUTHIA J M, JONES G I and HIGGINS D D (1999). Suppression of swelling associated with ettringite formation in lime-stabilised sulphate-bearing clay soils by partial substitution of lime with ground granulated blastfurnace slag. Engineering Geology 51, pp257-277.

WOOD C E J (1988). A specification for lime stabilisation of subgrades. 'Lime stabilisation '88', Symposium on Lime Stabilisation. British Aggregates Construction Materials Industries, London. 1-8.

9. ENQUIRIES

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

Chief Highway Engineer
Fllor D2
No 5 Broadway
Broad Street
Birmingham
B15 1BL

S SMITH
Chief Highway Engineer

Director of Trunk Roads: Infrastructure and Professional Services
Transport Scotland
Trunk Road Network Management
8th Floor, Buchanan House
58 Port Dundas Road
Glasgow
G4 0HF

A C McLAUGHLIN
Director of Trunk Roads: Infrastructure and Professional Services

Chief Highway Engineer
Transport Wales
Welsh Assembly Government
Cathays Parks
Cardiff
CF10 3NQ

M J A PARKER
Chief Highway Engineer
Transport Wales

Director of Engineering
The Department for Regional Development
Roads Service
Clarence Court
10-18 Adelaide Street
Belfast BT2 8GB

R J M CAIRNS
Director of Engineering

Volume 4 home page

APPENDIX A FIELD IDENTIFICATION OF COMMON SULFIDE AND SULFATE MINERALS

General

A.1 One useful reference for the identification of common sulfide and sulfate minerals is Bauer (1975). This reference contains detailed descriptions and photographs, but an outline is given below for information.

Pyrite (FeS_2 – Iron Sulfide)

A.2 Pyrite is the most common sulfide mineral. Well-developed pyrite has a very distinctive brassy yellow colour with a metallic lustre in reflected light, from which its common name 'fools gold' is derived and by which it can be recognised when present in large amounts. Pyrite is common as cube shaped crystals and the faces of the crystals are striated. It also occurs as irregular grains and masses. It is particularly common in shales, slates, mudstones and heavily over-consolidated clays. It forms in veins, nodules, as a replacement deposit in fossils and can be widely and erratically distributed through soils and rocks; these characteristics make it difficult to detect and to measure the concentration of pyrite in a material especially at the ground investigation stage. It is sufficiently hard to scratch glass.

A.3 The pyrite may be present in particles too small for field identification, by eye or hand lens, and identification is possible only by binocular microscope or X-ray diffraction analysis.

Marcasite (FeS_2 – Iron Sulfide)

A.4 FeS_2 can also be present as marcasite which has similar characteristics to pyrite but has a different crystal structure, being more tabular in appearance. It is much less common than pyrite and is generally found as nodules in the Coal Measures. Marcasite is likely to be as troublesome as pyrite in engineering terms and should be treated with as much caution.

Gypsum ($CaSO_4.2H_2O$ – Calcium Sulfate)

A.5 Gypsum crystals are generally white, grey or clear, although yellow, red and brown discolorations occur. The crystals of gypsum are columnar, tabular and needle-shaped in appearance ranging in size from coarse to fine grained. Gypsum occurs in evaporitic rocks, such as in salt deposits of the Permian, and as the weathering product of sulfides in sedimentary rocks. It is particularly common in some overconsolidated clays, and occurs in clusters, some of them large, and in discontinuous sheets. Gypsum can be damaged by the finger nail and, when it is in a well developed crystal form, it is commonly referred to as selenite.

APPENDIX B OCCURRENCE OF SULFIDE AND SULFATE MINERALS

General

B.1 Appendix A provides field descriptions of pyrite, marcasite and gypsum. The presence of these minerals indicates that swell problems may occur after stabilisation has taken place. Engineers and geologists should be familiar with the appearance of these minerals.

B.2 This Advice Note covers the reaction between lime, cement and sulfur minerals. Expansion of clays can also occur as a result of sulfide minerals oxidising and reacting with clay minerals. One example is the reaction of sulfuric acid and iron sulfate from pyrite oxidation with the clay mineral illite to form jarosite with associated expansion. Also clays and mudstones will expand and soften as a result of water ingress. Both these effects are discussed in more detail and references given in HA 44 (DMRB 4.1.1). It is emphasized that the description of the material from the core, or in the trial pit is the key method for locating the presence of sulfide and sulfate minerals. The laboratory testing will give a precise figure for the sulfur content, both as sulfide and as sulfate, at a particular location but will not give an overall assessment of the distribution of sulfur minerals.

