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Structural Modelling of Expansive Clay Subgrades Treated with Lime

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Abstract: *Given the wide spread existence of expansive soils across Australia, lime stabilisation of expansive subgrades to improve the California Bearing Ratio (CBR) has been widely used and accepted for well over 50 years. The process of spreading and mixing lime into expansive clays is simple and cost effective where permanent CBR improvements can be increased by a factor of well over 10. The use of structural and mix design conventions are readily available for use by designers to quantify these improvements. The 2017 edition of Austroads' Guide to Pavement Technology Part 2: Pavement Structural Design introduced a simple method for the modelling of lime stabilised subgrade materials where a treatment thickness and corresponding design CBR can be optimised. The resultant design CBR can be used as an input variable in empirical design methods or in layered elastic analysis software programs. Mix design procedures for the determination of binder type and quantity (typically lime in the case of expansive clays) are reasonably well documented throughout Australia, however many practitioners fall short of applying a thorough mix design regime prior to specifying lime application rates. This paper discusses the approach to designing an improved expansive subgrade material through the use of lime stabilisation. Methods outlining accepted structural design practices and minimum process requirements for undertaking mix designs are presented. Outcomes will be explored showing how expansive clays with low CBR values can be treated with lime to a calculated thickness such that significant improvements to the CBR can be achieved for use in pavement design modelling.*

KEYWORDS: lime, pavement, stabilisation, subgrade, design, expansive soil.

1 Introduction

Expansive clays occur widely throughout Australia and are a common factor inhibiting the long term success of road designers, road constructers and road owners.

Figure 1: Expansive Soil Distribution [1]

The effects of wetting and drying of expansive soils provides considerable challenges for pavements to adequately absorb traffic loads for the design period. Consequently very thick and expensive pavement structures are often required above expansive subgrades to reduce the risk of permanent deformation in the subgrade. If the subgrade is unable to support the overlying pavement, early rehabilitation intervention becomes a financial burden to asset owners. Unfortunately this is not uncommon and is often due to moisture movements that affect the ability of the clay subgrade to support the pavement structure. Figures 2 and 3 demonstrate the various ways moisture can enter a pavement and consequently stimulate shrink/swell characteristics of the subgrade.

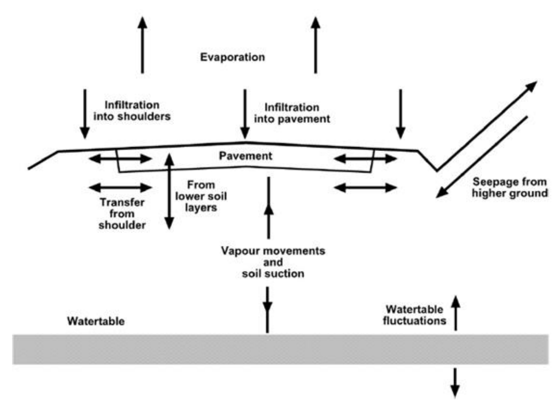

Figure 2: Mositure Movements in Pavements [2]

Figure 3: Shrink/Swell Effects [3]

Pavement designers rely on a number of input variables to arrive at optimised rehabilitation and/or construction solutions with nominated layer thickness recommendations for road owners. The input variable of design subgrade CBR is arguably the most influential parameter in the pavement design modelling process. In the untreated state, expansive subgrade soils are classified by Austroads [2] as shown in Figure 4.

Expansive nature	Liquid limit (%)	Plasticity Index	PI x % < 0.425 mm	Swell (%) (1)
Very high	> 70	> 45	> 3200	> 5.0
High	> 70	> 45	2200–3200	2.5–5.0
Moderate	50–70	25–45	1200–2200	0.5–2.5
Low	< 50	< 25	< 1200	< 0.5

1 *Swell at OMC and 98% MDD using standard compactive effort; four-day soak. Based on 4.5 kg surcharge.*

Figure 4: Guide to Classification of Expansive Soils [2]

There are numerous methods widely practiced to manage expansive clays and their ability to support pavement structures. Some common ones include (but not limited to): removal and replacement with better quality materials, placing excessively thick pavements on top of the subgrade, utlisation of geogrid materials, placement of capping or improvement layers, grading and plasticity modification and insitu lime stabilisation. Whilst there are proven case studies and qualitative arguments for each method, this paper considers the lime stabilisation method with a focus on the processes to be followed when carrying out design of lime stabilised subgrade materials. 'Design' in this instance refers to structural design and mix design elements, the former relating to assignment of a design bearing capacity and thickness determination while the latter relates to the composition of the treated clay with reference to binder type and binder quantity.

