DELIVERING FOR QUEENSLAND

Guideline

Structural design procedure for lime stabilised subgrade

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Queensland Government

Feedback

Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Contents

1 Introduction

This guideline details the structural design procedure for the insitu stabilisation of existing subgrade materials using a lime stabilising agent (that is, hydrated lime or quicklime) to create a strong, resilient, and homogeneous subgrade layer.

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 designed and constructed, a lime stabilised subgrade layer can reduce the subgrade's moisture sensitivity, reduce volumetric changes caused by wet / dry cycles, and provide a strong anvil (or support) to the overlying pavement layers.

The Department of Transport and Main Roads' materials testing and mix design procedure should be applied to determine the optimum amount of lime required to successfully stabilise the subgrade soils.

Ideally, the thickness of the insitu lime stabilised subgrade should be between 300 mm to 350 mm.

2 Purpose

The aim of this guideline is to detail the structural design procedure when adopting a lime stabilised subgrade as a permanent 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
-	*Pavement Investigation and Analysis*, Transport and Main Roads (see https://www.tmr.qld.gov.au/business-industry/technical-standards-publications/pavements-guidelines)
-	*Materials Testing Manual*, Transport and Main Roads Refer to Section 7 of *Materials Testing Manual*, Part 2 (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Materials-testing-manual

Reference	Title
MRTS07A	*Insitu Stabilised Subgrades using Quicklime or Hydrated Lime* (inclusive of MRS07A, MRTS07A.1 and MRS07A.1), Transport and Main Roads (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Specifications/5-Pavements-Subgrade-and-Surfacing#MRTS07A
Pavement Design Supplement	*Supplement to Part 2: Pavement Structural Design of the Austroads Guide to Pavement Technology*, Transport and Main Roads *(*see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Pavement-design-supplement)
Pavement Rehabilitation Manual	*Pavement Rehabilitation Manual*, Transport and Main Roads (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Pavement-Rehabilitation-Manual

4 Background

4.1 Stabilisation

When mixed with suitable soils in the correct proportions (or content), lime has a number of effects which can be categorised as soil drying, modification and stabilisation:

- **Soil drying** is a decrease in soil moisture content due to the chemical reaction between water and lime following the addition of lime into a moist soil.
- **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, (typically within 48 hours after the introduction of lime). The effects are more pronounced in soils with higher clay contents. However, the effects may not be permanent and can significantly increase the permeability of the soil which may jeopardise the pavement's long-term performance.
- **Soil stabilisation** can take place in soils containing a suitable amount of clay with the appropriate mineralogy to produce long-term permanent strength gains. Effective soil stabilisation requires additional lime, and a longer curing period. Soil stabilisation benefits initially from soil drying and modification, but the additional lime provides a permanent reduction in shrinkage, swelling and soil plasticity which can mitigate the effects of prolonged soaking.

The design procedure detailed in this guideline is intended for clay soils that are stabilised with lime (that is, **soil stabilisation**). This design procedure does not apply where soil drying or modification is the objective. Soil drying or modification should be applied with caution, as it can increase soil permeability, and compromise the pavement's long-term performance.

4.2 Benefits

Subgrade stabilisation with lime provides a number of benefits to the host soil's properties, including:

- greater durability as the effect of the plasticity is reduced
- improved strength
- less susceptible to rutting / deformation
- reduced permeability and moisture ingress potential
- reduced water sensitivity
- reduced volumetric changes caused by wetting and drying cycles, and
- generally, less cracking potential than cement (GP or GB) stabilised materials.

4.3 Design and constructability advantages

Subgrade stabilisation with lime has a number of design and constructability advantages, including:

- improved pavement support which will reduce the overlying pavement layer thickness, thus lowering material and cartage costs
- minimise remove and replacement of weak (or soft) existing (or natural) subgrade materials
- recycling and reuse of existing subgrade materials, thus reducing excavation, cartage and wastage costs
- longer working times than cement (GP or GB) stabilisation

- permits a two-stage process when incorporating the lime stabilising agent:
  - Day 1: spread and incorporate up to two-thirds of the lime stabilising agent and ameliorate overnight, then
  - Day 2: spread and incorporate the remaining lime stabilising agent component.

    This two-stage process has been successful in the treatment of subgrade materials with high plasticity and high moisture contents (near or above their optimum moisture content).
- ability to undertake a 'deep' insitu stabilisation subgrade treatment by incorporating lime beneath the subgrade layer to improve the strength of the anvil allowing for the construction of the lime stabilised subgrade layer.