B.3 However, although sulfates and sulfides are important and their extent should be appreciated, many of the problems associated with them can be alleviated by detecting the effect of sulfates during testing and by providing adequate compaction.

Sulfide Minerals

B.4 Table B/1 from Nixon (1978) provides broad guidance on the likely geological formations which contain pyrite.

Geologies with potential for causing expansion through pyritic oxidation (based on Nixon (1978))
Bembridge Beds
London Clay
Sandgate Beds
Weald Clay
Stonesfield Slate
Middle and Lower Lias
Carboniferous shales

Table B/1

Nixon (1978) was concerned with those geologies associated with the heave of floors in buildings, but the reactions that occurred and the resulting heave are also relevant to stabilised capping.

B.5 Table B/1 is intended to give an overview of pyritic materials and is by no means complete. It should not be used as the source of site specific information or as the sole reason to accept or reject lime stabilisation. In addition not all the individual strata within the geologies listed will have sulfide minerals. However, the table can be used to identify those materials where a higher level of investigation and more detailed testing may be required.

Sulfate Minerals

B.6 Table B/2 is based on results from Forster, Culshaw and Bell (1992) and other sources and lists geologies which may have high sulfate contents. The table includes all those geologies where up to 25% of the tests undertaken had total sulfate contents greater than 0.5%, water soluble sulfate contents of 1.9 g/L or higher, and sulfate contents in groundwater of 1.2 g/L or higher.

Volume 4 home page

Geologies with potential for high sulfate contents (based on Forster, Culshaw and Bell (1992))

Peat
Buried channel alluvium
Estuarine alluvium
London Clay (weathered and unweathered)
Woolwich and Reading Beds
Whitecliff Sand, Portsmouth Sand and Nursling Sand
Gault Clay
Kimmeridge Clay
Oxford Clay
Upper Fuller's Earth
Lower Lias
Blue Lias
Mercia Mudstone
Sherwood Sandstone
Edlington Formation

Table B/2

Table B/2 is intended to give an overview of geologies that might contain high sulfate contents and should not be used as the source of site specific information or as the sole reason to accept or reject stabilisation. This is because variations usually occur at site specific level due to non-uniformity of material and weathering. In addition not all the individual strata within the geologies listed will have sulfate minerals. However, the table can be used to identify those materials where a higher level of investigation and more detailed testing may be required. The Geological Survey of Northern Ireland can provide information on the geological formations likely to contain sufide minerals or with potential for high sulfate contents.

B.7 In general, the presence of sulfates should be suspected in any over-consolidated clay and the amount of testing needs to be planned accordingly.

B.8 Quaternary deposits, such as glacial tills, can contain high sulfate contents especially if they are derived from materials which have high contents in their fabric (such as those listed in Table B/1 and B/2). It is a misconception to assume that because the materials have been exposed to high levels of air and water, that the material will have oxidized all sulfides and that the sulfates have been weathered away.

B.9 Bessey and Lea (1953) and Sherwood (1957) noted that the sulfate contents of British soils are usually low in the surface layer, and that they then increase to a maximum with increasing depth. Figure B/1 illustrates this point and highlights the lack of sulfates in the upper 1 m of the Oxford Clay and the increasing amount of sulfate toward the base of the weathering zone. In this zone, the sulfates have been leached out, and then concentrated at a lower level. It is possible that a profile of sulfides in the same material would show a similar absence down to 1 m due to leaching, but also an absence at lower levels due to oxidation to form sulfates. Below 3 m, sulfide contents might be significantly higher, although not uniformly distributed.

