

# A NEW APPROACH TO PAVEMENT DESIGN USING LIME STABILISED SUBGRADES

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## ABSTRACT

Lime stabilisation of clay subgrades has a long and successful history in many urban regions of Australia, and this construction technique is cost effective and a necessary requirement for road authorities seeking long-life roads to minimise future maintenance costs.

Initially this process began as a construction expedient but is now used to reduce the depth of the overlying pavement layer. This process is applicable for new subdivisional work and existing roads for both light and heavy traffic levels.

One of the challenges for pavement engineers is to establish a rational design approach to determine the stabilised layer, and subbase and base thickness layers. In addition, the material stiffness design assumption should be backed up by some laboratory testing to confirm the potential to reach the material stiffness in the field.

This paper outlines various design procedures that have been known to be used and some of the shortcomings in their approach to specify suitable material properties and layer thickness. Each procedure provides a slightly different solution.

The aim of this paper is to propose a new design approach using either a mechanistic or empirical pavement analysis methods to find the pavement thickness and subgrade properties. The technique uses a combination of pavement analysis rules that are documented in the new interim Austroads pavement design guide and overseas studies.

This new approach should be challenged by practitioners in order to refine a design process to meet the desired performance requirements and for engineers to obtain consistent results to allow road authorities to evaluate design tenders without prejudice.

## 1 INTRODUCTION

The interim design method outlined in this paper is for review by engineers and to provide refinements or limitations based on their experience. The method is based on a combination of previous work by VicRoads, consultants, other Associations, presented in technical publications and at seminars [Vido, 2002]. It is noted that lime stabilisation of subgrades has been well understood for more than 30 years (Ingles, 1972) and the aim of the paper is to not reiterate the fundamentals of the process.

Lime stabilisation is an economical approach for clay subgrade with a PI exceeding 5%. In some regions cement is also added to the subgrade stabilisation process to enhance the strength of the material. Given a well-designed material, the use of sufficient lime will improve the short and long term strength of the subgrade material (Little, 1995).

This paper will commonly refer to the 1992 Austroads pavement design guide [Austroads, 1992] and the 2001 draft guide [Austroads, 2001]. When designing pavements to the draft 2001 guide, attention is drawn to the use of reliability factors on new pavements, whereas reliability factors are not required on pavements that are being rehabilitated [Austroads, 2002].

One of the challenges with any pavement design is the assignment of the design subgrade strength (or stiffness). Subgrades are inherently variable and reflect the changes in:

- ❑ topography
- ❑ soil type
- ❑ season
- ❑ drainage conditions

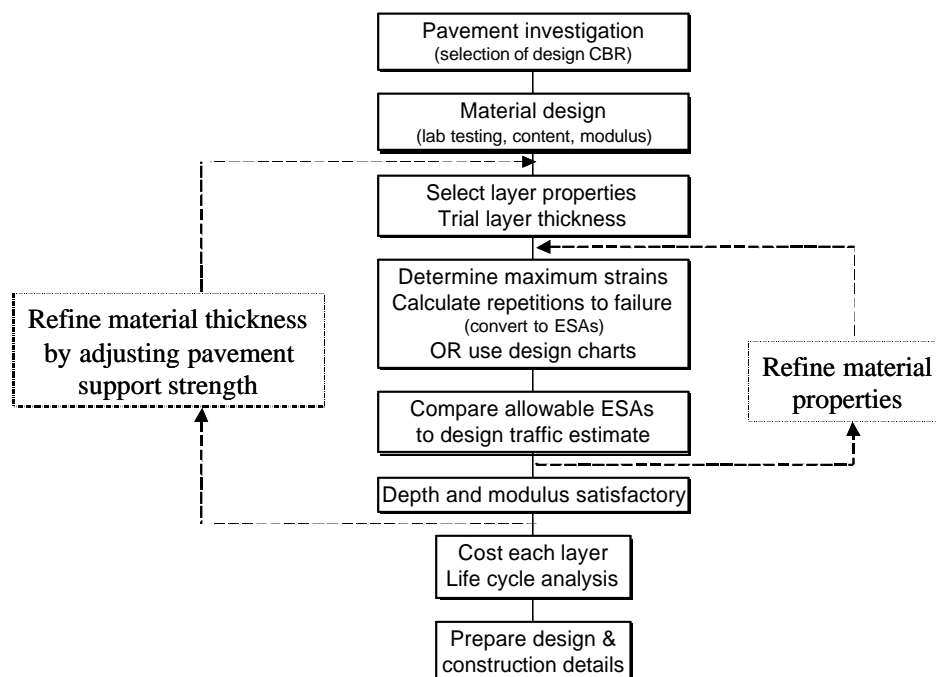
The following six factors are typically considered in the determination of the design stiffness or strength of the subgrade (Paul, 1998):

