Soil Treatment and Ground Stabilisation

Soil treatment has been used for road and airport construction in UK since the 1970s

JJMac Ltd would like to share some information and knowledge about Soil Treatment and Ground Improvement.

Soil treatment using Lime and Cement is used widely in road and pavement construction around the world. Other uses include:

- Temporary access and haul roads for construction sites such as wind farms and cross country pipelines.
- Construction of Car and Lorry parking areas
- Airport Runway and taxi ways
- Industrial Building floor slabs
- Reclamation and Remediation of contaminated sites

Soil Treatment binders are used to improve unsuitable soils that are soft and wet with low Shear Strength and low bearing capacity. Once treated with the binders these soils will be fit for use as sub-base material for road and pavement construction. The soils may be retained on site and used as opposed to being carted toff site to tips.

The house building sector of construction has embraced the Soil Treatment and Ground Stabilisation technology. Marginal load bearing soils can now be treated and used as a platform for the development of housing to allow for shallower foundations. Loading for the houses can be transferred into the treated and engineered soils without the need for the foundations to transfer the loading into the deeper competent strata.

The **objectives** of treatment are:

1. Enable the soil to be handled and placed such that maximum compaction with minimal air voids is achieved 95% compaction required.
2. Achieve a volumetrically stable treated soil
3. Realise a development that is free from detrimental settlement.

The **suitability** of hydraulically treated soils for domestic building applications is considered in the following steps:

1. A review of the available treating agents,
2. site investigation techniques specific to the technology
3. Soil chemical analysis appropriate to ground treatment

Verification testing is required to ensure that the treatment is competent, stable, and durable for the design life of the development

1. Laboratory evaluation tests
2. Site control tests during construction

Every job is unique and needs to be assessed on its own merits. There is no blanket recipe to cover all situations.

Lime chemistry

The lime that is mainly used in Soil Treatment Ground Stabilisation is the product resulting from the burning of **Chalk or Limestone (CaCO3)** at high temperature.

A **Chemical Reaction** takes place during the buring where **Carbon Dioxide (CO2)** is driven off leaving C**alcium Oxide (CaO)**, also known as '**quick lime'**. The quick lime is a granular product that is ground to produce different 'fineness' grades depending on end use.

When **quick lime** is exposed to **Water (H2O)**, this creates a hydration process. The following chemical reaction takes place, producing **Calcium Hydroxide (Ca(OH)2)**, also known **'hydrated lime'**. This has the appearance of a fine powder.

An Exothermic and Alkaline reaction takes place once the **quick lime** reacts with the moisture in the sopils, both of which play an important role in the treatment of soil using lime.

Quick lime is used for soil treatment and are not to be confused with agricultural lime, which is simply ground calcium carbonate, ie ground chalk or limestone.

If quick lime is left exposed for a significant period during the treatment process, it can, in combination with CO2 from the air, revert to chalk or limestone (CaCO3). The chemical reaction may be reversed. This reversion is known as '**carbonation'**. The reversion effectively converts the lime from an **'active'** state back to its original **'inert'** state.

Advice on lime treatment can be sourced from the British Lime Association (www.britishlime.org).

Lime treatment

When quick lime is added to a wet soil, the soil rapidly becomes drier and slaked lime is produced This is a highly exothermic reaction, which, together with the chemical combining of water with quick lime, significantly reduces the moisture content of the soil.

Exothermic reaction taking place during a drying process on a very wet site. Steam rising from the soil

The reaction with the quick lime also raises the alkalinity (pH) of the soil. If the soil is clayey (cohesive) and sufficient quick lime has been added to raise the pH of the soil to 12–13 (7ph being neutral). A second change takes place. The clay minerals undergo a **Physical Transformation** of

Flocculation. This transformation is also known as **'Cation Exchange'**, whereby the soil becomes less clay-like and more friable or sand-like.

This change is usually very rapid with cohesive or clayey soils and is known as '**Soil Modification'** Adding quick lime to clay soils results in drying and modification.

Modification and Stabilisation of Soils

The **Modification** of a clay soil **changes its properties and characteristics**.

These changes include:

1. Increase in OMC, enabling full compaction at higher moisture content
2. Increase in the plastic limit
3. Enhanced handling characteristics
4. Increased interparticle attraction leading to greater shear strength and improved bearing capacity
5. Reduced susceptibility to shrinkage and swelling
6. Lowering of the coefficient of compressibility and thus a material with
7. Lower settlement and heave characteristics.

This drying and modification occurs rapidly, usually within 24 hours and sets in motion a further chemical reaction with clayey soils, which continues in the long term and is permanent.
This reaction is **'Stabilisation'**.

Lime treatment

Pozzolanic reactions and stabilisation Clays are complex compounds. They essentially consist of silica and alumina. Once sufficient lime has been added to the soil to raise the pH to the required level, **Silica and Alumina** are dissolved from the clay and react with the lime to produce complex **Calcium Silicates** and **Aluminates** that are, in effect, **'Cement'**. (Cement manufacture is effectively a combination of lime and clay) The result is a matrix in which the clayey soil reacts **Hydraulically** with the lime which leads to **Strength Development** and **Increasing Resistance** to outside influences such as **Water, Frost** and **Loading**.