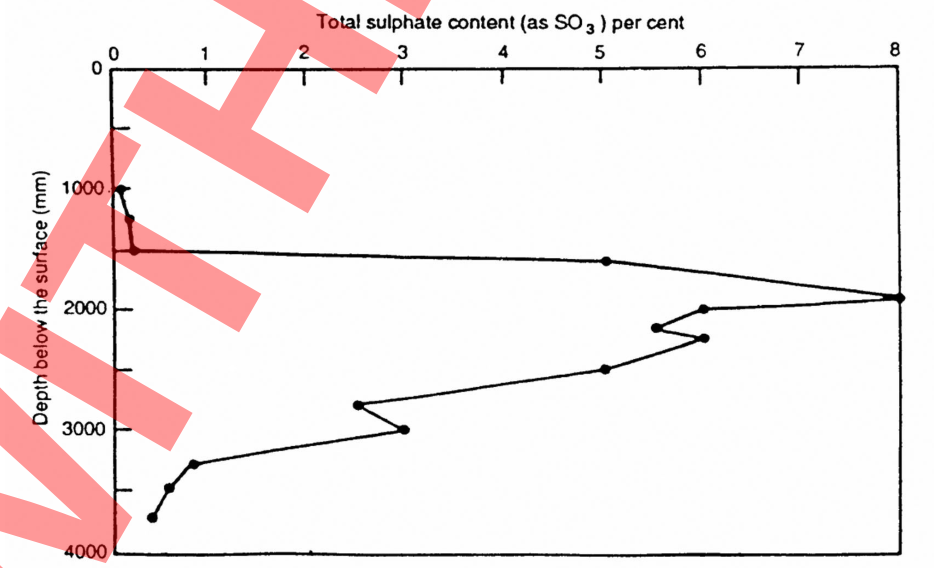

Figure B/1 Variation with Depth of Total Sulfate Content in an Oxford Clay Profile (from Sherwood, 1957)

Volume 4 home page

APPENDIX C LABORATORY IDENTIFICATION OF COMMON SULFIDE AND SULFATE MATERIALS

General

C.1 It must be emphasized that the descriptions of the material from the core, or from or in the trial pit, are the key methods for locating the presence of sulfides and sulfates. The laboratory testing will give a precise figure for the sulfur content, both as sulfide and as sulfate, at a particular location but will not give an overall assessment of the distribution of sulfur minerals. Observation using the descriptions in Appendix A should not be confined to the field but should continue in the laboratory. It is of the utmost importance that laboratory personnel are able to identify these minerals by observation as well as by analysis.

Sulfide Minerals

C.2 Sulfide minerals do not have an expansive reaction with lime or cement but have the potential to oxidise to sulfates which do. Also the oxidation process itself can cause expansion as the reaction produces sulfuric acid which reacts with any calcium or magnesium carbonate present and leads to the formation of gypsum (calcium sulfate) or epsomite (magnesium sulfate): both of these occupy a greater volume than the original chemical components. The calcium and magnesium carbonate can be present either within the sulfide bearing soil itself or placed adjacent to it. For example, both calcium and magnesium carbonate can occur in limestone aggregate. Sodium sulfate minerals which also have expansive properties are less common than calcium sulfate minerals and are highly soluble like magnesium sulfate.

C.3 Detection of pyrite and marcasite in hand specimens is relatively straightforward using the naked eye and hand lens provided the crystals are well developed. However, should the presence of these minerals not be detected in geological formations which the Preliminary Sources Study suggests are known to contain them, this may be because they are in a form too small to be seen. If this is the case, identification is only then possible using a microscope or by carrying out X-ray diffraction analysis in a specialised mineralogy laboratory.

C.4 Further characteristics of pyrite include its greenish-black streak and its hardness, 6-6.5 on the Mohs' hardness scale. (The streak of a mineral is its colour in a finely divided state, most conveniently determined by scratching the material across a piece of hard unglazed porcelain known as a streak plate. The Mohs' hardness scale ranges from 1 (talc) to 10 (diamond) in unequal steps (West, 1991), and has common equivalents depending on the scratching caused by fingernail, glass, a penknife or a hard file.) Marcasite differs from pyrite in that it has a greyish streak.

C.5 West and O'Reilly (1986) contains useful information on sulfide oxidation, reactions with calcium minerals and the likely effects: it should be consulted for more details and further sources of information.