- ❑ Subgrade variability
- ❑ Sequence of earthworks construction
- ❑ Compaction moisture content and field density achieved
- ❑ Moisture changes during service
- ❑ Effects of subsurface drainage on moisture content
- ❑ Pavement type cross-section

The first two factors mostly influence the decision to divide or otherwise the project into various sections with assigned design CBRs. In addition, the designer may assign a CBR of 5% in their design model but in the field, especially after a dry summer, the field determined CBR may be considerably higher, and road construction activities are able to achieve good compaction of pavement layers.

Many engineers have known since the regular use of the Benkleman Beam or Falling Weight Deflectometer on existing pavements that pavement layers perform well with high subgrade CBRs and conversely, the pavement material shows early signs of distress where the subgrade modulus is very low. In most cases the pavement material is likely to shows early signs of distress in those areas where the subgrade modulus from FWD back calculations is much lower than other sections of the roadway.

Once specific road sections have been assigned a design CBR an iterative design approach is required for all pavement materials to optimise the pavement material characteristics and the thickness of the layers given a specific subgrade condition and estimated traffic life of the road. **Figure 1** shows how this interactive approach may be taken to balance the costs of materials, construction activities and pavement life.



**Figure 1** The basic iterative pavement design approach.

Many designers will refine the thickness of pavement layers to achieve an optimum thickness of granular, cemented and asphalt layers. However, after costing a few pavement configurations to select the lower life cycle cost option a designer could also review the pavement thickness by increasing the subgrade strength. Increasing subgrade strength can be achieved by removing the existing subgrade materials and replacing them with suitable material or by using insitu stabilisation of the existing subgrade with lime.

The interim design approach outlined in this paper represents a step forward in the utilisation of subgrade improvements to produce economical pavements. This paper provides a rational approach using empirical charts or a mechanistic design as outlined in the Austroads pavement design guide [Austroads, 1992, 2001].

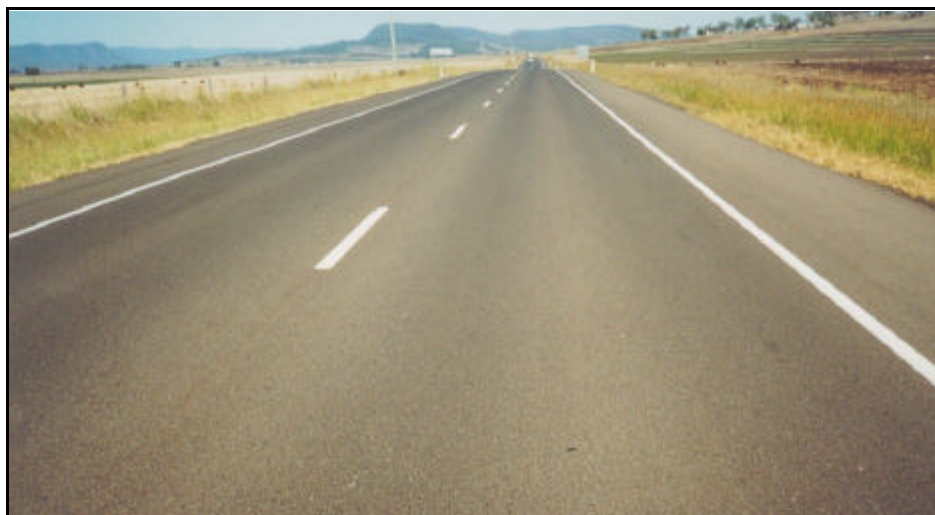
## 2 PERFORMANCE OF RECENT LIME STABILISATION PROJECTS