4.4 Mix design

Insitu lime stabilisation of a subgrade will typically involve the mixing of existing (or natural) clay materials. Effective soil stabilisation requires determining the optimal lime additive content to achieve the desired long-term performance.

It is imperative that adequate material sampling and laboratory testing is undertaken prior to the commencement of construction works to confirm the suitability and mix design for lime stabilisation. During the pavement investigation, the designer needs to consider the feasibility of lime stabilised subgrade and ensure that sufficient samples of the pavement and subgrade materials are collected for laboratory mix designs.

For testing purposes, the insitu subgrade materials that are sampled need to representative of what will be encountered during the insitu stabilisation process. For example, if a 300 mm thick lime stabilised subgrade layer is to be stabilised at -400 mm to -700 mm below finished surface level, then subgrade materials sampled and tested must reflect what will be encountered at -400 mm to -700 mm. Any grade-line adjustments will need to be duly considered.

Particle size distribution and Atterbergs laboratory testing is then undertaken on the sampled subgrade materials. Lime stabilisation can be considered when the insitu materials have enough clay with the appropriate mineralogy for the lime to react with. This typically requires the insitu subgrade materials to have the following properties:

- Plasticity Index (PI) ≥ 20 (in some cases, insitu materials with a PI between 10–20% may be suitable), and
- ≥ 25% passing the 0.075 mm sieve.

After classifying the insitu materials, lime demand and unconfined compressive strength (UCS) testing is undertaken to determine the mix design (also referred to as the design additive content by mass (%)). The design additive content of the lime will be the greater of the lime demand test results and the lime required to achieve a target UCS range between 1.0–2.0 MPa at 28 days. Ideally and if possible, a target UCS range between 1.0-1.5 MPa at 28 days would further alleviate any cracking potential.

Refer to Guideline *Pavement Investigation and Analysis* (see https://www.tmr.qld.gov.au/business-industry/technical-standards-publications/pavements-guidelines) and Section 7 of *Materials Testing Manual*, Part 2 (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Materials-testing-manual) for further details on material sampling, laboratory testing and mix design.

4.5 Material suitability

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

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

Stabilisation of unsuitable soils can lead to serious performance issues 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 materials laboratory testing.

5 Historical field testing and analysis

The department has completed field testing on several historical projects in Queensland which have lime stabilised subgrades. This involved undertaking Unconfined Compressive Strength (UCS) and Capillary Rise tests on cores extracted from constructed stabilised subgrades.

These projects included:

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

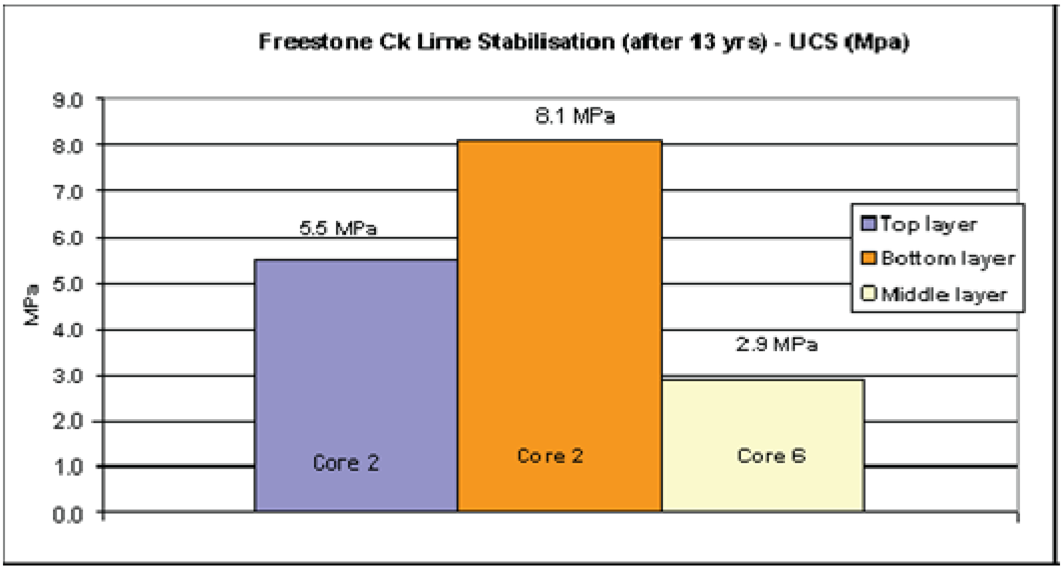
5.1 Cunningham Highway (17B), Freestone Creek / 8-mile intersection

The Cunningham Highway site has the following characteristics:

- subgrade stabilised for the widening of the existing road
- 300 mm of granular pavement in the widening
- constructed 1997
- wearing surface was 100 mm asphalt
- after 8 years (2005), an additional 100 mm asphalt was placed, and
- pavement performed very well.

