# AustStab Technical Note

No.1F January 2008

## Lime stabilisation practice

### 1 Introduction

Lime stabilisation of materials is one of the oldest forms of stabilisation and sometimes the least understood. The stabilisation of clay subgrades using quicklime has a long and successful history in many urban and rural regions of Australia, and is cost effective and a necessary requirement for Municipalities and State Road Authorities seeking long-life roads to minimise future maintenance costs.

The possible applications of lime stabilisation are to:

- increase subgrade stiffness for new roads (see Figure 1) or the rehabilitation of existing roads (see Figure 2),
- reduce the PI of insitu pavement and subgrade material,
- enhance volumetric stability for the top layer of select material or top of formation,
- modify subbase layers to improve stiffness of the pavement, and
- produce a temporary construction platform for civil works.

**Figure 1** Lime stabilisation of a weak subgrade for a light trafficked street in a new subdivision.

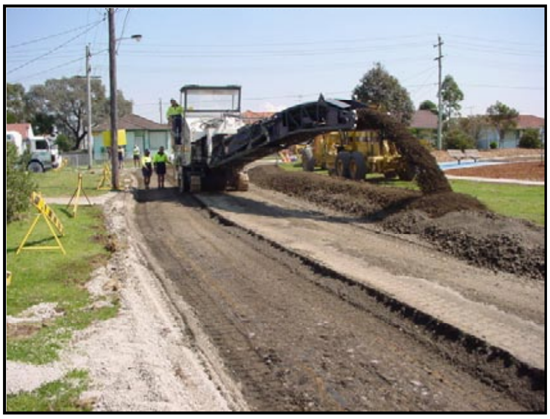

**Figure 2** The subgrade of existing local roads can be stabilised with lime using side casting techniques.

Over the last decade lime has been successfully used to minimise dust generation and reduce grader maintenance with use of lime in sufficient quantity to bind the combined pavement and subgrade materials.

**Figure 3** Unsealed road that was stabilised in 2002 with quicklime.

Limestone is also used for the treatment of acid sulphate soils and AustStab has developed a specification for supply of limestone for these problems sites.

The material type and condition of the existing pavement material will govern the application rate and construction practices. In order to understand the properties of lime and its reaction with materials, this technical note aims to highlight:

- the types of lime being used,
- the manufacture of lime,
- how does lime work with soil,
- application rate determination,
- mixing operations, and
- suppliers of lime in Australia.

### 2 Types of lime used

The word “lime” is a generic term used to describe either quicklime or hydrated lime as listed in Table 1 (but not limestone or agricultural lime). Quicklime manufactured in Australia is processed through a fluid bed, rotary or vertical shaft kilns. Problems associated with transporting lime by sea over long distances limits the importation of this binder.

The manufacture of quicklime involves the heating of excavated limestone in a lime kiln to temperatures above 900°C resulting in carbon dioxide being driven off and calcium oxide being produced (see Figure 4).