Ingles noted that lime stabilisation developed in the southern States of the USA in the 1930s (Ingles, 1972). By the 1950s the use of lime treatment for heavy clays was widespread in Texas, and still remains the case today. It would be hard to deny that a process that has been extensively used over many decades could not have performed in the field.

In New Zealand, Bartley Consultants have recently documented the performance of existing lime stabilised subgrades and in all three roads examined, the pavements had a higher than expected remaining life (Transfund, 1998).

There are many local government roads in Victoria and NSW that have had their subgrade stabilised with lime many years ago are still in service. One of the shortcomings is that the design and construction details were poorly documented and there is no quantitative data.

In the late 1990s the DMR constructed two trials near Warwick (QLD) using the current design philosophy of lime stabilisation and these trials have been well documented (Evans, 1998). In the Killarney Road project a range of 3% to 6% quicklime was constructed and to assess the performance of each test section with age. The other trial was constructed on the Cunningham Highway 13km east of Warwick during June 1997 and 8% quicklime was used. Recent visual observations indicate that the pavement has performed extremely well (see Figure 2).



**Figure 2** A view of the Cunningham Highway near Eight Mile Intersection in July 2002.

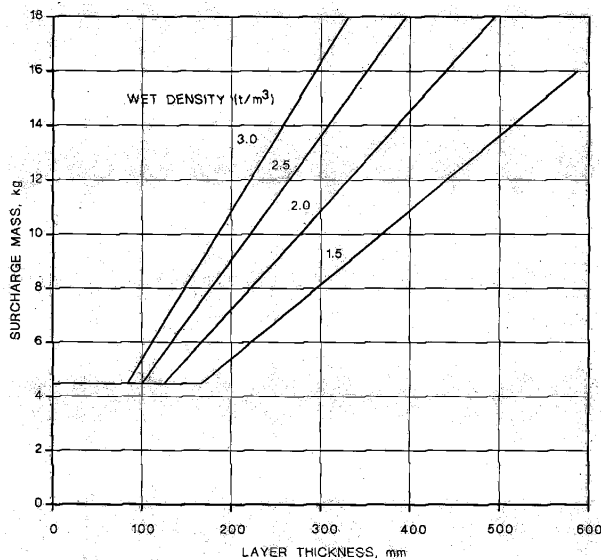
Sound specifications using best construction practice will also give the designer confidence that construction would be carried out to ensure that the lime reactions develop and are completed, and sufficient compaction of the stabilised material is achieved (AustStab,2002b).

### 3 MATERIAL DESIGN

The reactions that lime has with soils are well documented in various publications [Little, 1995, Austroads, 2002]. Both hydrated and quicklime is used for road stabilisation with quicklime the most common type used. Agricultural lime is cheaper than quicklime and does not provide the same strength reaction in soils and should not be used [Austroads, 2002, AustStab, 2002a].

Over the last five years the lime demand test (defined as the lowest percentage of lime required to achieve a pH of 12.4) has become recognised as a method to determine the minimum lime content to establish long-term stabilisation of the material [Austroads, 2002]. In Victoria the lime saturation test method [VicRoads, 2000] is used to determine the minimum lime content for stabilisation whereas in Queensland the lime demand test is used (Main Roads, 1999). This initial lime content is used to assess the initial laboratory CBR strength of the material and more lime may be required to provide additional strength in the subgrade layer to meet the designers requirements for the pavement configuration.