Lime stabilised subgrades have been proven to display reductions in plasticity index, reductions in mositure sensitivity, increases in volume stability and ultimately increases in bearing capacity which benefit pavement design outcomes.

2 State Road Authorities

Classification of expansive soils by most state road authorities in Australia and a subsequent prompt to 'do something' occurs when CBR swell values exceed 2.5% for highly expansive soils. Once these materials are identified, minimum cover requirements are triggered with examples shown below.

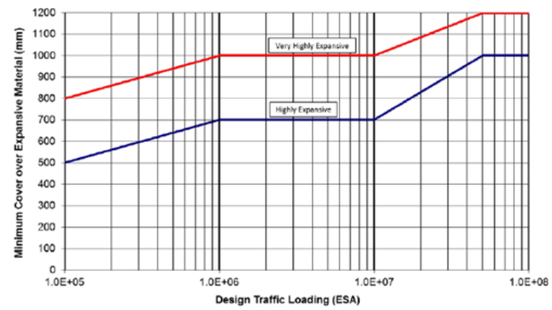

Figure 5: QLD DTMR Cover Requirements for Expansive Soils [4]

Figure 6: Vicroads Cover Requirements for Expansive Soils [5]

Untreated Material Swell (%)	Minimum Cover Over Reactive Material (mm)
>5.0	1000
>2.5 to ≤ 5.0	600
≥0.5 to ≤ 2.5	150

Figure 7: WA DMR Cover Requirements for Expansive Soils [6]

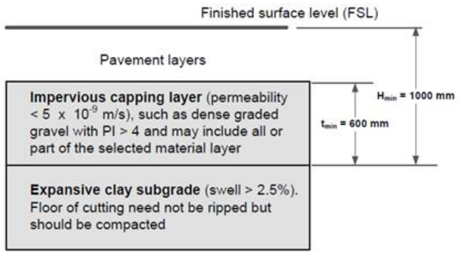

Figure 8: NSW RMS Cover Requirements for Expansive Soils [7]

The majority of state road authorities in Australia make reference to the use of lime stabilisation as a suitable treatment of expansive or reactive clay subgrade materials, which are particularly attractive given the large cover requirements shown above.

For those authorities who consent to structural contributions from lime stabilised materials in pavement design modelling, they note that this can only occur if the treatment is designed to remain permanent. In South Australia [8], the following is noted:

'Lime stabilisation of soft subgrades…are commonly used as construction expedients in DPTI works. Adoption of an improved design subgrade modulus due to these treatments should only occur if the long-term properties have been validated through field and laboratory testing.'

This concept will be explored further under the Austroads Mix Design Method.

3 Austroads Structural Design Method

The Austroads Guide to Pavement Technology, Part 2: Pavement Structural Design [2], provides guidance to practitioners on methods for the selection and design of stabilised subgrade materials to improve the California Bearing Ratio (CBR). Although the determination of design subgrade CBR value/s for untreated clays can be achieved using a variety of methods, such as statistical analysis of laboratory soaked CBR test reports or from field data (eg. dynamic cone penetrometer results), presumptive values are available as shown below.

Description of subgrade		Typical CBR values (%)	
Material	Unified Soil Classification	Excellent to good drainage	Fair to poor drainage
Highly plastic clay Silt	CH ML	5 4	2–3 2
Silty-clay Sandy-clay	CL CL	5–6	3–4
Sand	SW, SP	10–18	10–18

Figure 9: Presumptive Subgrade CBR Estimates [2]

Based on this table, expansive clays would typically result in selection of design CBR values less than 5% and are often supported by test data. Whilst pavement designs can theoretically be designed on a subgrade assigned with any CBR value, the risk of in-service performance not meeting design expectations is increased due to challenges with achieving specified density levels during construction. Austroads [2] supports this notion stating that '*Construction of full depth asphalt pavements will generally be very difficult for a pavement with a subgrade design CBR less than 5%.*', and should only be constructed on subgrades with a field CBR of 10%.