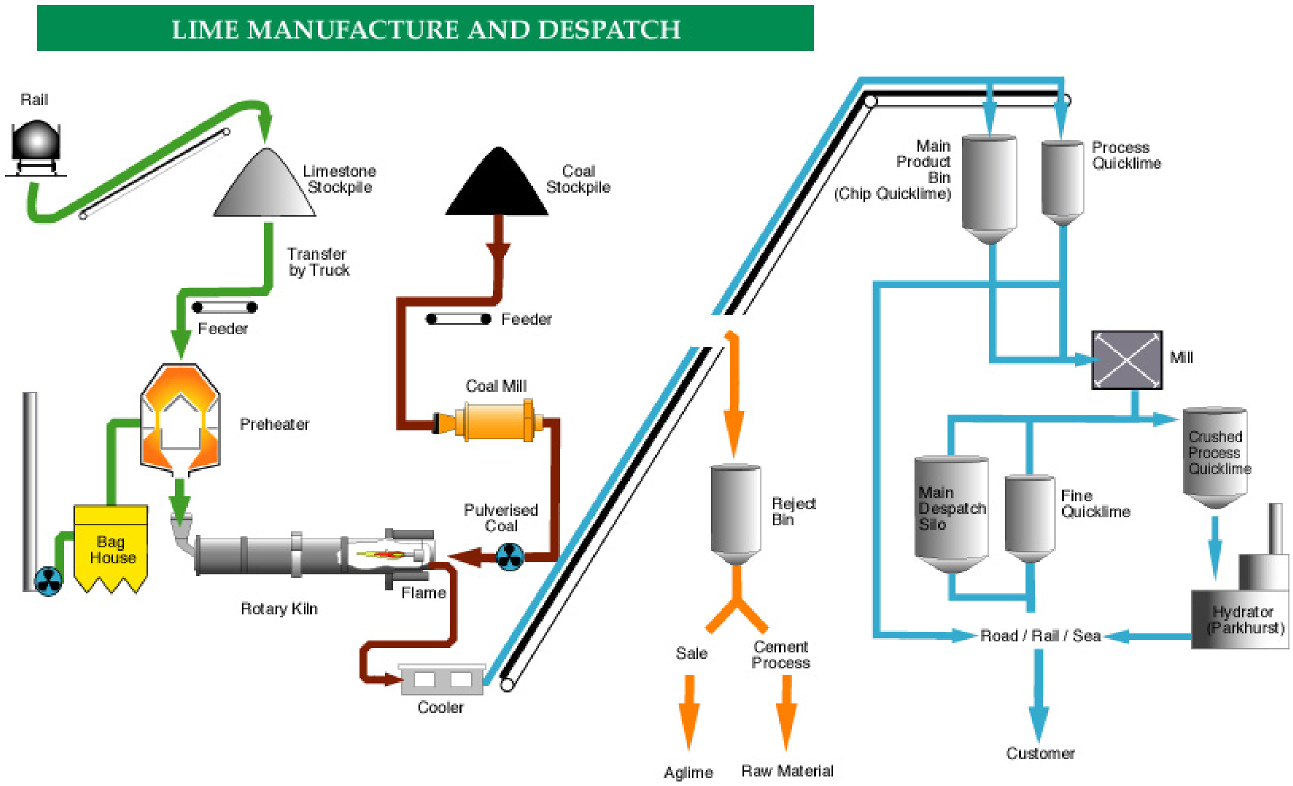


**Figure 4** Lime manufacturing plant.
(Diagram courtesy of Cement Australia Lime Products)

**Table 1** The properties of lime used for soil stabilisation.

| | Hydrated lime | Quicklime | Lime Slurry |
|---|---|---|---|
| Composition | $Ca(OH)_2$ | CaO | $Ca(OH)_2$ |
| Form | Fine powder | Granular | Slurry |
| Equiv. $Ca(OH)_2$ | 1.00 | 1.32 | 0.56-0.33 |
| Bulk density (t/m3) | 0.45-0.56 | 0.9-1.3 | 1.25 |

The chemical equation is as follows:

$$CaCO_3 \quad + \quad heat \quad \rightleftarrows \quad CaO \; + \; CO_2$$

(Calcium Carbonate) (Calcium Oxide)
(Limestone) (Quicklime)
(Heat of dissociation ~ 760 kcal/kg of CaO)

Limestone feedstocks for calcination are not pure calcium carbonate and the kilning processes have inherent inefficiencies and this means that commercial quicklime will never be 100% CaO.

Quicklime's ability to form alkaline solutions / suspensions in water is a key to its being able to modify certain soils in such a way that the end result is a benefit to road engineers.

At temperatures below 350°C, the calcium oxide component of quicklime reacts with water to produce hydrated lime (calcium hydroxide) as well as liberating heat. The equation below shows that (stoichiometrically) 56 unit weights of CaO (pure) will hydrate (be "slaked") with 18 unit weights of water. Conversely, it would need 320 litres of water to hydrate one tonne of CaO.

$$CaO + H_20 \quad \rightleftarrows \quad Ca(OH)_2 + heat$$

(Calcium Oxide) (Calcium Hydroxide)
(Quicklime) (Hydrated Lime)
(Heat of hydration ~ 272 kcal/kg CaO)

In practice, more water than the stoichiometric quantity is usually added (up to double in some instances) to allow for that which vents to the atmosphere as steam after it absorbs much of the heat of the hydration reaction.