The common test method in Australia for the laboratory strength of the subgrade material is the CBR test (AS 1289.6.1.1). This approach provides the CBR of a laboratory compacted material under soaked or dry material conditions using Standard compaction with or without surcharge loading. The surcharge loading is applied during the curing period to simulate the pavement material loading above the subgrade level. In NSW the total surcharge mass is set at 2.7 kg and VicRoads requires the use of 4.5 kg (not including the platter) as the surcharge mass. Test observations indicate that a higher surcharge loading will result in higher laboratory CBR values and increasing the selection of the surcharge as shown in **Figure 3** may reduce the conservative value of the nominated subgrade strength.



**Figure 3** Selection of surcharge from AS 1289.6.1.1.

Pre-treatments of the subgrade material may be necessary when dealing with particular types of material, such as highly weathered rocks (ie siltstone and shale). A geotechnical consultant would provide suitable advice on the requirements for pre-treatment of a subgrade material.

The VicRoads approach to improvements in the design subgrade using CBR laboratory testing is documented in Code of Practice RC 500.23 [VicRoads, 1999]. This approach uses the average of the lowest two sample CBR readings from a set of three samples soaked for 4 days prior to testing. This average value is then halved to take into account the differences between laboratory and field conditions. For instance, if the CBR results from three samples were 42%, 46% and 38%, the assigned laboratory CBR value is  $((42+38)/2)/2 = 20\%$ .

The duration of soaking is addressed in the interim design guide (Austroads, 2001) and Table 1 lists the recommended duration for the soaking of samples. Those areas which are subject to heavy rain periods would require a longer soak period before testing. In addition, the soaking period should also give consideration where a road is adjacent to irrigation channels or major rivers.

**Table 1 Recommended design moisture contents and soaking (Austroads, 2001).**

Median Annual Rainfall (mm)	Design Moisture Content/Testing Condition	
	Good Drainage	Poor Drainage
<500	OMC/unsaturated	OMC/1 to 4 day soak
500–800	OMC/unsaturated	OMC/4 to 7 day soak
>800	1.15 x OMC/unsaturated	1.15 x OMC/7 to 10 day soak

The CBR approach based on laboratory data is suitable for many empirical design charts to establish the granular layer thickness above the subgrade material. However, for mechanistic design methods the modulus of the subgrade material is required in the analysis. The relationship many designers use to relate CBR to modulus for use in a mechanistic analysis is:

$$\text{Modulus (MPa)} = 10 \times \text{CBR} \quad \text{Eqn (1)}$$

The current interim design guide (Austroads, 2001) notes that this "... equation is at best an approximation and modulus has been found to vary in the range 5 x CBR to 20 x CBR (Sparks and Potter 1982)."

For mechanistic design the selection of an appropriate maximum modulus in the analysis is covered in Section 5 of this paper.

Poisson's ratio adopted for subgrade materials are typically 0.45 and 0.35 for cohesive and non-cohesive materials respectively.

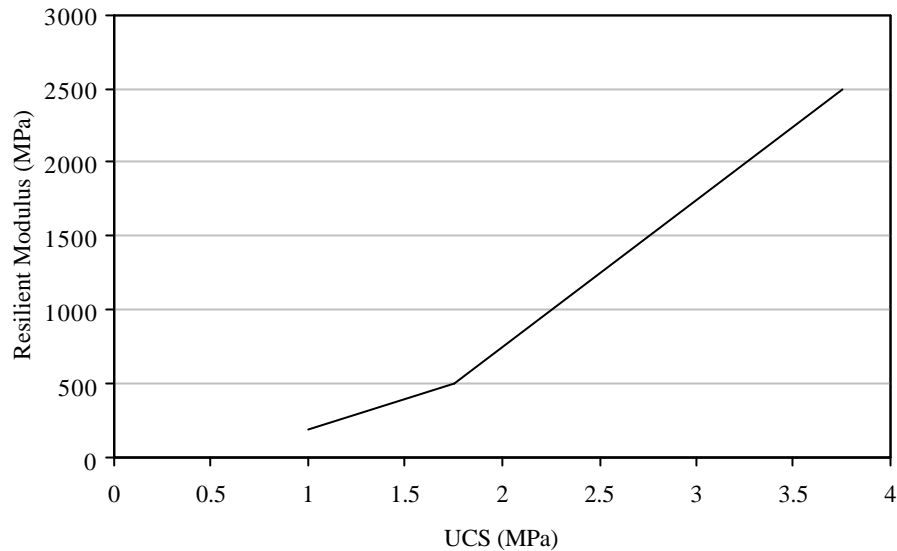
The use of the lime demand and CBR tests will provide the minimum amount of lime required for the pavement design.

