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The British Cementitious Paving Association

# SOIL IMPROVEMENT AND SOIL STABILISATION

DEFINITIVE INDUSTRY GUIDANCE

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Front cover images courtesy of Geofirma Ltd and Combined Soil Stabilisation Ltd.

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# Soil Improvement and Soil Stabilisation: Definitive Industry Guidance

## Contents



# Scope

**This document is an introductory and technical guide to mix-in-place soil improvement and stabilisation. It outlines industry best practice and provides technical information plus signposts to industry standards and further reading. As such, this is not an industry or technical specification.**

This guide explains the what, why, where and how of soil stabilisation. It describes the process of soil stabilisation for all infrastructure sectors. The planned future withdrawal by Highways England of 'HA74 Treatment of Fill and Capping Materials using either Lime or Cement or Both' means that the publication of this new Britpave guidance on soil improvement and soil stabilisation is well timed. The new Britpave guidance is not a replacement for HA74. It aims to provide a comprehensive introduction to soil improvement and soil stabilisation and although it covers highway works it does so as part of a wider scope of soil stabilisation applications. It has been developed by the industry for the industry with the added bonus of input from Highways England, with whom Britpave has a close working relationship.

The guide concentrates on the use of binders to improve and stabilise clays and fine-grained soils plus in-situ stabilised coarse aggregate mixtures. The binders considered in this guidance are limited to the following standard products: cement, fly ash, granulated blast furnace slag (ggbs), hydraulic road binder and lime. Fly ash is covered even though it is less commonly used and the UK supply is set to decline as UK coal-fired power stations are being decommissioned. Guidance on using cold recycled asphalt mixtures bound with foamed bitumen is not included. It is a different specialist technique and is more commonly used in base layers. Further information can be found in MCHW clause 948 and TRL Report 611.

This document refers to the Highways England Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works. This is abbreviated to MCHW1.

# 1 What and Why?

Both soil improvement and soil stabilisation consist of adding binders in-situ to improve the soil performance as an alternative to 'dig and dump'. They have a long track record and are both cost effective and sustainable. The benefits include reduced aggregate importing and off-site disposal and the attendant reduced vehicle movement. Soil improvement is also often used to gain rapid access to wet sites in a single operation.

Soil improvement and soil stabilisation can be used for fills, foundations, subgrade improvement, slope repairs, working platforms and hardstandings.

## Soil improvement

Soil improvement is generally achieved by adding binders. It is sometimes termed soil modification in the literature.

### The benefits

Soil improvement is used to address handling or compacting problems resulting from high plasticity or high water content. Such soils can be improved by mixing with lime. Adding lime to clay provides three important benefits:

- Breaking down clay inter-particle cohesion,
- Reduced plasticity,
- Moisture content reduction.

This improves the soil's ability to be:

- handled by conventional earthmoving plant;
- satisfactorily compacted in layers, especially when the moisture content is wet of optimum;
- trafficked and provide a working platform for subsequent layers;
- prepared for further treatment.

Lime is the only binder that breaks down clay inter-particle cohesion. This makes soil improvement a necessary first stage in cohesive soil stabilisation where more than one binder is to be used. A mellowing period may be required to allow the lime to break down the clay to achieve both adequate pulverisation and to allow full activation of secondary binders if used. Historically, a mellowing period of between 24 to 72 hours was specified. However, with the efficiency in mixing that modern stabilisation plant provides this can be much shorter depending on the soil properties and the secondary binders used.

## Soil stabilisation

Whilst soil improvement is beneficial for conditioning soils there may be limited strength increase. To improve strength it is necessary to go to a second stage termed soil stabilisation.

This is a ground improvement technique that involves controlled mixing of one or two binders. Common binder combinations are given below:

| Binder | Use |
|---|---|
| Lime only | Used to dry out soils or to improve strength sufficiently to form capping layers. It is best suited to higher plasticity soils, although it can be helpful on some granular soils to drive off excess moisture. Additional strength development can be achieved using lime content in excess of a parameter called the initial consumption of lime (ICL). This is traditional 'lime stabilisation' and is now seldom used because it is less easy to control in the field compared with lime + cement. In soil improvement the lime content is below ICL. |

| Binder | Use |
|---|---|
| Cement only | Suited to lower plasticity and granular soils to form higher strength mixtures. It does not dry out soils as well as lime. |
| Lime + cement | Commonly used to stabilise clays to a form higher strength and frost resistant mixes. Used where soils, principally clays, are unsuitable for treatment with cement only or need to be dried before stabilising. |
| Lime + ggbs | The strength development compared to lime + cement is slower but is suited to treating sulfate bearing soils to reduce the expansion risk. Ggbs needs additional lime content to act as an activator. |
| Lime + fly ash | This is a slower curing mixture and as such relies on the soil grading for stability under early trafficking. Siliceous fly ash is a pozzolanic material and requires a source of available calcium oxide, lime or cement to produce a hydraulic reaction. |

**Table 1: Binder uses**

## Binder standards

Without detailed laboratory testing, it is strongly recommended that binders are in accordance to a recognised product standard as follows:

- Lime conforming to EN 459-1, in the form of quicklime, or hydrated lime, or lime slurry.
- Cement conforming to EN197-1
- Fly ash conforming to EN 450-1 or fly ash conforming to EN 14227-4.
- Ggbs should either conform to EN 151167-1 or be partially ground ggbs conforming to EN 142227-2.
- Hydraulic road binder (HRB) should conform to EN 13282-1 or EN 13282-2.