The current approach to designing an improved subgrade through stabilisation is to select the design CBR based on three conditions as set out below. The minimum value from these conditions is adopted.

1. A CBR of 15%;
2. A value determined from CBR testing or a presumptive value;
3. A value determined from the support provided by the underlying material (eg. expansive clay).

Equation (1) provides the formula [2] to calculate the design CBR based on the underlying material support and is also a function of the proposed thickness of the stabilisation treatment.

$$CBR_{SS} = CBR_{UM} \times 2^{(TSS/150)} \quad (1)$$

where:

CBR_{SS} = *Design CBR* $_{stabilised\ subgrade}$

CBR_{UM} = *Design CBR* $_{underlying\ material}$

TSS = Thickness of the Stabilised Subgrade

The chart below demonstrates typical values that can be obtained for design subgrade CBR values for a range of existing subgrade CBR's (less than 5%) and stabilisation thicknesses, capped at CBR15 as per criteria 1 above. The stabilisation thicknesses shown represent those that can be successfully obtained during insitu construction practices.

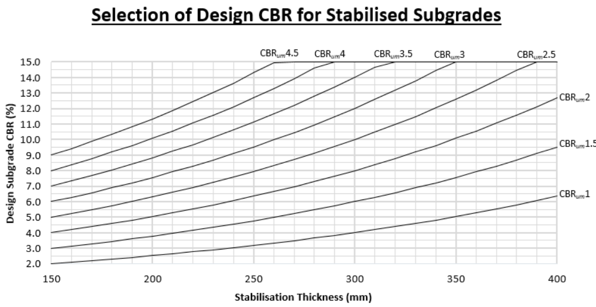

Figure 10: Stabilised Subgrade Design CBR Options

Of the three criteria provided by Austroads [2], it is common for No.2 to result in CBR values well in excess of 15%. For this reason the most common governing criteria is No.3 utilising Equation (1) or Figure 10. Once a design subgrade CBR has been selected, a vertical modulus (E_v) is established using Equation (2)[2] for input into layered elastic analysis models.

$$\textit{Modulus (MPa)} = 10 \times CBR \tag{2}$$

A maximum value of 150MPa is normally adopted with a poisson's ratio of 0.45 for cohesive materials and 0.35 for non-cohesive materials. As highlighted in Section 2, to enable use of this approach requires confirmation that the stabilised clay will permanently maintain the improved CBR properties which is discussed further in Section 4.

4 Austroads Mix Design Method

The Austroads Guide to Pavement Technology, Part 4D: Stabilised Materials [9], provides guidance to practitioners on methods for the selection and design of binder type and quantity, commensurate with the assigned structural design parameters. Whilst the most common binder type used to permanently modify and improve the properties of expansive clays is lime, Part 4D provides guidance on selection of binder type based on host material characteristics, as shown in Figure 11, where grading's and plasticity index are evaluated. This chart verifies that lime is usually suitable for clay materials that exhibit a plasticity index greater than 10%.

Particle size	More than 25% passing 75 µm sieve			Less than 25% passing 75 µm sieve		
Plasticity index (PI)	PI ≤ 10	10 < PI < 20	PI ≥ 20	PI ≤ 6 & PI x %passing 75 µm ≤ 60	PI ≤ 10	PI > 10
Binder type						
Cement and cementitious blends(1,3)	Usually suitable	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Usually suitable
Lime	Doubtful	Usually suitable	Usually suitable	Usually not suitable	Doubtful	Usually suitable
Bitumen	Doubtful	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Usually not suitable
Bitumen/ lime blends	Usually suitable	Doubtful	Usually not suitable	Usually suitable	Usually suitable	Doubtful
Granular	Usually suitable	Usually not suitable	Usually not suitable	Usually suitable	Usually suitable	Doubtful
Dry powder polymers	Usually suitable	Usually suitable	Usually unsuitable	Usually suitable	Usually suitable	Usually not suitable
Other proprietary chemical products(2)	Usually not suitable	Usually suitable	Usually suitable	Usually not suitable	Doubtful	Usually suitable