Work by Little in the mid-1990s indicated that a relationship between Unconfined Compression Strength (UCS) and modulus can be obtained and **Figure 4** shows significant increases in modulus as UCS increases (Little, 1998). The use of UCS testing has been adopted by the Department of Main Roads, Queensland to establish the optimum lime content for stabilisation (DMR, 2000). This process is adopted from work by Little and is used to establish the minimum lime content when the UCS of stabilised sample reaches a plateau with increasing lime content. The authors prefer the lime demand and CBR approach to the UCS approach for the minimum determination of lime content.

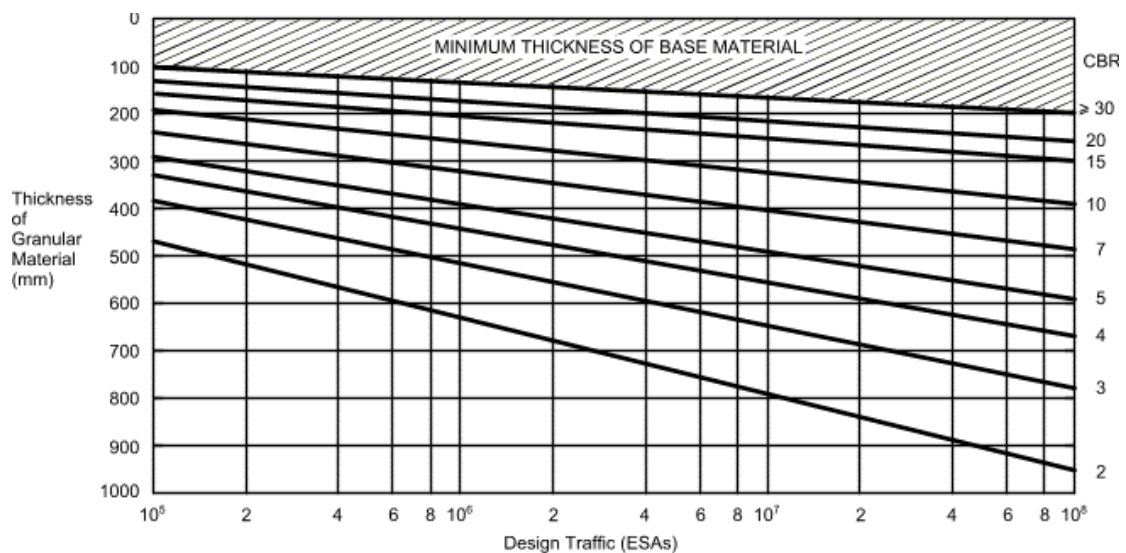
#### 4 STRUCTURAL DESIGN

The Austroads design guide allows for the use of empirical and mechanistic design approaches for the determination of individual pavement layer thickness. Figure 8.4 (Austroads, 2001) is used for an empirical approach to determine the minimum thickness of granular layers over subgrades (**see Figure 5**). Many pavement engineers believe this design chart is inappropriate when traffic levels exceed  $1 \times 10^7$  ESAs as thick layers of asphalt would be required over the granular layer to meet other design requirements.

Where the road is lightly trafficked, Figures 13.8.2(A) to 13.8.2(C) may be used from APRG Report 21 [Austroads, 1997].



**Figure 4** Suggested relationship between Unconfined Compressive Strength (UCS) and Resilient Modulus for lime stabilised subgrade materials (Little, 1998).