Blends of the standard binders described above can be used, provided the blending results in a homogenous mixture to a declared composition and controlled with adequate records. Other hydraulic binders not conforming to product standards are available, but it is recommended that they are used only after extensive laboratory and site trials. Some of these products may be deemed waste products and subject to regulatory controls.

Soil stabilisation can also be used to remediate contaminated soil by immobilising potential contaminants and rendering them non-leachable. It is suited to some contaminants better than others and requires careful mix design. Specialist advice should be sought and this technique is subject to Environment Agency regulation.

### The benefits

Soil improvement and soil stabilisation are proven civil engineering techniques. Treating materials in-situ is efficient, cost effective and offers a number of benefits.

#### Engineered material

Soil stabilisation results in engineered materials that provide:

- improved static load resistance
- improved resilient behaviour (stiffness) under dynamic loads
- reduced permeability
- improved freeze-thaw resistance

The keys to success are using the correct binder and ensuring compaction using good earthworks practice. This is covered in the 'How to' section of this guide.

**Reduced costs**

In-situ treatment of soil can be more cost-effective than traditional ‘dig and dump’ methods which incur transport plus importation and disposal costs including significant potential landfill tax.

**Reduced programme**

Soil stabilisation can reduce construction programme times by minimising site preparation and designing out imported materials and unacceptable material disposal. Soil improvement allows wet ground to be dried and strengthened within a very short timescale. This permits working in wet conditions and allows work to restart promptly following rainfall. For the construction programme benefits to be fully realised, longer lead-in time is needed during the design stage for ground investigation and mix design. Again, this is covered in the ‘How?’ section below.

**Improved Sustainability**

Soil improvement and stabilisation offer significant environmental benefits over traditional ‘dig and dump’. Improvement and stabilisation turn unacceptable soils into engineered material. They avoid off-site disposal and importing acceptable fill, which often comprise virgin aggregates. There is no removal of waste materials and corresponding importation of aggregates. This reduces lorry movements on the local road network and therefore greatly reduces traffic congestion and pollution.

The delivery of the above benefits relies upon strict adherence to the relevant technical specifications and standards, plus the full implementation of good practice by a specialist contractor.

# 2 Where to Use

Soil improvement and soil stabilisation may be used to treat the soil for a wide range of construction projects.

**Fig 1:** Typical pavement cross section options showing where in-situ stabilisation could be used.

<table>
<tr><td>Surface Course</td><td colspan="3">Asphalt</td><td rowspan="3">Pavement Quality Concrete</td></tr>
<tr><td>Binder Course</td><td colspan="3">Asphalt</td></tr>
<tr><td>Base</td><td>Asphalt</td><td>CBGM, FABGM, SBGM</td><td>Low strength Concrete, RCC</td></tr>
<tr><td rowspan="2">Foundation</td><td colspan="4">Unbound sub-base, or,<br>Hydraulically bound mixtures such as CBGM, FABGM, SBGM or soil cement</td></tr>
<tr><td colspan="4">Unbound capping, or,<br>Soil stabilisation to form capping (if required)</td></tr>
<tr><td>Earthworks</td><td colspan="4">Soil improvement (if required)</td></tr>
</table>

Notes:
1) Options for in-situ stabilisation highlighted in orange
2) CBGM = cement bound granular mixture.
3) FABGM = Fly ash bound granular mixture.
4) SBGM = Slag bound granular mixture.
5) RCC = Roller compacted concrete.

Soil cement differs from CBGM, FABGM and SBGM as it normally comprises in-situ treatment of the host soil, whereas the others require controlled aggregate specifications. Soil cement is not permitted as a sub-base layer within the foundation under rigid pavements according to the Highways England specification. Soil cement is permitted as a capping layer with the foundation under rigid pavement.

## Earthworks

Types of earthworks cover:

- transport infrastructure (roads, motorways, railways, waterways, airfields, ports);
- platforms for industrial, commercial and residential buildings;
- flood defence and coastal protection works;
- noise barriers, visual barriers and other non-load bearing earthworks;
- landscaping embankments
- backfilling of open-cast mines and quarries.

Materials that can be treated include:

- natural cohesive soils;
- natural granular soils;
- processed and as-dug aggregates;
- weak rocks including chalk;
- recycled materials;
- artificial and waste materials, for example incinerator and power station ashes.

The maximum particle size of the host material and binder should be compatible with the performance of the plant equipment being used, particularly layer thickness after compaction. In addition, there should be no constituent proportion that could adversely affect the setting, hardening, performance and volumetric stability of the treated earthwork material. Organic matter and sulfates are important constraints and are discussed in the 'How?' section below.