Sulfate Minerals

C.6 Ettringite ($Ca_6Al_2(SO_4)_4(OH)_{12}$) is formed by the combination of soluble sulfates, from gypsum for example, and dissolved alumina, produced by the effect of the high pH associated with adding lime. The crystallisation of ettringite is expansive and, in addition, is subject to further large volume changes as it takes in water. Thaumasite ($Ca_3Si(CO_3)(SO_4)(OH)_6$) will also form from ettringite but without a change in volume. The thaumasite form of sulfate attack is covered in detail in Thaumasite Expert Group (1999). Although ettringite and thaumasite occur naturally, they are not common and their expansive properties are only realised principally when the ettringite forms as a result of adding lime and water to sulfate bearing soils. Both ettringite and thaumasite are unlikely to be identified in the field during the ground investigation. Identification is only necessary after laboratory samples have been stabilised and swells observed, as this gives an indication of likely behaviour during stabilisation.

C.7 Ettringite and thaumasite may be identified in the stabilised material as colourless and white needle crystals with a vitreous lustre. Ettringite has a Mohs' hardness of 2 to 2.5 and thaumasite has a hardness of 3.5. However, X-ray diffraction analysis is considered the most accurate means of identifying the presence of these minerals. The X-ray diffraction analysis will, however, have difficulty distinguishing between the two minerals: this is not of great consequence as it is the presence of either ettringite or thaumasite that is important at this stage.

C.8 In addition to the descriptions in Appendix A, gypsum exhibits a white streak and has a Mohs' hardness of 2.

APPENDIX D SUGGESTED SPECIFICATION FOR LIME TREATED CLAY SLOPE REPAIRS

D.1 Materials shall conform to the requirements of Table D/1 and the construction shall conform to Figure D/1 and its Notes.

Material Property	Criteria and Limits
Untreated Material:	
Plasticity Index	10% or more
Particle size distribution	15% or more passing 63 micron 95% or more passing 28 mm 100% passing 75 mm
Organic Matter	No visible organic material: tree roots, or peaty soil
Treated Material:	
Lime addition	[2% dry weight of available lime to dry weight of soil starting point for testing, increased in 0.5% steps if necessary]
MCV for treated material	[Higher limit set at mc for 10% air voids immediately after mixing] [Lower limit set at mc for shear strength requirement tested immediately after mixing]

Table D/1 Material Requirements

D.2 Repairs shall be carried out working in either alternate or successive bays. A bay width of 10 metres should be maintained initially but may be increased, if temporary stability is satisfied, to a maximum of 20 m.

D.3 All topsoil shall be removed and stored for reuse prior to commencement of any excavation operations.

D.4 At the base of the existing slope, a shelf shall be excavated with nominal fall to a drain.

D.5 A geotextile separator to Clause 6 shall be placed both above and below a horizontal Type B (MCHW 1 Clause 505) granular drainage blanket. The bottom layer shall incorporate a pipe of internal diameter given in the Contract Drawings and their Notes.

D.6 The specification of the geotextile separator shall be:

> Minimum wide strip tensile characteristic load = 2 kN/m Pore size, 0_{90} = 50 to 150 microns
> Minimum water flow = 10 L/m^2/sec at 100 mm head

All characteristics to BS 6906.

D.7 Drainage continuity shall be maintained between the horizontal granular drainage blanket on each bench and sub-vertical drainage composite at the back of each bench.

The in-plane flow of the core under a pressure of 100 kPa and hydraulic gradient of 1 is to be greater than 200 m L/sec/m width. The geotextile in the sub-vertical drainage composite shall be as specified in Clause 6.

D.8 For areas where the toe of the embankment is subject to flooding the thickness of the basal drainage blanket shall be increased to a height sufficient to keep treated clay above flood level based on a 1 in 50 year event.

Volume 4 home page

D.9 Granulated quicklime shall be mixed with the clay fill, at an addition given in Table D/1 with four passes of the mixing machine or less passes if 95% of the treated material passes a BS 28 mm sieve. Mixing shall be undertaken either on adjacent ground to the repair, in a batch mixer, or within the repair if the stabilising machine will not damage the geotextile separator.

D.10 Compaction shall be in accordance with Method 7 (Table 6/4) and the MCV requirements in Table D/1.