The above process is called 'hydration' and should be strictly differentiated from the term 'slaking' which involves the production of a dispersion of $Ca(OH)_2$ in water (i.e. a milk of lime or lime putty). However, this distinction has blurred over time and the expression 'slaked lime' has come to be used as a generic term for hydrated lime, milk of lime and lime putty. In construction, when quicklime is spread onto the road surface, the application of water onto the quicklime is commonly called slaking in Australia.

The slaking process is believed to proceed via the migration of water into the pores of the lime particles. Hydration then occurs, associated with both expansion (volume increases can be over 2.5 fold) and heat liberation. This causes the particles to split, exposing fresh surfaces into which more water can migrate. The raw hydrate so produced consists largely of "fluffy" agglomerates of fine crystals. The product is essentially dry and generally contains less than 1% of unreacted water.

Quicklimes can be distinguished by their reactivity to water either by measurements of the rate of release of the heat of hydration (so called "slaking curve") or by the rate at which an aqueous suspension produces hydroxl (OH) ions. One method is to adopt the former practice at the factory, whilst some road authorities use temperature gauges to assess the completion of slaking in the field.

## 3 How does lime work?

Hydrated lime in the presence of water sets up an alkaline environment (pH>7) in which the lime will react with any Pozzolans (materials containing reactive silica and alumina) that are present in the pavement material or subgrade. This chemical process is at work in road stabilisation projects where clays provide the siliceous and aluminous components of the soil. Small quantities of organic material are likely to reduce the effectiveness of this chemical reaction.

The lime's reaction with the soil is two-fold. It firstly agglomerates fine clay particles into coarse, friable particles by a base exchange with the calcium cation (of the lime) displacing sodium or hydrogen ions with a subsequent ‘dewatering’ of the clay. Secondly, the lime raises the pH to above 12, which encourages chemical reactions that lead to the formation of calcium silicates and aluminates.

These calcium complexes initially form as a gel which coats and binds soil particles as the chemical processes move toward the crystallisation (cementitious) stage as they form hydrates. The rate of crystallisation is temperature dependent and may take many months to reach completion. This in turn correlates to a steady strength gain that can be tracked and measured using the CBR test.

The hydrate complexes are cementitious products, similar in composition to those found in cement paste, and are the end results of physio-chemical reactions with clayey soil minerals (or other Pozzolans such as fly ash) that dramatically reduce the plasticity of the soil, increase its workability and improve its compaction characteristics.

## 4 Lime reactivity

Understanding the reactive nature of quicklime leads to a better use of lime in pavement stabilisation work. Hydrated lime and quicklime are used directly in pavement stabilisation works with hydrated lime also being used as the activator for manufactured blended products that use blast furnace slags or fly ash. Quicklime is used extensively for subgrade stabilisation in heavy clays.

Quicklime is converted to hydrated lime either at the manufacturing plant or by the addition of water at site (see Figure 4). This process of slaking by adding water to the quicklime causes an exothermic reaction generating heat and steam. In the field this can sometimes be confused with dust generation.

There are factors which can effect the hydration of quicklime and these include:

- The inherent reactivity of the quicklime,
- Its mean apparent density and the distribution of its particle density,
- Its particle size distribution,
- Impurities, which if they were to form a surface layer on the quicklime particles, would inhibit the hydration process.

