Guideline

Structural design procedure of pavements on lime stabilised subgrades

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Queensland Government

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Contents

1 Introduction

Subgrade stabilisation can be defined as a means of enhancing soil strength and stiffness properties by adding a hydraulic binder (substances which harden to a water-resistant building material following the addition of water) such as lime. Correctly applied, stabilisation can also decrease the subgrade's water sensitivity and volume changes during wet / dry cycles.

The design procedures in this guideline are intended for soil that is to be stabilised with lime. These procedures do not apply where drying or soil modification is the overall goal; however, modification should be applied with caution, as it can increase soil permeability, and seriously compromise pavement life.

Lime is the most popular subgrade stabilisation additive because of its slow strength gain characteristics. Transport and Main Roads' established testing protocol and mix design procedure is available and should be applied to determine the optimum amount of lime to stabilise the subgrade. Ideally, the depth of subgrade to be stabilised should be 300 mm, with a minimum of 250 mm.

2 Purpose

The aim of this guideline is to specify a rational structural design procedure to be applied when designing a lime stabilised subgrade as a permanent structural pavement layer.

3 Referenced documents

This guideline should be read in conjunction with the following documents listed in Table 3.

Table 3 – Referenced documents

Reference	Title
MRS07A	Specification (Measurement) *Insitu stabilised subgrades using quicklime or hydrated lime*
MRTS07A	Technical Specification *Insitu stabilised subgrades using quicklime or hydrated lime*
MRS07A.1 Annexure	Specification (Measurement) Annexure *Insitu stabilised subgrades using quicklime or hydrated lime*
MRTS07A.1 Annexure	Technical Specification Annexure *Insitu stabilised subgrades using quicklime or hydrated lime*
Pavement Design Supplement	*Supplement* to *Part 2: Pavement Structural Design* of the Austroads *Guide to Pavement Technology*.
	Pavement Rehabilitation Manual
Materials Testing Manual	*Materials Testing Manual Part 2 – Application, Section 7 – Testing of materials for lime stabilisation*

4 Information

Lime has a number of effects when added to soil. These effects can be categorised as soil drying, soil modification and soil stabilisation:

- **Soil drying** is a rapid decrease in soil moisture content due to the chemical reaction between water and lime following the addition of lime into a moist soil.
- **Modification** effects include reduction in soil plasticity, improved compactability, reduction of the soil's capacity to swell and shrink and improved strength and stability after compaction. These effects generally happen within a short time period, typically 1–48 hours after the introduction of lime. The effects are more pronounced in soils with sizable clay content. The effects may not be permanent, and significantly increased permeability of the subgrade can jeopardise pavement life.
- **Lime stabilisation** can take place in soils containing a suitable amount of clay with the appropriate mineralogy to produce long-term permanent strength gains. Effective lime stabilisation requires additional lime, and a longer time period of 'curing'.

  A soil that is lime stabilised benefits initially from soil drying and modification, but the additional lime delivers a proven permanent reduction in shrinkage, swelling and soil plasticity which can resist the effects of prolonged soaking.

5 Field results and analysis

Transport and Main Roads has tested several Queensland projects with lime stabilised subgrades. This involved conducting Unconfined Compressive Strength (UCS) and Capillary Rise tests on cores extracted from the stabilised subgrades.

These projects included:

- Cunningham Highway (17B), Freestone Creek–'8-mile' intersection, constructed 1997.
- Warrego Highway (18B) Toowoomba–Dalby, constructed 2009
- Leichhardt Highway (26C) Murri-Murri section, constructed 2002.

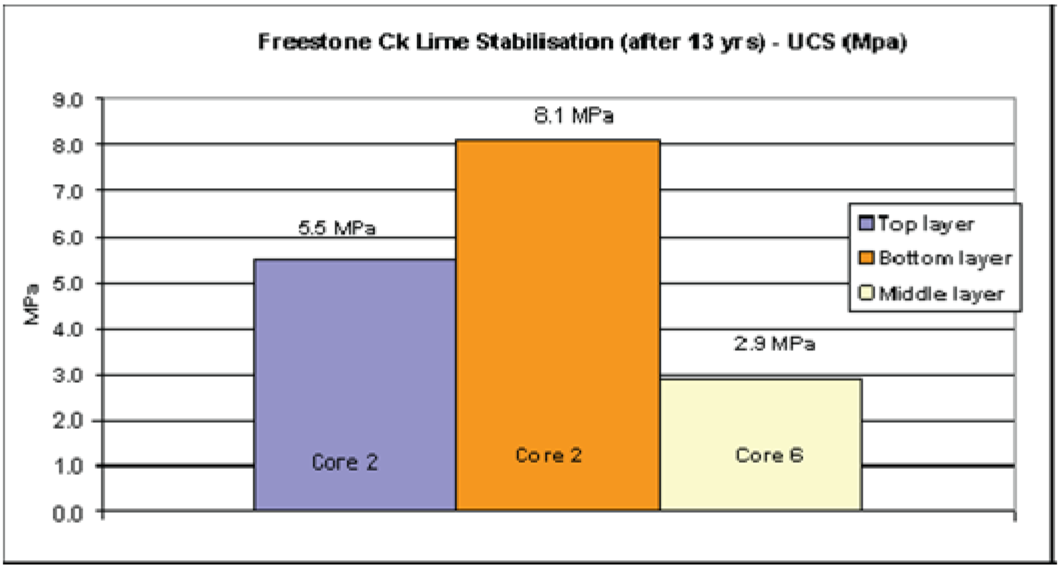
5.1 Cunningham Highway (17B)