D.11 Excavation shall extend up the slope, using benches and ensuring the excavation extends 300 mm below all slip surfaces subject to a minimum overall depth of excavation of 1.5 m.

D.12 If there is surplus clay, it shall be placed and compacted on the berm (where formed) or on the ground in front of the slope toe (if sufficient space) but not on the slope.

D.13 On completion of filling the slope shall be cut back to the design gradient and the completed slope surface shall be re-worked and sealed by tracking with a tracked vehicle, suitable for the purpose, on the slope, or by other suitable methods.

D.14 The slope shall be covered with top soil stored on-site to a depth specified in Fig D/1 and seeded with a mixture according to Table 6/5 of MCHW 1.

D.15 Lime treated repairs shall not be undertaken when the ground is frozen.

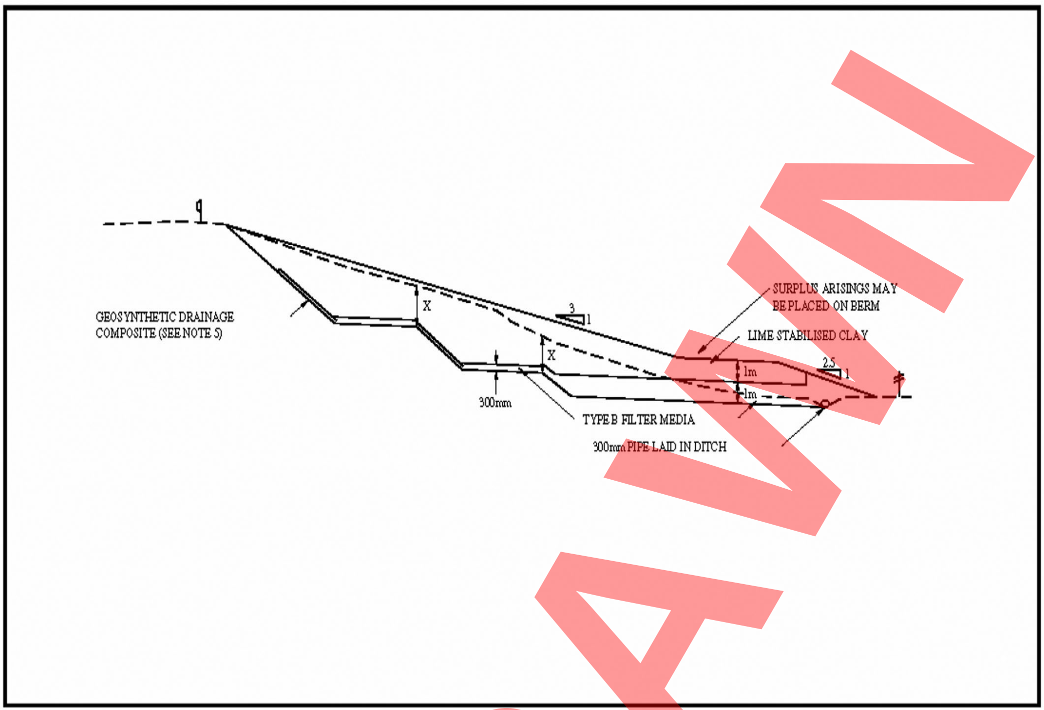

Figure D/1 Typical Section for a Lime Stabilised Clay Slope Repair on an Embankment

NOTES

1. This drawing to be read in conjunction with drawings - - - - - - - -
2. Section drawn at MP ___ at approximately the highest section.
3. Repair may be carried out working either in alternate or successive bays. Bay width of 10 metres should be maintained initially but may be increased if temporary stability is satisfactory – maximum width 20 metres.
4. A geotextile separator is to be placed above and below the drainage blanket Minimum wide strip tensile characteristic load 2 kN/m Pore size O90 between 50 and 150 microns Minimum water flow 10 L/m2/sec at 100 mm head All characteristics to BS 6906.
5. Sub-vertical parts of the drainage blanket are to comprise a geosynthetic drainage composite with a drainage core sandwiched between geotextile separators. The in-plane flow of the core under a pressure of 100 kPa and hydraulic gradient of 1 is to be >200 ml/sec/m width. Geotextile separators to be as Note 4.
6. Minimum excavation depth x to be 300 mm below lowest slip surface, 1.5 m minimum. Excavation depth to be agreed with the Engineer.
7. Invert of 300 mm pipe to be placed at existing ditch invert level. Ditch to be cleaned out where necessary to maintain minimum fall of 1:400.

