

# Performance and Design of Insitu Stabilised Local Government Roads

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## 1 Introduction

Local government roads have been constructed by insitu stabilisation since the 1950s [Ref.1] and Brisbane City Council has been regularly using this method since 1981 [Ref.2]. In that era the alternative to insitu stabilisation was reconstruction with imported material or by a preparing a soil or gravel in a pug-mill, transporting to site and compacting the soil with conventional equipment.

Jones [Ref.2] notes that insitu stabilisation has been very successful in Brisbane due to the following:

- **The use of 4% of blended cement in local roads was sufficient to gain strength.**
- **The use of linear elastic theory using CIRCLY in the design process for major roads.**
- **An emphasis on process control on the thickness of stabilisation and cement spreading rates.**

In the early days, the cement was placed on the ground in 40kg bags, opened and spread by rake and mixed to maximum depths of 200mm. Today, qualified contractors have computer controlled spreading machines and powerful reclaimers to provide a more consistent pavement material. These new construction techniques along with the availability of better laboratory tests has allowed insitu stabilised pavements to be reliable in content and predicted performance.

This paper examines three recent studies on the performance of thin (i.e. less than 200mm in thickness) insitu stabilised pavements and the design of these pavements based on extensive research programs and new Austroads research data.

## 2 Performance

### 2.1 Introduction

The first sign of distress for local roads tends to be on the surface rather than structural in nature, such as stripping or rutting. Delayed maintenance activity of surface defects may lead to water penetrating to the

base and subgrade, and weakening the pavement material.

Establishing structural distress before it happens in thin stabilised pavements is a difficult task and non-destructive techniques utilising pavement management tools are discussed in this section of the paper.

Much of the Australian research work initiated and managed by the Austroads Pavement Research Group has focused on heavy duty pavements with the exception of the ALF trials. Very little performance data has been collected for local government roads and the SHRP sites are heavy-duty roads.

Work by Hodgkinson in 1991 [Ref.3] attempted to quantify the performance of local roads in three Sydney municipalities. These roads were constructed in clay subgrades in the 1970s and the conclusions drawn from the study were:

- **Roads recycled by cement stabilisation have good long-term performance with a high probability of longevity exceeding 75% of the normal expectations of a new or reconstructed flexible pavement.**
- **At a cost of 35-50% of that of full reconstruction, the economic performance of the recycling process is very favourable.**

The Road Rehabilitation by Recycling Project (also referred as the GIRD Project) carried out a range of laboratory and field research projects at the University of South Australia from 1992 to 1995. The performance of three major trial pavements consisted of highways in South Australia and where insitu stabilised pavements with depths exceeding 350mm were constructed [Ref.4]. This project focused on the heavy-duty pavements and could prove useful in quantitatively assessing the performance of local government roads.

It has only been in recent years that researchers and practitioners have sought to improve the performance of insitu stabilised pavements. This has been driven by road owners trying to get more “value-for-money” out of the annual road budget, and addressing a community desire to look at techniques that recycle materials

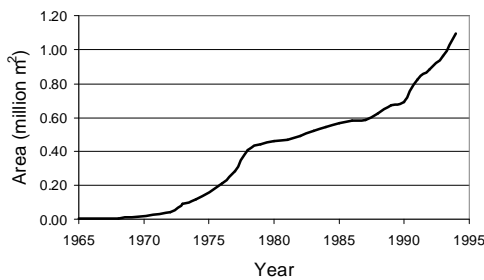
rather than dumping them at tip sites and using quarry products [Ref.18].

**2.2 Performance of Fairfield Local Roads**

In 1995, Hans Meijer of Fairfield City Council (FCC) carried out research on the performance of the local roads constructed by contractors using cement stabilisation [Ref.5]. The Council had carried out insitu stabilisation of many of its road and footpath pavements from 1965, and it totalled more than one million square metres of road pavement (see Figure 1). In 1995, more than 170 lane kilometres or 14% of the road network of Fairfield City Council's road network had been stabilised. The depth of stabilisation varied from 150 to 225mm and the percentage of cement binder varied from 3% to 6%.