The Cunningham Highway site has the following characteristics:

- subgrade stabilised for widening existing road
- 300 mm of granular pavement in the widening
- constructed 1997
- wearing surface was 100 mm asphalt
- after eight years (2005), a further 100 mm asphalt
- pavement performing very well.

Six cores from the subgrade were extracted in 2012 (after 15 years). Three of these were successfully tested to determine UCS as shown in Figure 5.1:

Figure 5.1 – Freestone Creek lime stabilisation (after 15 years) – UCS (MPa)

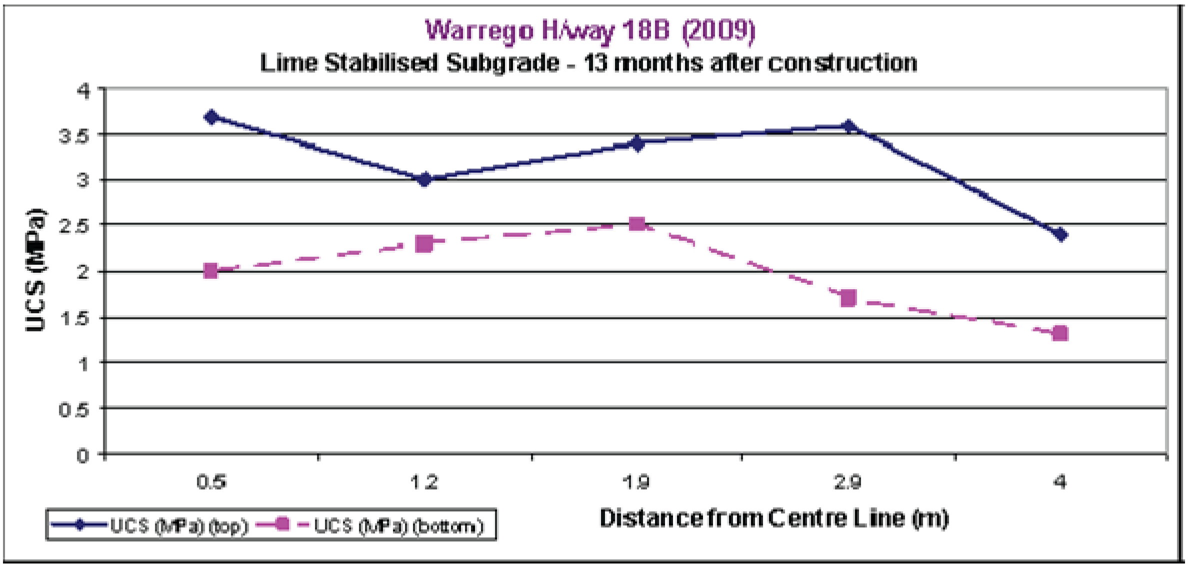


Note: All results are above 2.50 MPa.

5.2 Warrego Highway (18B) Toowoomba–Dalby

The results of cores taken from one trench on the Warrego Highway (18B) Toowoomba–Dalby, 13 months after construction are shown in Figure 5.2:

Figure 5.2 – Warrego Highway 18B lime stabilised subgrade – 13 months after construction