The amount of lime required for general fill is usually less than for capping – typically only 1% to 2% by dry weight of available lime – and is dependent on varying soil properties and the project specification to be achieved. The addition of lime to cohesive materials not only causes some reduction in moisture content, but also improves the soil's engineering properties.  These include moisture content, plastic limit and bearing capacity. Moisture content needs to be carefully controlled. Care should be taken not to change a too wet fill problem to one where the material is too dry for compaction.

## Pavement Foundation – Capping and Sub-base

The pavement foundation distributes the applied vehicle loads without causing subgrade distress. This is required both during construction and during the service life of the pavement. Traditionally, capping and sub-base layers use quarried aggregates. Increasingly, recycled materials with the similar properties are used, such as crushed concrete.

Standard pavement foundation designs are developed on the basis of protection of the subgrade during construction, provision of adequate support to the overlying pavement and practical minimum layer thickness for construction. Where increased construction traffic in excess of that required to construct the overlying pavement is needed, an enhanced and specially designed sub-base is essential. Standard sub-base designs are not intended to be general haul routes.

Capping is used to protect weak subgrades by using relatively cheap materials between the subgrade and the sub-base. Road pavement foundation design requires further subgrade treatment when CBR is less than 2.5%. Subgrades with CBR under 4% may also not support construction traffic and it may be practical or economic to include a capping layer. Sub-base thickness can be reduced by including a capping layer. Unbound aggregates and soils are at risk of deformation when subject to high stress. They have poor permanent deformation resistance and lower shear strength than bound materials.

Sub-base specification and performance is more closely controlled than for a capping layer. The sub-base also provides a regulating function.

Stabilising 'host' soils for capping layers is a viable alternative to 'dig and dump'. Weak subgrades can be treated using soil improvement or soil stabilisation, depending on the required level of performance. It is important to ensure that the improved or stabilised capping layer thickness is sufficient. The danger exists of a 'crème brûlée' effect of a thin crust of insufficient thickness to limit stress in a soft subgrade.

MCHW1 600 series gives material classifications before and after soil improvement and stabilisation. These are summarised in Table 2 below:

| Material | PI | Class | Process | Binder | New Class |
|---|---|---|---|---|---|
| Granular | <10 | | | | 1A, 1B |
| Cohesive | >10 | U1A | Improvement | Lime | 2A, 2B, 2C, 2D, 2E |
| Chalk | N/A | | | | 3 |
| Cohesive | >10 | 7E | | Lime | 9D |
| Cohesive | <20 | 7F | | Cement | 9B |
| PFA | N/A | 7G | Stabilisation | Cement | 9C |
| Granular | <10 | 6E | | Cement | 9A |
| Cohesive | >10 | 7I | | Lime + Cement | 9E |
| Granular | <20 | 6R | | Lime + Cement | 9F |

Notes:
1) Classes after improvement/stabilisation refer to the 600 Series applications
2) Classes prior to improvement/stabilisation can also be used to form 800 Series HBM Soil Cement mixtures subject to compliance

**Table 2: Material classifications before and after soil improvement and stabilisation**

## Pavement: Base

The base is the primary structural layer in a pavement, and as such, the required performance is much higher than for foundation layers. Traditionally, the road base is a relatively thick asphalt layer in the lower pavement construction. To keep this layer economic, base materials contain coarse aggregates that do not provide good ride quality.  For this reason the base is overlaid with binder and surface courses. HBMs and concrete are alternative base materials.

Recent updates to the MCHW1 800 Series give the designer a much wider choice of base materials over asphalt. These are collectively called hydraulic bound materials (HBMs). Included are binder cement to produce cement bound granular materials, slag to produce slag bound materials and fly ash to produce flay ash bound granular materials.

**Recycling soils into pavement base offers a high-valued added benefit. This can be more variable compared to mixed in plant methods but has been used successfully. However, consideration should be given to the accuracies of mixed-in place. The following should also be considered:**

- Increasing the binder content,
- Setting an achievable target strength allowing for variation,
- Achieving surface laying tolerances,

More heavily trafficked pavements require high performance materials that are best obtained using ex-situ mobile batching plants.

# 3 How?

The first documented use of soil stabilisation is the UK was in 1917. It has since benefited from a century of worldwide research, trials, project experience and advances in soil-mixing plant. This resulted in a better understanding of chemical reactions, more robust specification, a greater choice of binders and more efficient and effective plant. The 'How?' of each soil improvement and soil stabilisation project must be supported by ground investigation and design phases that are well-managed; with good earthwork practice being observed on site.

## Ground Investigation and its procurement

Ground investigation for foundations and ground contamination can be insufficient for soil improvement and stabilisation. There are two important constraints that are specific to soil improvement and stabilisation:

- Organic compounds that impair the chemical reactions of lime and cement,
- Sulfates in the soil that cause an expansive chemical reaction with lime.

Eurocode 7 requires a desk study as part of a ground investigation. Soils with a high risk of sulfates can be identified at this stage. Some problems have occurred with the stabilisation of Lower Lias, Boulder Clay and Till. These problems have since been addressed and solutions have now been found that are included in this guidance.