**Table 2** General properties of lime stabilised soils.

| Property | Description |
|---|---|
| Plasticity | The plasticity index decreases, as much as four times in some circumstances. This is due to the liquid limit decreasing and the plastic limit increasing. |
| Moisture density relationship | The result of immediate reactions between lime and the clay soil is a substantial change in the moisture density relationship. The moisture density changes reflect the new nature of the soil and are evidence of the physical property changes occurring in the soil upon lime treatment. |
| Swell potential | Soil swell potential and swelling pressures are normally significantly reduced by lime treatment. |
| Drying | Lime (particularly quicklime) aids the immediate drying of wet clay soils. This allows compaction to proceed more quickly. |
| Strength properties | Both the Unconfined Compressive Strength (UCS) and CBR increase considerably with the addition of lime. These values can be further increased by a follow up treatment of cement after the initial lime treatment. Experience has shown increases of CBR's from 3 up to 20 with lime only treatment and as high as CBR 50 with a follow up cement treatment. This gain in strength is often used in the design of pavements in order to reduce the depth of pavement material required. |
| Water resistance | The lime stabilised layer forms a water resistant barrier by impeding penetration of moisture from above and below. Thus, the layer becomes a working platform shedding water and allowing construction to proceed unaffected by weather. Experience in Victoria is that a second treatment with cement is required to achieve long-term waterproofing of the clay-stabilised layer unless the stabilised layer is covered by another pavement layer as quickly as possible. |

Loss of reactivity of lime is caused by over burning, or by holding lime in the kiln at too high a temperature for too long. When lime is calcined, the release of carbon dioxide leaves pores in the lime, creating extra surface area on which the reaction can occur. Over burning results in the collapse of these pores, reducing the ability of lime to react with water. Over burning will also result in the impurities in the lime (mainly silica, alumina and iron) forming cement clinker minerals, further reducing the calcium content available for reaction with water.

A slow reacting quicklime in terms of slaking does not necessarily mean that the lime is not pure but will require the contractor to delay the mixing of slaked quicklime.

Concentrations of sulphate ions and organic impurities may prevent the reaction of lime with the clay minerals. The current limit for the application of lime stabilisation of soils with sulphate ions is < 0.3%.

## 5 Material properties of lime stabilisation

Lime stabilisation has a significant effect on the engineering properties of the clay material. Some of these properties are detailed in Table 2 which helps the understanding of design considerations.

## 6 Laboratory testing to determine lime effectiveness

Hydrated lime is used for the assessment of lime effectiveness with soils in the laboratory. Therefore, the laboratory technician would commonly quote application rates in terms of hydrated lime. However, quicklime is the most common lime used on site and it is recommended that the quantity of quicklime is specified rather than hydrated lime (refer to Section 8 for conversion details).

The common tests carried out for lime stabilisation for roads are:

- Determination of the Available Lime Index (ie CaO or $Ca(OH)_2$ content) of the lime
- Lime demand test
- Determination of CBR
- Unconfined compressive strength
- Capillary rise and swell potential

In Australia the most common test method used for the determination of the available lime content is AS 4489.6.1[1]. The Standard expresses the amount of CaO or $Ca(OH)_2$ content in a sample of quicklime or hydrated lime respectively.

The lime demand test is becoming more common today where in the past it was used as a research tool. The aim of the lime demand test is to identify the quantity of lime to satisfy cation exchange by reaching a specific pH level (ie alkaline level of 12.4) to produce long-term reactions. Some soils may not gain strength due to a dominant ion exchange process or the presence of organics substances in the pavement material.

In Australia the following test methods are used to determine the lime demand:

- VicRoads Test Method RC 131.01 - Lime Saturation Point of a Soil (pH Method) or Main Roads Test Method Q133 Lime Demand Test.
- DMR Transport Technology - Testing Protocol for Lime Modification and Lime Stabilisation.
- RTA - T144 Determination of the Lime Saturation Point of Roadmaking Materials by the pH Method.

The determination of CBR is carried out in accordance with AS 1289.6.1.1 in either the unsoaked or soaked condition.