Six cores were extracted from the lime stabilised subgrade in 2012 (15 years after completion of construction). Three of these cores were successfully tested to determine their UCS with all 3 results exceeding 2.5 MPa. Refer to Figure 5.1.

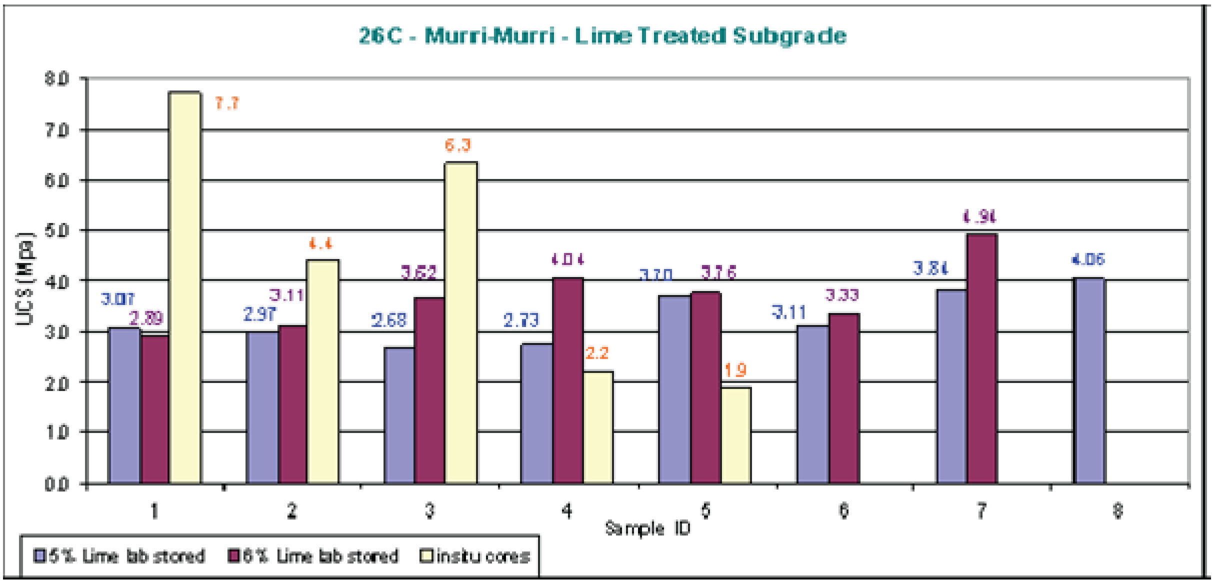
Figure 5.1 – Freestone Creek / 8-mile intersection lime stabilisation UCS results



5.2 Leichhardt Highway (26C) Murri-Murri

UCS testing was undertaken on cores taken from the constructed pavement and from stored cores left over from the laboratory mix design The stored cores either had 5% or 6% lime added. For the 20 cores tested, all results exceeded 2 MPa except for one core which was noted to have the largest length to diameter ration of all core samples. Refer to Figure 5.2.