Ground investigation for soil stabilisation has the following special features:

- Trial pits are preferred so that the presence of sulfate and sulfide minerals can be more easily identified.
- Sulfate assessment requires a large number of samples covering the entire profile of the soil to be stabilised. This is because sulfate concentrations vary with depth. Leaching that has taken place naturally over geological time often means that near-surface soils have low sulfate concentrations but they typically increase at depth.
- The chemical tests for sulfates are laid out in TRL 447. The sulfate tests for buried concrete and ground contamination are unsuitable for soil stabilisation.
- Other tests specific to soil stabilisation include ICL and organic content
- Soil samples should be examined for sulfate minerals by a qualified specialist.

| Field Identification |
|---|
| **Pyrite ($FeS_2$ – Iron Sulfide)**<br>Pyrite is the most common sulfide mineral and has a distinctive brassy yellow colour with a metallic lustre. It is particularly common as cube-shaped crystals in shales, slates, mudstones and heavily over-consolidated clays. If pyrite is present in particles too small for field identification, binocular microscope or X-ray diffraction analysis should be used. |
| **Marcasite ($FeS_2$ – Iron Sulfide)**<br>Marcasite 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)**<br>Gypsum crystals are generally white, grey or clear, although yellow, red and brown discolourations 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 and as the weathering product of sulfides in sedimentary rocks. It is particularly common in some over-consolidated clays, and occurs in clusters, some of them large, and in discontinuous sheets. |

**Table 3: Field and laboratory identifications of common sulfide and sulfate minerals**
*(continued on page 10)*

| Laboratory Identification |
|---|
| It should be noted that the descriptions of the material from the core, or from the trial pit, are the key methods for locating the presence of sulfides and sulfates. 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. |
| **Sulfide Minerals**<br>Sulfide minerals do not have an expansive reaction with lime or hydraulic binder 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. Sodium sulfate minerals which also have expansive properties are less common than calcium sulfate minerals and are highly soluble, like magnesium sulfate. |
| **Sulfate Minerals**<br>Ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}$) 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. Although ettringite and thaumasite occur naturally, they are not common and their expansive properties are only realized 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.<br>Ettringite and thaumasite may be identified in the stabilised material as colourless and white needle crystals with a vitreous lustre. |

Soil testing for organic matter, sulfates, sulfides and total potential sulfate (TPS) should be examined in accordance with the following:

| Organic matter | BS1377: Part 3 |
|---|---|
| Water soluble (WS) sulfate content | TRL Report 447, Test No. 1 |
| Oxidisable sulfides (OS) content | TRL Report 447, Test No. 2 and 4 |
| Total potential sulfate (TPS) content | TRL Report 447, Test No. 4 |

**Table 4: Soil testing**

While the MCHW1 specifies test methods to EN 1744 for sulfates, TRL Report 447 methods are recommended as they are more effective at identifying TPS.

Limiting values of swelling due to the presence of sulfide and sulfate are defined through the swelling measured in accordance with the following soaked CBR tests:

| | |
|---|---|
| CBR | BS EN 13286-47 |
| Swelling | BS EN 13286-47 |

**Table 5: CBR tests**

Materials such as pyritic clays and sulfate bearing strata will be particularly susceptible to expansion. Pyritic argillaceous materials, such as colliery shales, will not be suitable for lime improvement. Project and client specific requirements should be included at the early stages of assessment.

HA74/07 gives limiting values of swell for compliance, with the treatment permitted if average swelling recorded is < 5mm, with no individual specimen more than 10 mm; provided that results are approaching an asymptotic value.

This limit is based on the CBR specimen swell test detailed in BS EN 13286-47. Other swell test methods are available, including the 'accelerated, unconfined, expansion test' detailed in BS EN 13286-49. Some research has been completed to compare swell test methods (''Review of Swell Testing Procedures for Stabilised Soils" - Highways Consultancy Group - Highways Research Group October 2008 and ''A Comparison of 3 Swell/Stability tests on Clay Soils Treated with Lime, Cement and GGBS" - Britpave Soil Stabilisation Task Group:- Project Report December 2013).

Results of swell tests may be used to determine the upper limit for the sulfate content in groundwater. 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)

An upper limit for WS and TPS should be specified based on the swell test results. Authoritative guidance can be found in BP51 *"Guidelines for stabilisation of sulfate-bearing soils"* - Britpave (2011).

A 2% organic content upper limit 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, that 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 this 2% limit could be raised. Soils containing higher percentages of organic material can be successfully stabilised and the upper limit for organic matter should be entered into the specification for the individual project.

The following are sometimes overlooked during procurement:

- Procuring the ground investigation as competitive tender whilst leaving the tenderers to define the scope. Ground investigation requires a large number of low cost samples. Competitive tendering on scope can compromise this.
- Deciding to use design and build procurement at a late stage for the stabilisation mix design. This neither saves time nor does it de-risk the project. Time lost at the project start is rarely recoverable and the subsequent time pressures can result in corners being cut.