CONSTRUCTION SEQUENCE

1. Strip topsoil.
2. Below midpoint of existing slope, excavate 10 m wide bay to profile shown. Base of excavation to be ____mm below existing ground level.
3. Place 1.0 m thick drainage layer (SHW Clause 505 Type B) with geotextile separator above and below.
4. Granulated quicklime to be mixed with clay arisings at the rate of 2% (5 kg lime per sq m on 200 mm thick loose layer) Lime and clay to be mixed with pedestrian controlled rotovator prior to compaction.
5. Extend excavation up slope, benched as shown, ensuring that excavation extends below all slip surfaces.
6. Drainage continuity is to be maintained between the horizontal granular drainage blanket and the sub vertical drainage composite.
7. Surplus clay may be placed and compacted on the berm.
8. Spread ___ mm topsoil and seed.

Volume 4 home page

APPENDIX E SITE STABILISATION CHECKLIST

1 The following checklist provides a means of ensuring quality control during planning, design and construction of soil stabilisation works.

Volume 4 home page

Section	Number	Audit Details	Yes/No	Comments
		Desk Study and Feasibility Study		
1	1.1	Have any ‘Guidelines for Best Practice’ been referred to?		
	1.2	Is the Site Investigation easily available?		
	1.3	Are the materials in the SI on the list in HA74 App-B?		
	1.4	Has TRL447 been used for guidance on sampling and testing in the SI?		
	1.5	What is the highest Sulfur Content recorded in the SI?		
	1.6	What is the highest Total Potential Sulfate Content in the SI?		
	1.7	What is the highest Sulfate Content recorded in the SI?		
	1.8	What is the highest Organic Content recorded in the SI?		
	1.9	If these materials are above recommended levels – has the client been informed?		
		Laboratory Trial Mixes		
2	2.1	Have samples been taken for a laboratory design mix?		
	2.2	What was the frequency of sampling?		
	2.3	Has a suitably qualified and experienced professional sampled the site?		
	2.4	Have samples been taken for chemical analysis?		
	2.5	Have the samples been sent to a suitably qualified and experienced laboratory?		
	2.6	Have the samples been Classified?		
	2.7	Has a range of binders been chosen?		
	2.8	Has a mellowing period been chosen?		
	2.9	Has the degree of pulverisation been chosen?		
	2.10	Has a suitable strength/CBR and/or stiffness been chosen?		
	2.11	Has a suitable moisture range been chosen?		
	2.12	Have appropriate Swell tests been conducted?		
	2.13	Has a frost heave test been conducted?		
	2.14	Have the remainder of the samples been kept for in accordance with BS5930 for sufficient time after the report has been issued?		
	2.15	Has a Laboratory report been issued to the Client?		
	2.16	When was the report submitted to the client?		

Volume 4 home page

Section	Number	Audit Details	Yes/No	Comments
Design and Specification				
3	3.1	Has a suitably qualified and experienced professional assessed the results?		
	3.2	Are the results clearly set out by the designer?		
	3.3	Has an environmental assessment been conducted, for Noise, Dust and any other potential hazards?		
	3.4	Is the water supply available and suitable?		
	3.5	Has a maximum Sulfur content been chosen?		
	3.6	Has a maximum Sulfate content been chosen?		
	3.7	Has a maximum Organic content been chosen?		
	3.8	Has a minimum Binder content been chosen?		
	3.9	Has the quality of binder been specified?		
	3.10	Has a suitable moisture range been chosen?		
	3.11	Has a minimum mellowing period been chosen?		
	3.12	Has a suitable depth been chosen?		
	3.13	Has a suitable overlap been chosen (Horizontal and Longitudinal)?		
	3.14	Has a degree of pulverisation been chosen?		
	3.15	Has a minimum working temperature been chosen?		
	3.16	Has a method compaction been chosen (size of roller and number of passes required?)/ or		
	3.17	Has a suitable Target compaction been chosen? (Target % of MDD, or Maximum Air Voids content)		
	3.18	Has a suitable maximum working period been chosen?		
	3.19	Has a minimum strength/CBR and/or Stiffness been chosen?		
	3.20	Has a maximum Swell been chosen?		
	3.21	Has the frequency of Classification and Chemical checks been stated?		
	3.22	Have the frequency of Binder content checks been stated?		
	3.23	Have the frequency of Depth checks been stated?		
	3.24	Have the frequency of Moisture/MCV checks been stated?		