**Figure 5** Design thickness for a granular pavement on various subgrade strengths [Austroads, 2001].

When using a mechanistic approach it is recommended that sublayering of granular layers is adopted in the analysis model when a cemented material or asphalt is constructed over the granular layer, with the rules for sublayering set out in Section 8.2.2 of the 2001 Interim Guide.

Work by Bartley Consultants [Transfund, 1998] supported a view that lime stabilised subgrade layers could be sublayered in a mechanistic model. Some of their recommendations reported were:

- ❑ The elastic modulus at the top of the stabilised subgrade should not be greater than 3 to 4 times the elastic modulus of the original subgrade.
- ❑ The layer should be treated as having anisotropic elastic parameters as required for normal subgrade layers.
- ❑ Sublayering scheme should be such that two or three sublayers 50 to 150 mm in thickness are required so that the maximum modular ratio between adjacent layers does not exceed 2.

Given that subgrade materials tend to be fine-grained soils, it would be more appropriate to treat them as layered subgrade materials. It is therefore recommended that the sublayering rules applied in Section 8.2.2 be adopted with the maximum modular ratio between sublayers set at 2.

Modulus for layers could be determined from FWD data or laboratory results. Granular or bound layers above the subgrade could be modelled according to material properties outlined in Chapter 6 of the Austroads Design Guide [Austroads, 2001].

Using this approach, it is also recommended that the proposed Austroads (Austroads, 2001) subgrade strain criterion be used:

$$N = \left[ \frac{9300}{\mu\varepsilon} \right]^7 \quad \text{Eqn (2)}$$

where  $\mu\varepsilon$  = the vertical strain (in units of microstrain) at the top of the subgrade, and  
 $N$  = the allowable number of repetitions of a Standard Axle of this strain before an unacceptable level of rutting develops.

## 5 EQUIVALENT SUBGRADE LAYER STRENGTH

Many Australian engineers have used the Japan Road Association's approach to establishing the weighted subgrade strength from stratified layers of subgrade strength. Recently, the method was presented in the 2001 Austroads interim design guide.

The use of the method is for subgrade materials within 1 metre of the underside of the subbase which shows vertical stratification. The determination of the design CBR is adjusted based on a multi-layered subgrade system. The formula given in Equation 2 provides a model that may be used to determine this equivalent design subgrade strength ( $CBR_m$ ) based on the stiffness of the supporting soil depth.

$$CBR_m = \left[ \frac{\sum_i h_i CBR_i^{0.33}}{\sum_i h_i} \right]^3 \leq 20 \quad \text{Eqn (3)}$$

where  $CBR_i$  is the CBR value in layer thickness  $h_i$ , and  
 $\sum h_i$  is taken up to a depth of 1.0 m.

The following conditions apply to the use of this equation:

- Layers of thickness less than 200 mm must be combined with an adjacent layer. The lower CBR value must be adopted for the combined layer.
- It is assumed that higher CBR materials will be used in the upper layers. The formula is not applicable where weaker layers are located in the upper part of the subgrade.
- Filter layers must not be included in the calculation.
- The maximum CBR from the use of this formula is 20%.

For example if the CBR of the top 200 mm is assigned a value of 25% and the lower 400 mm is 5%, the effective CBR is:

$$\text{CBR}_m = \left[ \frac{\sum_i (0.2x25^{0.33} + 0.4x5^{0.33})}{\sum_i (0.2 + 0.4)} \right]^3$$

$$= 9 \%$$

Another approach is also given in Chapter 6 (Section 6.2.3.2) of the 2001 interim guide where the equivalent modulus ( $E_e$ ) of the bound material is:

$$E_e = \left( \frac{\sum_{i=1}^n (t_i [E_i]^{1/2})}{T} \right)^3 \quad \text{Eqn (4)}$$

where  $E_e$  = equivalent modulus of total thickness of bound material (MPa),  
 $E_i$  = modulus of layer  $i$  (MPa),  
 $t_i$  = thickness of layer  $i$  (mm), and  
 $T$  = total thickness of overlying bound materials (mm).