Mix design requires large samples that can only be obtained by trial pitting using excavation plant. Mix design samples should be targeted at the most unfavourable soil. For example, that with the highest sulfate and/or highest organic content. For this reason mix design samples should be retrieved separately once the ground conditions have been determined. To fully realise the cost and programme benefits during construction, the decision to stabilise needs to be made early in the design programme.

**Some mix design tests can take at least 40 days plus time for sample preparation. This is often overlooked and the full benefits of soil stabilisation may be lost simply because of the time involved is not appreciated.**

## Sampling on site for stabilisation design mix

The following should be considered when sampling for a design mix for lime, cement or any hydraulic binder:

- Assess the site investigation and cut/fill drawings prior to visit to help determine trial pit location
- Know the formation level for the stabilisation layers
- If possible, have an suitable specialist (engineering geologist/geotechnical engineer/material specialist/ground investigation specialist) present so samples from accurate levels can be taken
- Always assess material to at least 0.5m below the bottom of the stabilised layer
- Take representative bulk samples of each material type encountered – typically 200kg

- Ensure sufficient samples of each material type are taken
- Run the relevant mix design on each material type encountered
- Most trial pits should be undertaken in the cut areas
- Samples from cut materials will be required as this material will be the fill material which might require treatment and will form the formation in the fill area
- Samples from formation at underside of cut should be taken as this will be the actual material to be stabilised.
- Assess the cut fill and ensure that some samples are taken from the deepest areas – this is critical in areas where sulfate bearing soils are present, as these are normally covered with non sulfate bearing soils at varying depths.
- Any changes in material type within 500mm of the formation should be sampled and tested for sulfates using TRL447, especially on sites that are known to have elevated sulfates

## Site quality control

A recommended minimum requirement for site quality control should be a full-time site technician. It is also advised to complete a demonstration area and apply an enhanced testing regime. If successful, testing may be relaxed for the following works.

It is important that all test results are readily available to ensure good quality control and process confidence.

Generally, there will be several parties involved in the site quality control of a stabilisation project. These include the following:

- Project designer – responsible to the client for the design
- Project manager – responsible for the overall control of the project
- Stabilisation contractor – responsible for carrying out the stabilisation
- Testing laboratory – responsible for the required testing.

Two or more of these roles may be combined. For example, the stabilisation contractor may have an in-house laboratory for testing, or one party may be responsible for the design and another for the overall project control. It is recommended that the testing laboratory is UKAS accredited.

## Recommended quality control procedure for stabilised materials

1. Confirm soil properties before treatment are the same as assumed in the design. If changes are found then refer back to the designer.
2. Assess moisture content of material before treatment to adjust binder or water content if required
3. Check rate of spread of binder and adjust rate of spread if required; or re-spread if insufficient binder has been added
4. Check mixing depth by hand dug trial holes and adjust and re-mix to the correct depth if necessary
5. Assess moisture content of mix after mixing – the mix should bind together and be homogeneous when moulded into a ball by hand. NDG gauge readings will provide a guide to moisture content. Take samples for laboratory moisture content testing to correlate with gauge readings. Where practical, consider rapid methods for moisture content testing, such as microwave oven for granular materials or MCV for cohesive materials and adjust water addition accordingly.
6. Check the pulverisation after mixing. This is important for cohesive materials, especially heavy clays, to ensure that the binder is well mixed. Multiple passes or an extended mellowing period can be required for some materials to break down. This should be determined from initial trials and replicated in the main works. Remix if satisfactory pulverisation is not achieved

7. Check the performance or strength of the mix at agreed intervals and take samples for relevant laboratory testing.
8. Check the compaction by in-situ testing and compare with refusal densities from laboratory specimens or a target density from compaction curves. Define compaction method from site trials and replicate for the main works. Close control and feedback to the roller operator is essential while the material is still workable, so that additional passes can be made if required.
9. Check levels while material is still workable. If too low, more material will be placed, then the full depth of the stabilised layer re-mixed, adding more binder if deemed necessary.
10. Complete any performance testing on the finished layer if required. Allow curing time required for the material to gain strength before testing and trafficking in accordance with specification
11. Protect finished works from damage by signage or physical barriers where required, until it has reached the required strength or performance for the intended use.
12. For cold weather working, ensure that materials are frost free before treatment and treated materials are protected when low temperatures are anticipated. Additional curing time before trafficking may be required due to slower strength gain at lower temperatures.
13. For hot weather working consider treating smaller areas so that works are completed before the material dries out.
14. Site trials are important to establish working methods that should be used for permanent works and achieving any specific performance criteria.

## Plant

The in-situ improvement/stabilisation process requires the thorough mixing of the designated binder with the host soil. This is to maximise contact between the binder and test soil. Large ‘clods’ of soil will remain wet or weak if only the outer surface is treated.

Purpose-built rotavators have been developed to promote efficient mixing. Unlike agricultural rotavators, stabilisation plant ‘up-cuts’ in the direction of travel, which ensures that the binder is fully mixed, and not simply moved to the bottom of the layer.