Volume 4 home page

Section	Number	Audit Details	Yes/No	Comments
Design and Specification (continued)				
	3.25	Have the frequency of Pulverisation checks been stated?		
	3.26	Have the frequency of Strength Tests been stated?		
	3.27	Have the frequency of In situ Density checks been stated?		
	3.28	Have the frequency of Swell Tests been stated?		
	3.29	Have the frequency of Frost checks been stated?		
	3.30	Has a sealing coat been chosen?		
Site Trials				
4	4.1	Are Health & Safety policies in place for the specialist work, and have they been issued.?		
	4.2	Has a site trial been conducted?		
	4.3	Have the materials been reclassified?		
	4.4	Are the materials as expected and compliant?		
	4.5	Has all the plant to be used, been listed for the client?		
	4.6	Have all operators been fully trained with records in place showing any Tool Box talks etc.?		
	4.7	Are all materials such as Diesel and Emulsion stored in Bunded Areas with a written policy?		
	4.8	Is there an Environmental method statement and is it being followed?		
Initial Site Control				
5	5.1	Has the Area to be worked been checked for level and laid out as expected (to the correct depth)?		
	5.2	Is the strength/CBR and/or Stiffness of the underlying layer suitable?		
	5.3	Is the Binder the same quality as used in the Lab design?		
	5.4	Has the Insitu Dry density of the soil been checked?		
	5.5	Has the Equipment for tray checks been calibrated? or		
	5.6	Has the Integrated Hopper been regularly calibrated?		
	5.7	Have sufficient binder checks been conducted?		

Volume 4 home page

Section	Number	Audit Details	Yes/No	Comments
Initial Site Control (continued)				
	5.8	Have binder delivery records been kept?		
	5.9	Have depth checks been conducted?		
	5.10	Has Moisture been added to meet the spec?		
	5.11	Has the pulverisation been recorded?		
	5.12	Has the material been left to mellow to Specification?		
	5.13	Has the material been compacted to Specification prior to Mellowing?		
	5.14	Has a suitably qualified Employee/Tech/Organisation been used to conduct the above checks?		
Final Site Control				
6	6.1	Have sufficient binder checks been conducted?		
	6.2	Have binder delivery records been kept?		
	6.3	Have all areas of excess binder been dealt with properly? (e.g. at ends of Bays and around Silo)		
	6.4	Has the depth been adjusted to take into consideration any bulking between mixes?		
	6.5	Have depth checks been conducted?		
	6.6	Have all samples been taken diagonally across the area?		
	6.7	Has Moisture been added to meet the spec?		
	6.8	Has the pulverisation been recorded?		
	6.9	Has the method compaction been witnessed (size of roller and number of passes required)?/ or		
	6.10	Has a suitable Target compaction been achieved? (Target % of MDD, or Maximum Air Voids content)		
	6.11	Have sufficient DD/MC Relationships and Particle Density Tests been conducted?		
	6.12	Have sufficient Strength Tests been conducted?		
	6.13	Have sufficient Swell Tests been conducted?		
	6.14	Have sufficient Frost heave Tests been conducted?		
	6.15	Has the material been suitably protected prior to placing the next layer?		

Volume 4 home page

Section	Number	Audit Details	Yes/No	Comments
Final Site Control (continued)				
	6.16	Has a sealing coat been applied at the correct rate?		
	6.17	If multiple layers, has the level and number of each layer been recorded?		
	6.18	Has a suitably qualified Employee/Tech/Organisation been used to conduct the above checks?		
	6.19	Have all of the results been recorded as soon as available?		
	6.20	Has a final report been written up and passed over to the client?		
	6.21	Have any areas of Non-compliance been clearly brought to the attention of the client?		

Volume 4 home page