This is **Stabilisation**, which, with correct design and proper construction practice, is a **Permanent Process.**

The Stabilisation reaction commences at the same time as modification and immediately involves a significant increase in strength. This increase in strength can continue to develop over many years. Because lime stabilisation results ultimately in a '**Cemented**' matrix of clayey soil and lime, the mixture needs to be '**Cured**' (prevented from drying by sealing the surface of the layer with **Bituminous Emulsion**) If not properly cured the full cementing potential will be compromised.

Cement

Portland Cement - CEM I - BS EN 197-1:2011[15]

Compared with lime, which depends on other constituents (eg clay) for cementitious chemical reactions and strengthening to take place. Cement Treatment is more straightforward.
Cement is a **Hydraulic Binder**. A powder that hardens in the presence of water. It will bind into a Cementitious material with inert materials like sand and gravel without the addition of another material other than water.
Cement is used primarily with granular soils and aggregates and the reaction is both very quick and permanent.

Although cement may be used with Clayey Cohesive soils, it is not as effective as lime in breaking down the clay content and rendering it friable.

It can be effective with low plasticity materials such as clayey sands and gravels where there may be insufficient clay present for effective lime stabilisation.
Cement may sometimes be used as a follow-up to initial lime treatment.

Lime will render the soil friable to enable cement to be finely mixed with the modified clay to produce a more robust and stronger '**Cementitious**' material.
Cement used in this way provides additional benefits whereby lime is liberated during cement hydration and is then available for a secondary reaction with the silica dissolved from the modified clay.
Unlike the initial quick reaction with water, this reaction can continue over many months, even years. It is, however, very much the secondary reaction compared with the initial cementing.

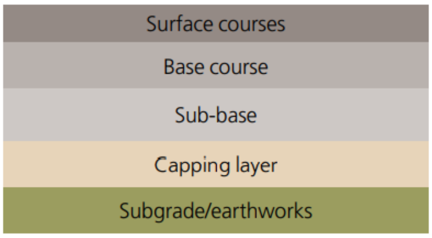

Figure 2: Road structure in common use in the UK

Lime and Cement stabilised Haul Road

Construction methods

Soil treatment using lime and cement is usually carried out using one of two basic methods of production/construction:

Stationary Plant method of production. Constituents are introduced via hoppers and silos to a mixing unit. The constituents, including water if necessary, are mixed before being discharged into a vehicle for transport to the point of use.

In Situ method of production.

Combined Spreader and Mixer in use.

Tractor Mounted Mixer and Spreader

Highways England

Highways England provide Guidance and specification for the use of Soil Treatment and Ground Stabilisation under IAN 73 (draft HD 25)[22]) and in SHW Series 600[23].

This guidance for treated **Capping Layers** and **Pavement Sub-Base**. HE's structural design for capping (thickness and surface stiffness) is included in Adherence to the requirements of these documents is intended to produce a capping layer capable of maintaining the necessary strength and durability over the design life of the pavement, typically 40 years. The production a layer that is permanent and '**stabilised**'

HE verifies that '**stabilisation**' is achieved in the field through California bearing ratio (CBR) testing on laboratory samples. These samples should achieve a soaked CBR value of not less than 15%. In addition, the samples should not exhibit a swell greater than 5 mm nor greater than 10 mm on any individual sample. This equates to an overall average expansion of 4% and an individual maximum expansion of 8%. These values are deemed acceptable for **Highway Road** use.

HE guidance for stabilised capping to IAN 73 and SHW Series 600 is found in HA 74[24], which details the necessary steps – 'using an experienced engineering geologist or geotechnical engineer'

Treated soils are also permitted for sub-base (ie the layer above the capping and below the road pavement base). The structural design for sub-base is covered by IAN 73 (draft HD 25) with specification covered in SHW Series 800[25]. Both documents refer to the hydraulically bound mixtures standardised in BS EN 14227.

Highway England emphasis for treated soil for sub-base relies on controls on:

1. The soil/aggregates, including testing for **Sulfates** and **Sulfides** with a maximum limit of **0.25% Total Potential Sulfate (TPS),** unless otherwise deemed suitable by the overseeing organisation
2. Strength after immersion in water testing to determine the long-term volumetric stability with a requirement category of 0.8.
   The specimen strength after immersion in water should not be less than 80% of the non-immersed specimen strength
   a. strength specimens on the resulting field mixture
   b. in situ density testing on the compacted layer
   c. surface stiffness testing on the finished layer.

As is to be expected, performance requirements for sub-base are more rigorous than for capping. Literature and guidance to support the HE approach for earthworks, capping and sub-base is also provided by the industry bodies:

Britpave, British Lime Association, Concrete Centre, Cementitious Slag Makers Association and UK Quality Ash Association.

Requirements for the fresh mixture.