Depending on the end use of the fill, the method of mixing binder must be considered. Using specialist stabilisation equipment rather than disc harrows or ploughs has the following advantages:

- Improved output of mixing, placing and compaction
- Improved consistency of mixing and reduced binder wastage
- Reduced environmental impact due to wind blown dust

The following plant is used for improvement and stabilisation:

- Self-propelled – these machines have the rotavator built into a drive unit. They are computer controlled and provide very efficient mixing, depth control and integrated water addition. It is recommended that only self-propelled rotovators should be used for higher quality applications such as road foundations or base layers
- Tractor/machine-mounted mixers – the rotavator is usually mounted on a large agricultural tractor. Whilst they provide an efficient mix of materials, they are less likely to have depth and water control
- Hydraulic excavators – these should only to be used in the very wettest of soils for mixing in granulated lime. Extreme caution must be taken to avoid applying too much lime at once as this can generate excessive steam and reactive dust. Thorough mixing must also take place to avoid pockets of un-hydrated materials being left.

- Binder delivery - usually supplied as powder in bulk tankers of 28-30 tonnes and transferred into bulk storage silos on site. However, some binders can be procured in 1 tonne or 25kg bags. Granulated lime is also available that is delivered in bulk tipper lorries similar to graded aggregates.
- Silos – Bulk storage silos are often required on site. Guidance on the safe delivery of powders and silo standards can be found in ‘’BRITPAVE Safe Delivery of Powders”
- The binder spreading units are designed to accurately deposit the binder in the surface of the material, in accordance with the specification for the project. As with the rotavators, they can be self-propelled, towed by or mounted on a machine.
- Adequate compaction plant and methods are required. Smooth drum vibratory self-propelled rollers greater than13 tonnes must be used in all layers exceeding 250mm. Pneumatic Tyre Rollers (PTR) offer a better solution to the compaction of fine grained soils and provide immediate trafficking of the layer.
- Trimming is normally carried out using a grader although a dozer is sometimes used to level and trim improved soils/capping layers depending on surface tolerances and output required
- Water bowser, either self-propelled or towed, should be thoroughly cleaned before use to ensure that only clean water is used.

## Health and safety and environment

### Plant/Person Interface Safe Zones

As with all construction operations, the interface between plant and people is of greatest importance. Whilst the process is relatively slow-paced, there are a number of operations being carried out simultaneously, sometimes within a relatively small area. Those operating machinery must actively look for and see people on the ground. All site personnel should be briefed on plant/people interfaces and on the need to be seen by other site operatives.

Safety briefings must be carried out prior to the commencement of any works; and all personnel must have the relevant training/qualifications for their element of the works – plant used in improvement/ stabilisation falls within CPCS Categories A19, A31, A33, A68, A71, A71.

Binder manufacturers and suppliers must be able to provide data sheets for their products. This must include safety and environmental information for the end-user. Anyone who comes in to direct and secondary contact with binders should either wear, or be issued with the following:

- Dust masks to FFP3 – goggles or close-fitting glasses – gloves (if handling binder) – disposable coveralls.
- Eye wash bottles and clean water should be available in all plant.