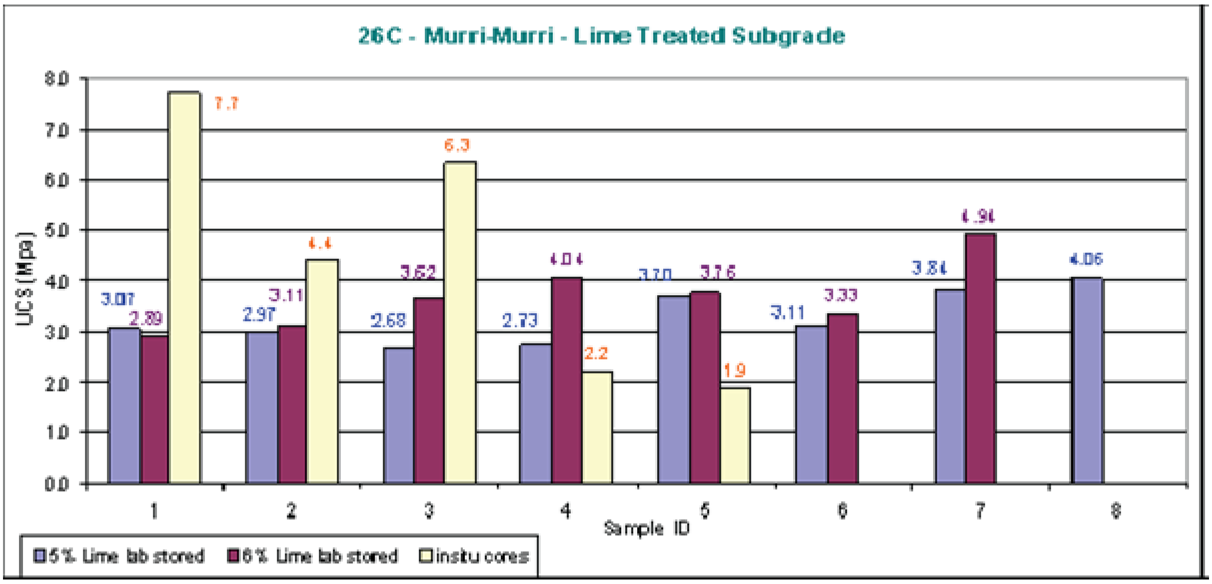


Note: All but one of the above results are above 1.50 MPa.

5.3 Leichhardt Highway (26C) Murri-Murri

Results were taken from cores taken insitu and also from stored cores left over from the mix design stage of the construction project. The stored cores either had 5 or 6% lime added. See Figure 5.3.

Figure 5.3 – 26C – Murri-Murri – lime treated subgrade



For the 20 cores tested, all results were above 2.0 MPa except for one. It was noted that the exception had the largest length to diameter ration of all cores.

6 Design parameters

Lime stabilisation can be considered when there is sufficient clay for the lime to react. This normally requires a Plastic Index (PI) equal or above 10%, Stabilisation of clayey material with lime generally results in pavements that have a much lower cracking potential than if the subgrade has been cement stabilised. Lime stabilised subgrades are also more durable as the effect of the clay has been reduced, rather than masked, as is the case with cement stabilisation.

The dosage rates of lime for construction will be the greatest of the lime demand test results and the lime required to achieve the target UCS of 1.5 MPa at 28 days. The range of UCSs should be between 1.0–2.0 MPa with a target UCS of 1.50 MPa (28 days) to make the lime stabilisation successful.

Based on the new information, the current Austroads design methodology considerably undervalues the structural strength of lime stabilised subgrades. The Transport and Main Roads design procedure to exploit more of the subgrade strength as a structural layer is fully explained in the following section. Note that this is still a conservative approach.

7 Structural design guidelines for pavements incorporating lime stabilised subgrade layer

7.1 Requirements for use of lime stabilised subgrade:

When lime stabilised subgrade is used:

- there shall be only one layer of lime stabilised subgrade; multiple layers of lime stabilised subgrade shall not be constructed. Multiple thin layers are significantly more prone to fatigue as compared to a single monolithic layer
- the thickness of the lime stabilised subgrade layer shall desirably be 300 mm with a minimum of 250 mm.

7.2 Lime stabilised subgrade

Appropriate uses for stabilisation of clay subgrades using lime include the following:

- where the materials to be stabilised are suitable (for example, have enough suitable pozzolans, the amount of organic carbon is not excessive) and the dosage rate required is acceptable, and
- for treatment of subgrades under existing pavements, only where removal and replacement of the existing pavement can be tolerated (for example, in terms of traffic management, cost).

Lime stabilisation can be adversely affected by any one of the following:

- a lack of suitable pozzolans
- the presence of excessive organic carbon
- the presence of soluble sulphates
- the presence of highly weathered soils with high ferric-oxide levels (for example, some lateritic soils).

The latter can actually interfere with the pozzolanic reaction.

Stabilisation of unsuitable soils can lead to serious problems which, at times, can only be rectified by removing and replacing the treated materials. If such problems occur, the overlying pavement layers must be removed. This can be a very expensive consequence of simply not undertaking adequate and appropriate testing.

It is crucial that adequate testing is conducted before the decision is made to stabilise a subgrade with lime. Advice should be sought from the Senior Engineer (Pavement Rehabilitation) to ascertain appropriate testing protocols. **Transport and Main Roads' protocol should be applied.**

Reference should also be made to Transport and Main Roads' *Pavement Rehabilitation Manual* and Technical Standard MRTS07A *Insitu stabilised subgrades using quicklime or hydrated lime*.