Unconfined compressive strength (UCS) testing is carried out by some road authorities to consider the strength of the material at 28-days. The sample is prepared using standard compaction in a nominal

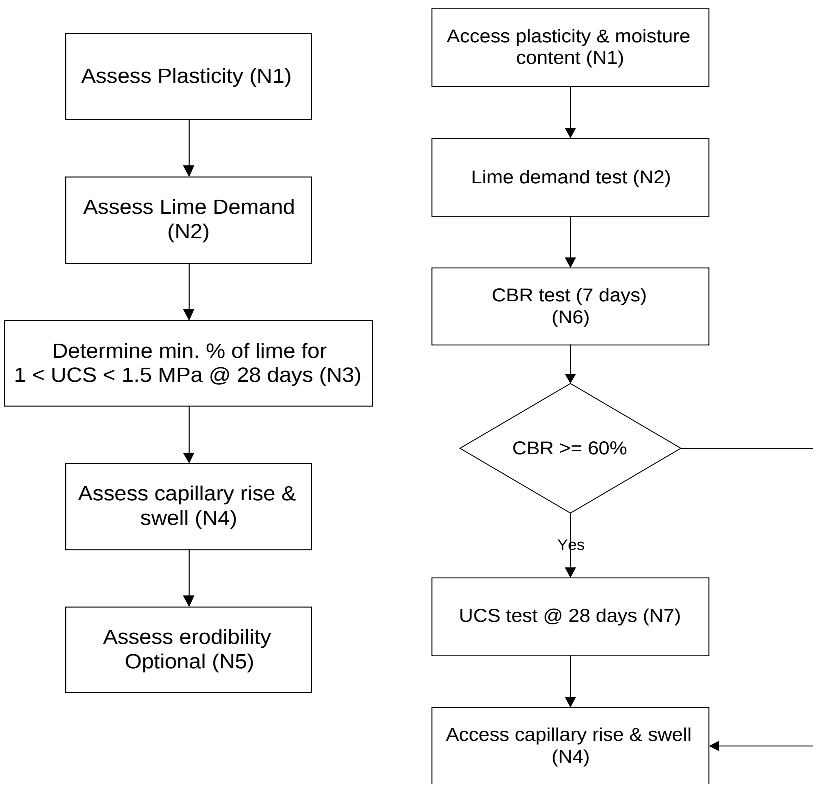


**Figure 5** The determination of the minimum lime content using the UCS and CBR approaches (Austroads, 2006).

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1 AS 4489.6.1 – Test method for limes and limestones Method 6.1: Lime index – Available lime

115 mm diameter by 105 mm high mould. Refer to the next section for more details.

It is best to use hydrated lime in the laboratory within 4 to 6 months of the manufacturing date.

## 7 Pavement material design with lime

In the late 1990s an Austroads working group developed the following laboratory protocols for the determination of lime content for soil modification and stabilisation. The binder content may be determined by the UCS (left hand flowchart) or by the CBR (right hand flowchart) approach as shown in Figure 5. Currently, either approach is used with some regions preferring one approach to another.

The following notes are used in conjunction with Figure 5.

N1 No limit is specified on PI. An initial assessment is still suggested using the Lime Demand test.

N2 The Lime Demand identifies the quantity of lime to satisfy cation exchange and long-term reactions ($L_d$). Some soils may not gain strength due to a dominant ion exchange process in the pavement material.

N3 It is suggested that lime content for testing should be at least $L_d$ + 2% and $L_d$ + 4%. Further refinement is usually carried out after the results are obtained.

N4 Capillary rise test is applicable for wet subgrades and the limit suggested is 25 mm rise in a 100 mm high sample (i.e. 25% rise limit) in 24 hours. Moisture content needs to dry back to below 'optimum' for the material to gain strength.

N5 If using lime in an area subject to poor drainage/high water tables; the designer should give some consideration to ensure erosion resistance, i.e. provide a bound material.

N6 Conduct soaked CBR test after 7 days normal curing. Should the CBR be less than 60% then the pavement is likely to behave as an unbound material. For a CBR ≥ 60% it is suggested further tests are conducted to establish the UCS of the stabilised pavement material.

It is common practice to carry out a CBR test on the parent material, and compare this result with the CBR value after stabilisation. If there is no increase in CBR strength, the designer should re-evaluate the use of lime for this subgrade material.