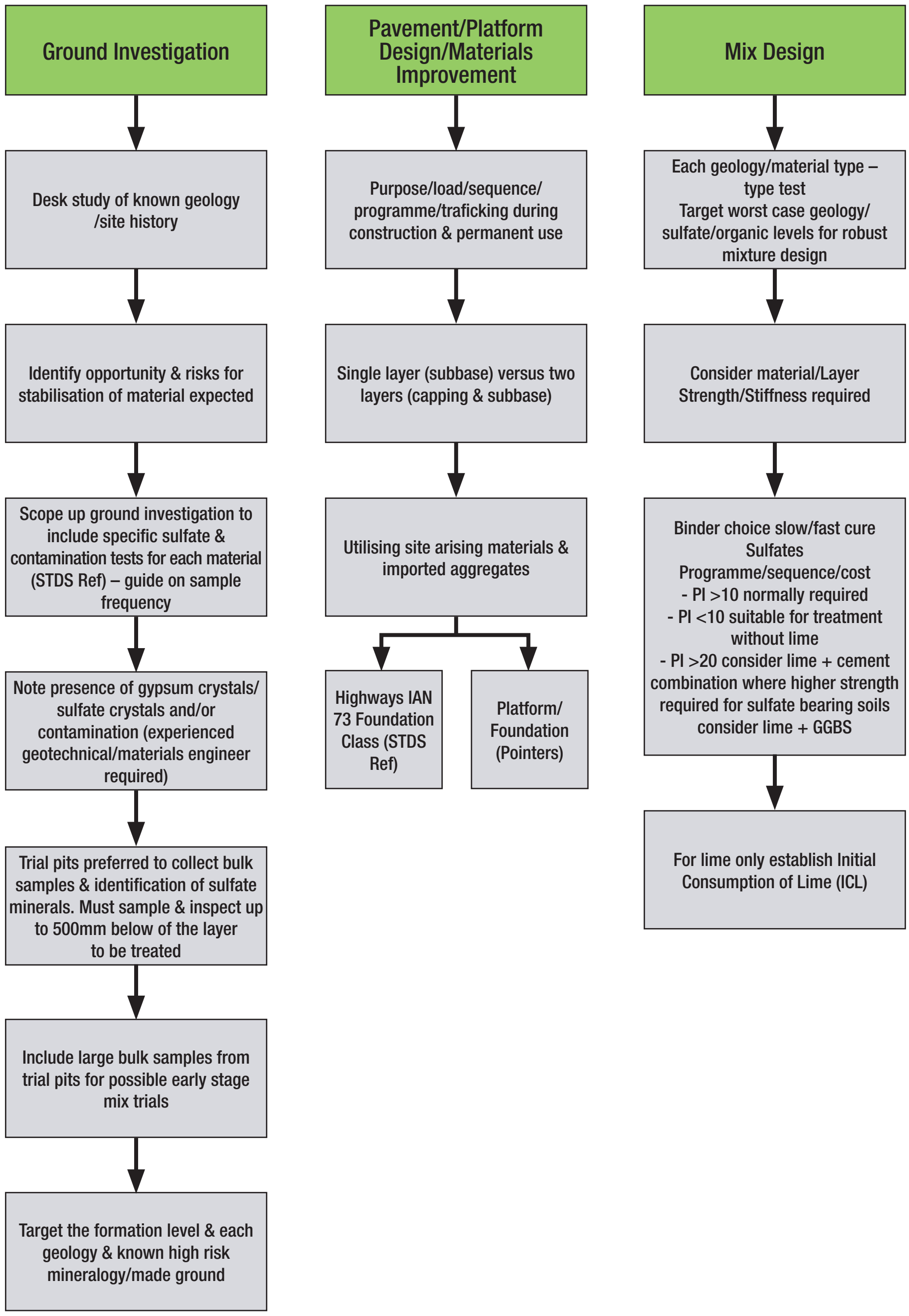
### Environment

To minimise environmental impact, the following should be considered:

- Control of run off
  - Before addition of binders – general earthworks good practice and interface with other/main contractor(s)
  - After addition of binders – ensure fully mixed, fully compacted and curing protection applied
- Dust – note wind-blown risk and option for integrated spreader. Ensure that mixing closely follows the spreading operation
- Change in material properties due to an increase in pH of stabilised soils. The pH is likely to remain elevated and this should be considered when proposing landscaping and planting.

# APPENDICES

## A1 Phased project progress



## Laboratory Trials

- Improvement/modification
  MC/MCV before
  Add binder – mellowing period
  MC/MCV after
  Check swell – soak for 28 days where risk of sulfates is identified
- Binder content range.
  Minimum of 3 different % of binder
  - Simulate mellowing periods/time between two binders & assess pulverisation
  - Early age strengths to establish trends
  - Correlate simple site tests e.g. cube strength or CBR to stiffness to enable routine monitoring during main works
  - Effect of water on pavement layers:
    OMC +1.2 x OMC (strength drop)
    Ingress of water
    (immersion test Cl.880)
  - Consider frost susceptibility, if required:
    Deemed non-frost if >C2.3/3 compressive strength or >0.25MPa tensile strength
    Testing using frost cabinet
  - Effect of swell
    Control sample – no binder
    Cover binder range
    Longer age soaking range, >28 days if risk known
    Consider European accelerated swell test as well as CBR swell test
  - Correlate maximum Water Soluble sulfates & Total Potential Sulfates limits with acceptable swell & insert limits into project specification

## Site Trials

- Repeat chosen mixture from laboratory trials
- Assess mixing & pulverisation of material methodology (single pass?/type of plant/mellowing period)
- Assess compaction plant size/ type of output
  Check compaction/insitu air voids & verify compaction regime
  Consider PTR for surface finish & early trafficking
- Where imported aggregate treated over clay allow extra depth of aggregate as buffer to avoid contamination from below
- Assess trafficability for construction plant/laying next layers (test strength)
  surface modulus gain v time
- Trafficking trials to ensure treated material can support plant to lay next layer
- Consider vehicle marshalling to avoid damage
- Consider wet trafficking trials to establish controls after rain
- Correlate site testing methods – LWD/FWD if required
- Curing – immediate overlaying/ wetting between layers/ emulsions

## Compliance Monitoring

- Methodology approved from site trials, repeat if anything changes
- Feedstock checks where required: PI, PSD, sulfates
- Protection of the works from:
  Weather, trafficking, interface with follow on activities
  Sequencing/temperature protection
  Possibly build a stronger layer if required
- Compliance testing:
  - LWD or FWD for pavement
  - Layer strength/stiffness or bearing ratio for mixed material
  - Wet density – target
  - Insitu density – compaction air voids, target <5% air voids for cohesive & >95% of Mix DD for granular mixtures
  - Target MCV <12 on cohesive mixtures
  - Pulverisation – essential for - heavy clays
  - Depth of mixing – hand dug trial holes to verify treated depth
- Finished level should be high to ensure cut back into compacted material- no top up required
- If layer strength fails carry out LWD on a grid to determine area, remix if required