Figure 11: Selection of Initial Binder Type [9]

A common misunderstanding related to mix design procedures for binder selection, is the type of lime to be used for laboratory testing and then in construction. The two types of lime available for use in the road stabilisation industry in Australia are Hydrated Lime and Quicklime. Lime slurry and agricultural lime are not used for conventional road stabilisation projects in Australia. Typical uses and properties for each type of lime are shown in the table below (assuming no impurities).

Table 1: Hydrated Lime v Quicklime [9]

	Hydrated Lime, $Ca(OH)_2$	Quicklime, CaO
Composition	$Ca(OH)_2$	CaO
Form	Fine powder	Granular
Equivalent $Ca(OH)_2$ /unit mass	1.00	1.32
Bulk Density (t/m^3)	0.45 to 0.56	1.05
Used in Laboratory	Yes	No
Used in Construction	Yes (least common)	Yes (most common)

If quicklime (Q/L) is specified for use in the field, a conversion factor 0.76 is applied to the laboratory determined hydrated lime (H/L) application rate.

$$\textit{Q/L (\% in field)} = \textit{H/L (\% in lab)} \times 0.76 \tag{3}$$

Prior to moving to construction however, the mix design process needs to confirm the minimum quantity of hydrated lime to achieve the assumed strength from the structural design phase. Austroads [9] provides two methods:

<u>Method A</u>: requires the lime content such that the unconfined compressive strength (UCS) is within the range 1-2MPa moist cured for 28 days.

<u>Method B</u>: requires the CBR of the material to be tested and the lime content adjusted to satisfy the required design CBR.

Method A is most commonly used in Queensland by the state road authority whereas Method B is used widely throughout the rest of Australia for all road classes.

Both methods are underpinned by an initial lime demand test to determine the minimum quantity of lime required to achieve long term strength which then supports the use of the design CBR value in structural design modelling.

The lime demand test is a simple test that measures the pH of the soil/moisture mixture at various lime contents. A plot of these results is evaluated to identify the lime demand value (LD) which is characterised as the minimum lime content to satisfy cation exchange by reaching a pH of 12.4 [10].

Once the lime demand test has identified the minimum lime content to achieve long term reactions, CBR testing is undertaken to verify that the target design strength has been met. Lime application rates for CBR testing are recommended to be at LD, LD+1% and LD+2% as a minimum testing regime.

Confirmation of a recommended design application rate is then determined by selecting the lime content where the CBR exceeds the design CBR by a factor of 2 to account for variations in host material and lime properties.

The above process is shown below in basic form, with links to the earlier investigation and structural design phases.

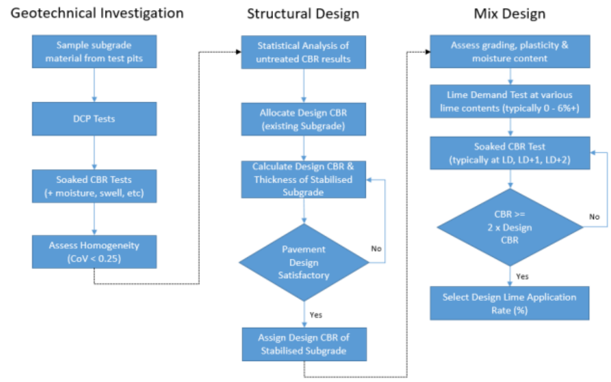

Figure 12: Basic Design Process for Lime Stabilsied Subgrades

5 Design Example

A local Council designs a rehabilitation treatment for a neighborhood road. The following design parameters have been assigned:

- Traffic loading: 9.0E+05 DESA
- Existing expansive clay subgrade: CBR2.5 and 3.5% swell

Due to the risks associated with building a pavement on expansive clays, lime stabilisation of the subgrade is being considered as an option to protect the natural subgrade from permanent deformation and early pavement failure.