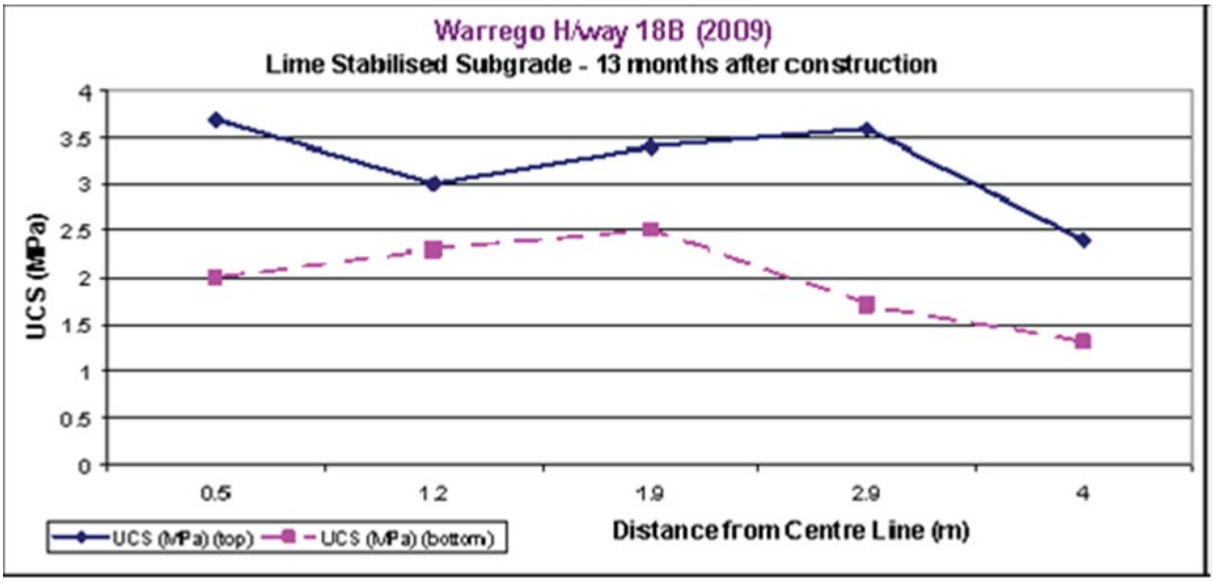
Figure 5.2 – Murri-Murri lime stabilisation UCS results



5.3 Warrego Highway (18B) Toowoomba to Dalby

UCS testing was undertaken on core samples taken from a pavement investigation trench 13 months after completion of construction. All but one of the results is above 1.5 MPa. Refer to Figure 5.3.

Figure 5.3 – Warrego Highway lime stabilisation UCS results



6 Structural design

6.1 Thickness

Where a lime stabilised subgrade is used:

- The preferred thickness of the lime stabilised subgrade layer shall be 300 to 350 mm.
- There shall be only one monolithic layer of lime stabilised subgrade. Multiple layers of lime stabilised subgrade shall not be constructed for road pavements as multiple thin layers are significantly more prone to fatigue compared to a single monolithic layer. Multiple lime stabilised layers have been constructed to help support structures (for example, silos); however, this approach is not applicable for road pavements and this guideline.

Reference should be made to Transport and Main Roads' *Pavement Rehabilitation Manual* (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Pavement-Rehabilitation-Manual) and Technical Specification MRTS07A *Insitu Stabilised Subgrades using Quicklime or Hydrated Lime* (see www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Specifications/5-Pavements-Subgrade-and-Surfacing#MRTS07A) for construction requirements.

6.2 Structural design parameters

Based on the department’s field research, refinement of the mix design methodology and improvements to construction process details in MRTS07A *Insitu stabilised subgrades using quicklime or hydrated lime*, the current Austroads design methodology for lime stabilised subgrades underestimates the structural strength and benefit provided to the pavement system. The department has developed a structural design procedure to exploit the structural benefit provided from a lime stabilised subgrade.

Like lightly bound materials, lime stabilised subgrades target a UCS strength range of 1.0-2.0 MPa. Further to this, the behaviour of lime stabilised subgrades can be considered similar to a lightly bound improved layer.

The lightly bound structural design approach outlined in the *Pavement Design Supplement* (see https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Pavement-design-supplement) shows that for a lightly bound improved layer manufactured with a lower quality granular material, a vertical modulus of 210 MPa applies, regardless of the thickness and modulus of the overlaying materials and the underlying support conditions.

Therefore, for the purposes of mechanistic-empirical design, lime stabilised subgrade can be modelled with the following parameters shown in Table 6.2.

Table 6.2 – Design parameters of lime stabilised subgrade

Design modulus	Poisson's ratio	Degree of anisotropy	Sub-layering
210 MPa	0.45	2	NOT sub-layered[1]

Note:

[1] Apply a single vertical design modulus for the full depth of the lime stabilised subgrade layer.

In designing the pavement thickness, permanent deformation is assessed using the vertical compressive strain at the top of the underlying untreated subgrade, rather than at the top of the lime stabilised layer.

6.3 Minimum overlying pavement thickness

The recommended minimum overlying pavement thickness is shown in Table 6.3.

Table 6.3 – Minimum pavement thickness overlying lime stabilised subgrade

Average daily ESA in design year of opening	Minimum pavement thickness overlying lime stabilised subgrade (mm)
< 100	150
100 to 1000	200
> 1000	250