# A2 Design testing requirements for material sourced off-site

**Lime Modified and Stabilised**

| Test at Hydraulic Binder Addition | Test Reference | Modified/Improved | Stabilised |
|---|---|---|---|
| MCV | EN13286-46 | x | x |
| Moisture Content | EN 13286-2 | x | x |
| Pulverisation | EN 13286-48 | | x |
| Bearing Ratio (CBR) | EN 13286-47 | x | x |
| Swell | EN 13286-48 | x | x |
| Moisture Content | EN 13286-2 | | x |
| In-situ Density | BS1924-2 or BS1377 Part 9 | x | x |
| Frost Heave Test | BS1924 Part 2 | | *x |

* If in the frost zone – normally 450mm

**Hydraulically Bound Materials**

| | | HBM | |
|---|---|---|---|
| Test | Test Reference | Soils | Granular mixtures |
| Water Content | BS1924-1 | x | x |
| Grading Aggregates | EN1097-5 | x | x |
| Grading Soils | BS1924-1 | x | x |
| Plasticity | EN 13286-47 | x | x |
| Mixture Grading including Binder | EN933-1 | x | x |
| Water Content at Final Compaction | BS1924-2 | x | x |
| *MCV at mixing and Final Compaction | EN13286-46 | *x | |
| Pulverisation | EN13286-48 | x | x |
| Spread Checks | Sub-Clause 870.3 | x | x |
| Depth of Mixing for 'Mix in Place' at each stage of the mixing process | Sub-Clause 870.4 | x | x |
| In-situ Wet Density | Sub-Clause 870.5 | x | x |
| Laboratory Mechanical Performance | As Required by Table 8/15 | x | x |
| Strength After Immersion | Subclause 880.4 | x | x |
| FWD | | x | x |
| LWD | | x | x |
| * Cohesive Mixtures Only | | | |

# A3 Design testing for site won materials treated with lime and/or hydraulic binders

**Incl Cl.840 Soil Cement**

| Test | Standard | Lime Fill | Lime Fill | Engineered Fill | Engineered Fill | Capping/ Subbase Replacement | Capping/ Subbase Replacement | Soil Cement - HBM | Soil Cement - HBM | HBM |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Class 1 | Class 2 | Class 1 | Class 2 | Class 1 | Class 2 | Class 1 | Class 2 | Quarried |
| Plastic Limit | BS 1924 - 1 | x | x | x | x | x | x | x | x | |
| Liquid Limit | BS 1924 - 1 | x | x | x | x | x | x | x | x | |
| Plastic Index | BS 1924 - 1 | x | x | x | x | x | x | x | x | x |
| PSD | BS 1924 - 1 | x | x | x | x | x | x | x | x | x |
| Uniformity Coefficient | | x | | x | | x | | x | | x |
| Organic matter | BS1377:part 3 | x | x | x | x | x | x | x | x | |
| TRL447 | TRL Report 447 | x | x | x | x | x | x | x | x | x |
| ICL | BS1924: Part 2 | | | | | | #x | | | |
| CBR | EN 13286-47 | x | x | x | x | x | x | x | x | |
| Swelling | EN 13286-47 | x | x | x | x | x | x | x | x | |
| MCV Untreated | BS1377:Part 4 | | x | | x | | x | | x | |
| MCV Treated | EN 13286-46 | | x | | x | | x | | x | |
| MC Untreated | BS 1377:Part 2 | x | x | x | x | x | x | x | x | x |
| MC Treated | EN 13286 - 2 | x | x | x | x | x | x | x | x | x |
| OMC 2.5kg | EN 13286 - 2 | | x | | x | | x | x | | |
| OMC 4.5KG | EN 13286 - 2 | x | | x | | x | | | | |
| OMC Vib Hammer | EN 13286 - 2 | | | | | | | x | x | x |
| Particle density | BS1377:Part 2 | | | x | x | x | x | | | |
| MCV Relationship | | | | | x | | x | | x | |
| Frost Susceptibility | BS1924: part 2 | | | | | x | x | *x | *x | x |
| IDD of Chalk | Cl. 634 MCHW1 | | | | | | | | | |
| Compressive Strength | 13286-51 | | | | | | | x | x | x |
| Strength After Immersion | Cl.880.4 | | | | | | | x | x | x |
| Resistance to Frost | Cl.880.6 | | | | | *x | *x | *x | *x | *x |
| Modulus Of Elasticity | EN 13286-43 | | | | | | | x | x | x |

* If Compressive Strength is less than C2.3/3 at 28 days

# Lime Only Capping (15% CBR Max)

# A4 Further reading

## Technical Reports and Guidance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britpave

The British Cementitious Paving Association

Britpave, the British In-situ Cementitious Paving Association, was formed in 1991. It is active in all areas of transport infrastructure including roads, airfields, light and heavy rail, guided bus, safety barriers and drainage channels, soil stabilisation and recycling.

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