<u>Step 1</u>. Structural Design

- Using the chart from Figure 10, a trial stabilisation thickness of 300mm has been selected.
- The maximum allowable design CBR is 10% which satisfies the <15% requirement.

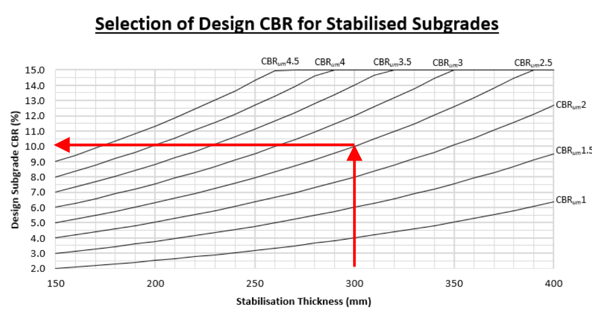

Figure 13: Subgrade Design CBR Selection

Using the Austroads Fig. 12.2 [2] empirical design methodology, the following outcomes are obtained:

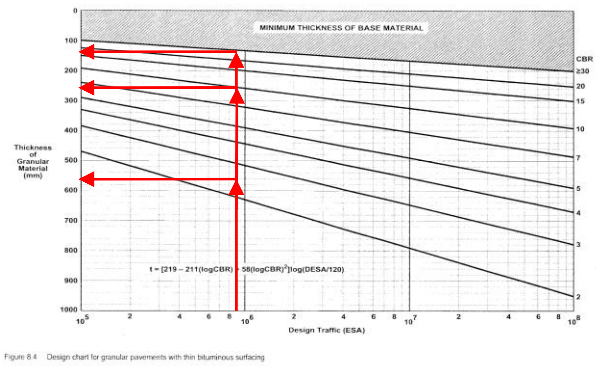

Figure 14: Selection of Minimum Cover Requirements

1. Minimum total cover over expansive clay subgrade CBR2.5 = 560mm

   (normally check if this needs to be increased based on local authority minimum cover over expansive soils - assumed satisfactory for this example)

2. Minimum cover over 300mm Stabilised Subgrade CBR10 = 260mm

3. Minimum thickness of granular base CBR80 = 140mm

4. Balance thickness for granular subbase CBR30 = 120mm

Step 2: Mix Design

- Lime demand testing resulted in LD=4%.
- CBR testing was carried out at LD=4% which resulted in CBR=49% and Swell=0% (LD+1 and LD+2 not provided in this example).

Pavement Design Recommendation:

As the CBR test result at LD (4%) exceeded the target strength of CBR20 (design CBR10 x 2), the final design to be adopted is shown in Figure 11.

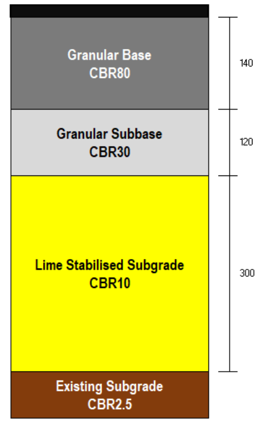

Figure 15: Pavement Design with Lime Stabilised Subgrade

6 Case Studies

6.1 The proposed airport in Cape Preston near Karratha was designed to carry B737-800 aircraft. Material properties of the expansive soil are illustrated in Table 2.

Table 2: Cape Preston Airport Expansive Clay Properties

Material Type	Gilgai soil
Placticity Index	Up to 41%
Soaked CBR	1% – 3%
CBR Swell	> 12%

Without treatment of this material and being faced with placement of at least 1m cover of imported material to protect the subgrade, lime stabilisation was investigated which showed that a reduction of up to 40% of imported material requirements could be achieved. Figure 12 shows the CBR and swell improvement over time with the incorporation of hydrated lime.