N7 Carry out 28-day UCS strength testing to AS 1141.51 using standard compaction and curing. Some regions use 7-day accelerated curing techniques. As a rule of thumb the 7-day UCS values represent one-half of the 28-day strength. For UCS values greater than about 1 MPa, the material is considered to be a bound layer.

Once the lime application rate has been determined, the pavement design values can be used in either empirical design charts or in a layered elastic analysis. In a layered elastic analysis the relationship between CBR and flexural modulus can sometimes be assumed to be E = 10 CBR (MPa)[2].

The VicRoads approach to the determination of the design CBR is to calculate the mean of the two lowest soaked CBR test values obtained from three lime-stabilised samples. The assigned CBR strength of the lime-stabilised material is one-third of this value with upper limits according to the design traffic (VicRoads, 2000).

## 8 Application rates

In the laboratory hydrated lime is used and the $Ca(OH)_2$ component determines its reaction with pavement materials. In the field quicklime is used extensively and slaked on site to form hydrated lime. As the available CaO in quicklime and accordingly $Ca(OH)_2$ when slaked, varies with source and manufacturer, a conversion factor to determine the field spread rate for quicklime is necessary. In summary, hydrated lime used in the laboratory is not pure and quicklime used in the field varies significantly in the Available Lime Index[3] among sources.

Many specifications refer to a lime application rate as a % or kg/m$^2$ and they do not distinguish between the use of hydrated lime or quicklime. It is recommended that specifications in Australia state a quicklime application rate based on 100% of the Available Lime Index, expressed as CaO, and include some allowance for construction tolerances. The construction tolerance is typically 0.5% as an addition to the laboratory determined hydrated lime rate.

The Available Lime Index can be expressed as either "available CaO" or "available $Ca(OH)_2$". These terms are directly related by a conversion factor for a specific sample of hydrated lime. The atomic mass of CaO is 56 and $Ca(OH)_2$ is 74 and the ratio (56/74 = 0.76) of atomic masses is used to determine the conversion factor from hydrated lime to quicklime. To clarify this further, pure 100% $Ca(OH)_2$ (hydrated lime) has an Available Lime Index of 100% of $Ca(OH)_2$.

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[2] The constant 10 varies from about 5 to 15 for various soil types.

[3] Available Lime as determined from AS 4489.6.1

The designer can determine the percentage of quicklime at 100% CaO based on the % calcium hydroxide in the hydrated lime used for testing as follows:

$Rate_{FQ} = 0.0076\ (Rate_{LH} + Rate_{TOL})\ AL_x$

Where:
$Rate_{FQ}$ = Field application rate of quicklime (%)
$Rate_{LH}$ = Hydrated lime rate percentage determined in the laboratory test program using hydrated lime from supplier X (%)
$Rate_{TOL}$ = Allowance for construction tolerance (%)
$AL_x$ = Available Lime Index for $Ca(OH)_2$ using hydrated lime in the laboratory test program from supplier X determined from AS4489.6.1 (%)

The contractor will determine the quicklime spread rate in kg/m$^2$ ($Rate_{SPREAD}$) according to the Available Lime Index of the quicklime (CaO) to be supplied, dry density of the pavement material and depth of stabilisation. This is done using the following equation:

$Rate_{SPREAD} = Rate_{FQ}\ \gamma\ T / AL_y$

Where:
$Rate_{SPREAD}$ = Field application rate of quicklime (kg/m$^2$)
$Rate_{FQ}$ = Field application rate of quicklime (%)
$AL_y$ = Available Lime Index of quicklime expressed as available CaO from supplier Y determined from AS4489.6.1 (%)
$\gamma$ = Dry density of the pavement material (kg/m$^3$)
T = Thickness of stabilised layer (m)

An example of how this may be applied in practice is shown below.