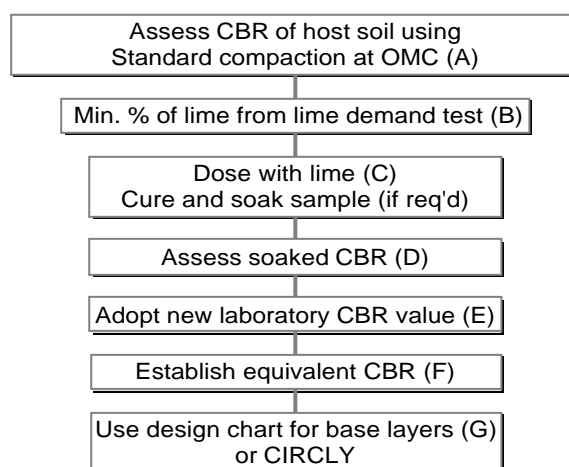
The equivalent subgrade strength or stiffness derived using equations 3 and 4 will provide similar values.

What is the appropriate maximum CBR for the top of any layer for the purpose of structural design? In both Austroads design guides the maximum CBR curve for the granular overlay thickness has been set at 30%. VicRoads assigns a maximum CBR value of 10% for pavements with traffic loadings exceeding  $1 \times 10^6$  ESA's, otherwise 15% may be used (VicRoads, 1980).

In this paper it is suggested that with the use of the lime demand test and appropriate laboratory testing of lime stabilised materials the maximum CBR assigned to the top of the subgrade should be limited to 20%.

## 6 INTERIM DESIGN METHOD

The design method proposed is outlined in **Figure 6** is not limited to any traffic levels.



**Figure 6** Interim design approach for lime stabilisation of subgrade materials.

Notes for Figure 6 (Flowchart).

- A. The laboratory subgrade CBR is determined using AS 1289.6.1.1. It is noted that Standard and not Modified compaction is used in the preparation of the sample.
- B. The Lime Demand test identifies the quantity of lime to satisfy cation exchange and short-term reactions. Some soils may not gain strength due to a dominant ion exchange process in the pavement material and other binders may need to be investigated.

Where a subgrade may be exposed for sometime, the designer may consider cementitious stabilisation as a secondary treatment to the initial lime stabilisation. This may then negate using the lime demand test.

- C. Additional lime may be used above the minimum value given in step B. Curing the sample is by 3 days air cure followed by soaking as noted in Table 1.

Since the design approach halves the laboratory determined CBR and this design approach limits the maximum design CBR to 20% it is suggested that a target laboratory CBR should be in the range of 30% to 60%.

- D. CBR testing is carried out to AS 1289.6.1.1 and the sample is tested in the unsoaked / soaked condition as required. Refer to Table 1 for the period of soaking the samples.
- E. The assigned laboratory CBR is taken as half the average of the two lowest test results to a maximum value of 20%.
- F. The design subgrade CBR may be calculated by either using the equivalent CBR approach (ie equation 3) or using the sublayering techniques described in the paper..
- G. Determine pavement layer thicknesses from empirical design charts or a mechanistic approach.

## 7 SUMMARY

Engineers are continually improving their knowledge of the material and structural design of pavements. ALF and field trials, along with observations of projects designed using various parts of the above mentioned design approach has increased our confidence to construct lime stabilised subgrades for local and main roads around Australia.

Some of the key issues that need to be taken into consideration in this interim design model are:

- There will always be differences in the subgrade CBR over a length of existing road and this will vary according to the season. Selecting a statistical value for the variance is regarded as best practice today.
- The laboratory CBR value is based on a sample of material compacted to a specific energy level to ensure repeatable results in the laboratory. The laboratory CBR value would normally reflect the worst case site conditions and this method provides a minimum factor of safety of 2.
- Field performance is continually showing that lime stabilisation of subgrades is working well. Short cuts taken in the specification or by the contractor should be avoided.

Design methods of the past tended to focus on either the material or structural design of the pavement and subgrade. This interim design method combines a rational approach for material and structural design of lime stabilised subgrade layers for pavements.