7.3 Characterisation for design

Stabilised subgrade materials are considered to behave as unbound soil materials with improved stiffness.

For the purposes of mechanistic design, they shall be modelled with the following properties:

- be cross-anisotropic (with a degree of anisotropy of 2)
- have a Poisson's Ratio of 0.45
- be sublayered, and
- have a maximum potential modulus of the top sub-layer of the lime stabilised subgrade layer of 200 MPa.

7.4 Design

The steps for pavement design are best illustrated through an example as shown in the steps following:

Step 1 Develop a trial design by selecting a thickness for the stabilised layer of 300 mm, as shown in Table 7.4(a).

Table 7.4(a) – Trial pavement for the example

Material type	Thickness (mm)
Sprayed seal surfacing[1]	–
Unbound granular material Type 2.1 E_{max}=350 MPa	200 mm for start (for this example)
Min. thickness of the lime stabilised subgrade layer	For this example, 300 mm
Design subgrade CBR = 3% (for this example)	Semi-infinite

Note[1] Surfacing is sprayed seal

Characterisation of the trial pavement shall be obtained using steps 2–5. The allowable loading can be calculated using CIRCLY as shown in Step 5.

Step 2 Characterisation of the subgrade below the layer of subgrade stabilised with lime

For this example:

Unstabilised Subgrade CBR 3%, Vertical modulus E_v = 30 MPa and EH= 15 MPa Poission's Ratio = 0.45, Shear Modulus = 20.7 MPa.

Step 3 Characterisation of the subgrade layer stabilised with lime

The maximum potential modulus of the top sub--layer of the subgrade layer stabilised with lime is assumed to be 200 MPa (presumptive); hence

E_v = 200 MPa and Eh= 100 MPa, Poission's Ratio = 0.45, Shear Modulus = 137.9 MPa.

Step 4 Other remaining lime stabilised subgrade sub-layers

Divide the total depth of the lime stabilised subgrade layer thickness into five equi-thick sub-layers, each of this in this case is 300 / 5 = 60 mm.

Calculate the ratio of moduli of adjacent layers:

R = (E_{top} of stabilised subgrade layer / E_{top} of unstabilised subgrade layer) $^{1/5}$ = (200 / 30) $^{1/5}$ = 1.46

Table 7.4(b) summarises the values.

Table 7.4(b) – Modulus of stabilised subgrade sub-layers

Material type	Thickness (mm)	Vertical elastic modulus (MPa)	Poissons's Ratio	Shear modulus (MPa)
Lime stabilised subgrade	60	200	0.45	137.9
	60	137	0.45	94.5
	60	94	0.45	64.8
	60	64	0.45	44.1
	60	44	0.45	30.3
Subgrade	Semi-infinite	30	0.45	20.7

Note: No automatic sub-layering should be used in CIRCLY for this stabilised layer

Step 5 Moduli of the unbound granular base sublayers above the lime stabilised subgrade layer

The minimum granular material required above the lime stabilised subgrade layer shall be modelled and sub-layered as per Austroads' *Guide to Pavement Technology* Part 2.

Divide the total depth of the unbound granular layer thickness into five equi-thick sub-layers, each of them in this case is 200 mm / 5 = 40 mm.

Calculate the ratio of moduli of adjacent layers:

$R = (E_{\text{top of granular layer}} / E_{\text{lime stabilised subgrade}})^{1/5} = (350 / 200)^{1/5} = 1.12$

Table 7.4(c) summarises the values:

Table 7.4(c) – Modulus of granular sub layers

Material type	Thickness (mm)	Vertical elastic modulus (MPa)	Poissons's Ratio	Shear modulus (MPa)
Unbound granular base	40	350	0.35	259.3
	40	315	0.35	233.3
	40	281	0.35	208.1
	40	251	0.35	185.9
	40	224	0.35	165.9
Lime stabilised subgrade	300 (been sub-layered)	200	0.35	137.9

Step 6 Calculate the allowable loading

Using CIRCLY7 based on these thickness and moduli (for this example, assuming ESA / HVAG = 0.83 and desired project reliability of 90%). calculate the allowable loading.

In this case the allowable loading from CIRCLY7 is = 1.1E6 NDT. Or 9.1E5 ESAs.

Step 7 Iterate to arrive at a final design as required

If required iterate through steps 1–5 to determine a final design (for example, by varying the thickness of the granular layer).

Independent of this analysis, the minimum base thickness above the lime stabilised subgrade should be as shown as follows in Table 7.4(d).

Table 7.4(d) – Minimum base thickness above lime stabilised subgrade

Average daily ESA in design year of opening	Minimum unbound granular thickness above lime stabilised subgrade (mm)
<100	150
100–1000	200
>1000	250