A laboratory test program using hydrated lime from supplier X established that the minimum amount of this hydrated lime required to meet the subgrade CBR improvement was 3%. The hydrated lime used in the laboratory program had an Available Lime Index of 90% (i.e. $Ca(OH)_2$ content) and the contractor proposes to use quicklime from a supplier where the Available Lime Index is 85% (ie CaO). The road authority uses 0.5% for construction tolerance, and the pavement stabilisation depth is 200 mm and the dry density of the material is 1900 kg/m$^3$. The designer would specify the following application rate of quicklime:

$Rate_{FQ} = 0.0076\ (Rate_{LH} + Rate_{TOL})\ AL_x$

$= 0.0076\ (3 + 0.5) \times 90 = 2.4\%$

The spread rate of quicklime from supplier Y would be:

$Rate_{SPREAD} = Rate_{FQ}\ \gamma\ T / AL_y$
$= 2.4 \times 1900 \times 0.2 / 85 = 10.73$ kg/m$^2$

**Table 3** The benefits and limitations of using hydrated lime or quicklime.

| Lime type | Benefits | Limitations |
|---|---|---|
| Hydrated | Does not require as much water on site. | More susceptible to dusting. |
| Quicklime | More economical as it contains about 30% more available lime<br>Greater bulk density<br>Faster drying action in wet soils | Needs more water than hydrated lime application<br>Generates steam during slaking operation |

Using AS 2706 for rounding numbers the spread rate of quicklime for this project would be 11 kg/m$^2$.

The practice in NSW, South Australia and Queensland is that specifications call for the supply of hydrated lime to have a minimum content of Ca $(OH)_2$ of 85%. Laboratory testing is carried out using approved hydrated lime and the field requirement is specified directly as a percentage of an approved lime. In these cases the laboratory determined available lime is not used as described above. In this instance, if quicklime is used in the field then the application rate should be 0.76 of the specified hydrated lime application rate.

Spread rates in the field can be verified by examining the load cell readings from calibrated spreaders or the use of trays or mats.

## 9 Lime subgrade design

The Austroads pavement design guide does not have a design approach for lime stabilisation of subgrades. However, AustStab has published an interim design approach (Vorobieff, 2003).

The design approach takes into consideration the laboratory test program and limitations between laboratory and field performance.

## 10 Use of lime in the works

The use of hydrated, quicklime or lime slurry is based on the circumstances of the construction site. Table 3 provides some guidance on the use of either quicklime or hydrated lime applications. Lime slurries are available and only competitive in special applications.

The completion of the slaking of quicklime may be determined in the field using one of the following simple approaches:

- Using a glove it can be noted that the quicklime has been slaked when the lime becomes a fine powder.
- No steam occurs after the quicklime is sprayed with water.
- There is no further temperature rise (use a surface thermometer).

In some instances vehicles found to have driven over quicklime should refer to AustStab for some guidance to clean the vehicle (refer to www.auststab.com.au/pdf/AustStab_CV_V1.pdf ).

**Figure 6** Slaking of lime produces steam for a short period and appropriate traffic control measures should be considered.

## 11 Mixing

Similar to cement and bitumen stabilisation, adequate pulverisation and mixing are essential to achieve satisfactory results in lime stabilisation. Whilst many soils may only require one-pass mixing, heavier more plastic soils require multiple pass mixing. AustStab always recommends that the maximum spreading of hydrated lime is set at 20 kg/m$^2$ to ensure that adequate mixing and distribution of the lime takes place inside the mixing hood. For quicklime the maximum spread rate is 12 to 15 kg/m$^2$ to ensure that all the quicklime is slaked.

A typical mixing speed for a stabiliser for lime stabilisation is 10 to 15 m/minute and as the soil becomes more plastic the speed may need to be reduced. The contractor will use a stabiliser with long apertures from the drum to ensure efficient mixing. Some machines have rotors with small apertures that make it a less effective mixer.

The following guidelines are given regarding one or multi-pass mixing operations.

One-pass One-pass mixing operations are applicable for low application rates. Water may be applied in the mixing hood to optimise compaction. In addition and prior to mixing, the soil may be ripped to enhance drying. After the first pass the mixed material may be lightly rolled to allow the road to be trafficked and to minimise the risk of water penetrating the subgrade if rain may occur between mixing operations.