## REFERENCES

- Australian Standards AS 1289.6.1.1 (1998) *Methods of testing soils for engineering purposes Method 6.1.1: Soil strength and consolidation tests - Determination of the California Bearing Ratio of a Soil – Standard laboratory method for a remoulded specimen* Sydney. [www.standards.com.au]
- Australian Standards AS 1289.6.1.3 (1998) *Methods of testing soils for engineering purposes Method 6.1.1: Soil strength and consolidation tests - Determination of the California Bearing Ratio of a Soil – Standard field-in-place method* Sydney.
- Austrroads 1992 *Austrroads Pavement Design Guide* Sydney, 1992 (Note 1997 amendment).
- Austrroads (1998a) *Guide to Stabilisation in Roadworks* Austrroads, Sydney, 1998.
- Austrroads (1998b) *A Guide to the design of new pavements for light traffic* APRG Report No.21, Vermont South, January, 1998.
- Austrroads (2001) *Austrroads Pavement Design Guide (Final Draft) for Public Comment* AP-T10 Sydney, 23 November 2001.
- Austrroads (2002) *Austrroads Rehabilitation Guide (Final Draft) for Public Comment* AP-T10 Sydney, 23 November 2001.
- Austrroads (2002) *Mix design for pavement materials stabilised insitu (Flow charts)* AP-T16 Sydney, June 2002
- AustStab (2002a) *Lime stabilisation practice* AustStab Technical Note, Australian Stabilisation Industry Association, Artarmon, NSW. [www.auststab.com.au/technotes/TNote1.pdf]
- AustStab (2002b) *Insitu Stabilisation of subgrades and pavement materials using lime for Local Government Roads* AustStab Model Specification No.5, Australian Stabilisation Industry Association, Artarmon, NSW. [www.auststab.com.au/specifications/]
- DMR (2000) *Lime treatment of clay subgrades* Technical Note Issue No.13 Department of Main Roads, Qld, Herston, QLD.
- Evans, P, Smith, W and Vorobieff, G (1998) *Rethink of the design philosophy of lime stabilisation* Proceedings 19<sup>th</sup> ARRB Conference, Sydney. [www.auststab.com.au/19arrb/19arrbEvans.pdf]
- Ingles, OG and Metcalf, JB (1972) *Soil stabilization Principles and Practice* Butterworths, Sydney, NSW.
- Little, D (1995) *Lime stabilization of bases and subbases* Kendall Hunt Publishing Company, Iowa, USA, 1995.
- Little, DN (1998) *Evaluation of structural properties of lime stabilized soils and aggregates Volume 1: Summary of findings* Published by National Lime Association, USA.
- Manual for Asphalt Pavement* Japan Road Association, 1989.
- Paul, R, Papacostas, A and Mulholland, P *Identify design CBR procedures* APRG Document 98/15 (DA) June 1998.
- Sparks, GH and Potter, DW (1982) *An Investigation Into The Relationship Between CBR and Modulus For Two Clays* ARRB Internal Report, AIR 295-1, South Vermont, Victoria 1982.
- Transfund (1998) *Mechanistic design of pavements incorporating a stabilised subgrade* Transfund New Zealand Research Report No. 127, 1998.
- VicRoads (1980) *Design of Flexible Pavements Guide* Technical Bulletin No 31, Kew, September, 1980.
- VicRoads (1999) *Lime Stabilised Subgrade Materials – Lime Content And Assignment Of CBR And Percent Swell* Code of Practice RC 500.23, Kew, 1999.
- VicRoads (2000) *Lime saturation point of soil* Test Method RC 131.01, Kew, Victoria, November, 2000.
- Vido, O and Vorobieff, G (2002) *Discussion Paper on the design of lime stabilised clay subgrades for local roads and subdivisions* Joint Australian Geomechanics Society and Australian Stabilisation Industry Association seminar, North Melbourne, 13 February, 2002. [www.auststab.com.au/seminars/limesubgradedesign.PDF]