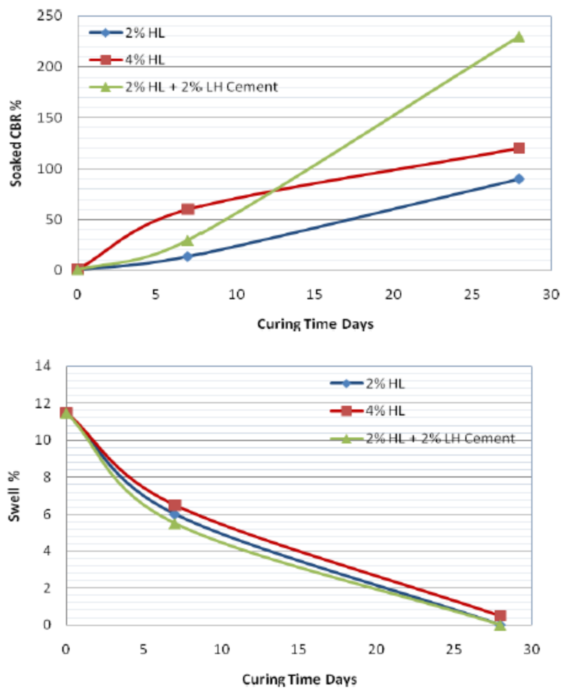

Figure 16: Effect of Lime on CBR and Swell - Cape Preston Airport

CBR improvements were significant with values above 50% achieved after approximately 3 weeks and as expected, much higher with the 50/50 lime/cement blend due to the cement component. Swell reduction appeared to be indpendent of mix design constituents, however all reduced the swell to less than 1% in less than 1 month.

6.2 Ramanujan [3] presented historical evidence of successful performance of lime stabilised subgrades on behalf of the Department of Transport and Main Roads (TMR) in Queensland. Figure 17 illustrates how lime stabilised subgrade materials on the Oakey Pittsworth Rd performed after being inundated by flood waters in 2014. Whilst all unbound shoulder and existing subgrade materials were washed away, the stabilised subgrade remained unaffected.

Figure 17: Oakey Pittsworth Road Performance post Flood [3]

7 Conclusions

Insitu lime stabilisation of expansive clay subgrade materials has been practised widely throughout Australia for many years. During that time much progression has been made on the design aspects relating to thickness selection and mix design protocol. It has been shown that whilst there are numerous options available to asset owners in the treatment of expansive clays, lime stabilisation can be extremely effective to limit permanent deformation and reduce the overlying pavement thickness, as long as proper design methods are followed.

Utilisation of the Austroads design methods for thickness selection and allocation of a design CBR for a stabilised subgrade can be achieved with Figure 10, resulting in design CBR increases of approximately 200-400%. Adoption of this approach provides long term benefits as well as upfront capital cost savings by significantly reducing the need for imported materials.

Mix design conventions have been outlined which specify the need to ascertain minimum lime content from the lime demand test, followed by CBR testing to verify the structural design target has been achieved with a factor of safety of two being applied to the selection of a design lime application rate.

References

1. Karunarathne, A., N. (2016) Investigation of Expansive Soil for Design of Light Residential Footings in Melbourne.
2. Austroads. (2017). Part 2: Pavement Structural Design. *Guide to Pavement Technology.* Sydney.
3. Ramanujan, J. (2015). *Accessed 13.09.18 from* h*ttp://www.roads.org.au/Portals/3/CONFERENCE/JotHi%20Ramanujam.pdf*
4. Queensland Government, Department of Transport and Main Roads. (2018). Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology.
5. Victoria State Government, Vicroads. (2018). Selection and Design of Pavements and Surfacings. Code of Practice RC500.22.
6. Western Australian Government, Main Roads Western Australia. (2013). Western Australian Supplement to the Austroads Guide to

Pavement Technology Part 2: Pavement Structural Design. *Engineering Road Note 9, Procedure for the Design of Road Pavements*.

7. NSW Government, (2018). Roads and Maritime Supplement to Austroads Guide to Pavement Technology Part 2: Pavement Structural Design.

8. Government of South Australia, Department of Planning, Transport and Infrastructure. (2018). Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design.

9. Austroads. (2019). Part 4D: Stabilised Materials. *Guide to Pavement Technology.* Sydney.

10. Little, D.N. (1995). Stabilization of Pavement Subgrades and Base Courses with Lime. *Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime*, 64-66.