Two-pass The two-pass mixing process consists of a preliminary mixing stage with curing for a period ranging from about 24 to 72 hours. Where the lime application rates are in excess of 4% sometimes half the lime is applied in the first pass with the remaining mixed in the second pass. The initial pass is used to distribute the lime throughout the soil and thereby allow the mellowing operation to take place, followed by some cation exchange and some pozzolanic reactivity.

A third pass of mixing may be required for some plastic soils.

**Figure 7** The first mixing pass with heavy clays will produce material with large pieces of clay.

**Figure 8** Subsequent mixing passes with heavy clays will produce finer material suitable for compaction.

All lime stabilisation works should be carried out with specialised equipment. There are a range of experienced stabilisation contractors available to carry out this work, either in the form of a full stabilisation contract or by providing experience and specialised plant to enable road contractors to use their own equipment in conjunction with the specialised stabilisation equipment. Contact details for these contractors are available from AustStab or on the AustStab website.

## 12 Costs

About 25% to 50% of the cost of a project is in the supply of the binder, and therefore, the selection of the binder for large projects becomes a primary concern for the road owner. However, for subgrade stabilisation the binder and operational costs are usually less than that which would be required to remove and dispose the subgrade material and there is a reduction in the base pavement materials layer thickness due to the increase in subgrade support. This may also be beneficial if the surface level needs to be minimised in certain locations.

Typical costs of various options for subgrade improvement, excluding base course material and wearing surface, are:

*Option 1*: **Excavate, send to waste and import materials**.
Excavation costs \$10 to \$15/$m^3$
Subgrade preparation & import material \$35 to \$45/$m^3$

*Option 2*: **Insitu stabilise subgrade**
Insitu lime stabilise subgrade \$25 to \$30/$m^3$

In the above exercise the saving in construction costs are about 50% compared to traditional rehabilitation solutions, and the improved subgrade is less likely to deteriorate due to future wet weather.

## 13 Who supplies lime to road stabilisation industry?

Table 4 lists the companies supplying lime for road stabilisation.

**Table 4** Lime suppliers for road stabilisation.

| Company | Location of plant |
|---|---|
| Adelaide Brighton | Angaston, SA<br>Mataranka, NT<br>Dongara & Munster, WA |
| Blue Circle Southern Cement | Maralun, NSW |
| Hyrock | Charbon, NSW |
| Unimin Australia<br>. | Tamaree, via Gympie (QLD)<br>Marmor, via Rockhampton (QLD)<br>Attunga, via Tamworth (NSW)<br>Lilydale (VIC)<br>Traralgon (VIC)<br>Mole Creek (Tas) |
| Cement Australia | Rockhampton & Gladstone, QLD |

## 14 References


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VicRoads (2000) *Lime Stabilised subgrade materials – Lime content and assignment of CBR and percent swell* Codes of Practice RC 500.23, GeoPave, VicRoads, Kew, Victoria.

Vorobieff, G and Murphy, G (2003) *A New Approach to Pavement Design Using Lime Stabilised Subgrades* Proceedings of 21st ARRB Conference, Cairns, QLD.


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**Lime suppliers:**

| | |
|---|---|
| Blue Circle Southern Cement | www.bluecirclesouthern.com.au |
| Cement Australia | www.cemaust.com.au |
| Cockburn Cement | www.adbri.com.au |
| Hyrock | www.hyrock.com.au |
| Unimin Australia | www.unimin.com.au |

**Contractors experienced in lime stabilisation:**

| | |
|---|---|
| Andrew Walters Construction | www.awconstructions.com.au |
| Downer EDI Works | www.downerediworks.com.au |
| Roadtek | www.mainroads.qld.gov.au |
| Stabilime Distributors | www.stabil-lime.com.au |
| Stabilised Pavement of Australia | www.stabilisedpavements.com |

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QCL Group (1999) *The manufacture of lime* QCL Group Technical Note, Brisbane, QLD.





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