This deals with the required characteristics of the mixture during construction. In particular:

1. Moisture content
2. Pulverisation (particle size) of the mixture after mixing
3. Immediate Bearing Capacity
4. MCV - Moisture Content Value
5. Workability period (the time available between mixing and final compaction).

These tests is used to establish what is achieved in the field mixing and compaction. These in turn will determine the strength and durability of the constructed layer.

Sulfates and Sulfides

There have been problems in the past with the treatment of soils with high sulfate/sulfide levels. These problems are now better understood, and potential performance issues can be minimised by ensuring that the following steps are followed:

1. Proper and thorough desktop analysis to flag up the potential for sulfates and sulfides
2. Extensive site investigation to identify the occurrence and degree of sulfates and sulfides
3. Correctly formulated laboratory testing using the relevant treating agents.

In all considered applications, performance over time needs to be evaluated. Swelling and Expansion issues can occur with total (acid soluble) sulfate levels as little as 0.25%. The choice of treating agent is essential to minimise the risk of sulfates and sulfides disruption.

Construction recommendations

Lime and cement treatment, and more latterly treatment involving ggbs and coal fly ash, had been used in the UK for over 30 years to produce stabilised capping layer for highways.

The construction process is described fully in HA 74 and in the case of lime involves what is known as 'two-stage mixing' where an initial mixing of the lime with the soil is carried out followed by a maturing period of at least 24 hours but up to 72 hours

Lime treatment to improve soils, generally cohesive soils, for use in earthworks fill for highways is a more recent development in the UK and is also catered for in HA 74. It is described as '**lime improvement'**. Lime improvement is essentially a drying process to change unsuitable material (wet clayey, granular or chalky soils) into acceptable soils for optimum compaction.

This is enabled, controlled and managed by adding sufficient quantities of quick lime to soil located in a cut or a dedicated mixing area in order to:

1. Raise the MCV of the soil from what might typically be less than 8 (ie very wet) and thus considerably much wetter than optimum (MCV 12–13) to within the MCV range (8–12)
2. Produce a dry soil more suitable for excavation and placement at the point of use
3. Enable appropriate compaction using a method specification in order to achieve a fill with good density and minimal air voids.

The process of lime improvement as required in HA 74 for highway application is a one-stage mixing process.

Preparation for Soil Treatment and Ground Stabilisation

This will depend on whether treatment is at source, at a dedicated mixing area or at the point of use. In all cases, the potential density of the soil after treatment and compaction will need to be established in order to determine the necessary spread rate of lime and treatment depth.

Quick lime spreading.
This usually requires the use of spreaders fitted with flotation tyres for efficient traversing of wet and thus low-bearing capacity soil.

Mixing and pulverisation
Mixing the binding agents with clays to intimately introduce the lime to the soil and reduce the lump size. This will optimise drying and may involve at least two mixing passes of purpose-made rotovators.

Grading and Levelling
Ensuring a grade profile to a slight fall to assist surface water run-off, placement of the treated soil in the fill in layers via the scraper or dozer.

Compaction and Finishing of the improved soil.
Correct selection of Compaction Equipment is essential to ensure the required Compaction levels are achieved. Rollers and Whacker Plates will achieve the required compaction levels and Finishing of the final layer to produce a sealed and 'tight' well-closed surface.

Environmental and health & safety

Both lime and cement are strong alkalis and require operatives to have adequate personal protection equipment.

Measures must be adopted to minimise airborne dust to a level that will not present a risk either within the site or to health and the environment outside the confines of the site.

These include:

1. Proper maintenance and working of the dust filters on the spreader units to minimise problems during filling of the treating agent from the delivery road tanker
2. Use of rubber skirts that reach the ground at the discharge point on the spreaders,
3. Cessation of working during windy conditions
4. Provision of water spray to damp/wet down the treating agent exposed on the ground
5. Once the treating agent is spread, prevention of plant from driving over it
6. Prompt mixing-in of the spread treating agent.

It is paramount that skin contact with cement and lime particularly should be avoided since, in the presence of water, burns can result.
It is the responsibility of Binder suppliers to provide safety data sheets to all purchasers. Specific advice on handling treating agents can be found in the Health and Safety at Work etc Act 1974[50].
Once mixed in, the possibility of treating agent leachate or run-off is unlikely because they will be promptly consumed chemically within the treated soil with correctly undertaken construction.
If leaching were to occur, it would also be quickly consumed within the surrounding ground due to reaction with the soil minerals and water.

Studies of the potential for quicklime to migrate through clay soils, for example, have found this to be negligible.

Sustainability

The main overriding advantage of employing soil treatment is its ability to be used with indigenous soils,

1. Minimising **'disposal off site'**.
2. Haulage on site and off site of unsuitable material and replacement with suitable material is significantly reduced.
3. Construction trafficking will then be limited
4. Lorry Movements through the local road network is reduced.
5. Energy consumption
6. Carbon Footprint has been shown to be significantly less for soil treatment compared with conventional practice in road construction