The performance of the stabilised pavements was assessed using the Council's pavement management system rating scheme. This system was design by SMEC and used a pavement condition index (PCI) rating from 0 to 10 (see Table 1). The data was analysed in three arbitrary traffic ranges, namely:

- ❑ AADT < 500
- ❑ 500 ≤ AADT ≤ 2,000
- ❑ AADT >2,000



**Figure 1** Cumulative pavement area (million m<sup>2</sup>) of insitu stabilisation from 1965 to 1994 at Fairfield City Council.

**Table 1** Pavement condition ratings devised by SMEC.

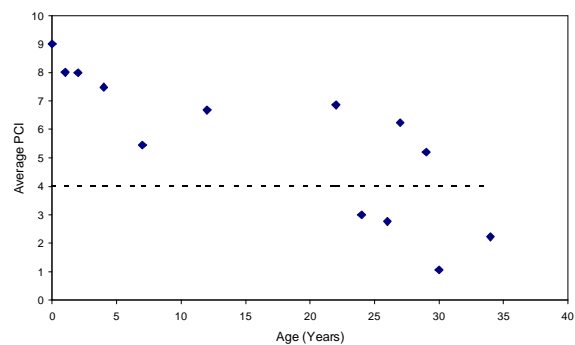
PCI Scale	Road condition
≤ 0 to 1.0	Failed
1.0 to 2.5	Very poor
2.5 to 4.0	Poor
4.0 to 5.5	Fair
5.5 to 7.0	Good
7.0 to 8.5	Very good
8.5 to 10.0	Excellent

This approach provides the pavement manager with an objective approach to assessing the "health" of the pavement, and determine the performance or pavement end of life. Figures 2 to 5 show the PCI for various ages, and in terms of the three traffic categories. Meijer noted in his work that where an insufficient length of road was stabilised in a particular location for

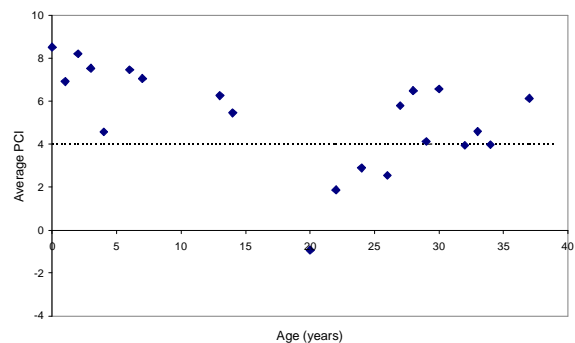
a particular category, the data was considered not representative and hence omitted.

The data indicates that the majority of cement stabilised pavements had a PCI exceeding 4 (i.e. considered reasonable) at ages up to about 25 years for the two traffic categories less than 2,000 AADT. Very few roads were stabilised where the traffic volume exceeded 2,000 AADT and the results (Figure 5) showed mixed performance, although a 20 year life is achievable.

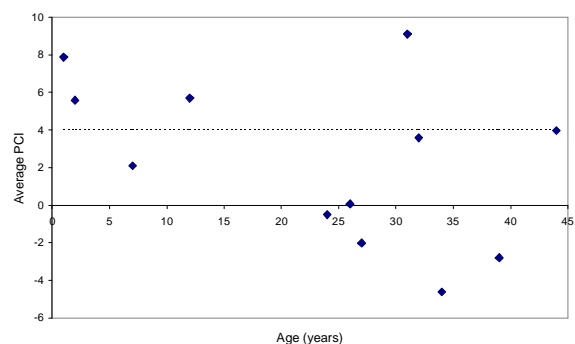
Meijer concluded that the *results suggest that cement stabilisation techniques are best suited to roads with low AADT, at least when the depth of stabilisation is less than or equal to 200mm and the material being stabilised is of a mainly clay content.* The performance data highlights that this road pavement alternative in Fairfield has met the 20 year design expectation for a flexible pavement.



**Figure 2** Pavement Condition Index (PCI) for stabilised roads with traffic at an AADT < 500.



**Figure 3** Pavement Condition Index (PCI) for stabilised roads with traffic at an 500 ≤ AADT ≤ 2,000.



**Figure 4** Pavement Condition Index (PCI) for stabilised roads with traffic at an  $2,000 < \text{AADT}$ .

### 2.3 Performance of Lake Macquarie Local Roads

In late 1997, engineer Matthew Pike at Lake Macquarie City Council (mid-NSW coast) completed his research work on the performance of insitu stabilised local government roads in the Lake Macquarie region [Ref.7]. The scope of the research was:

- Only ten roads were selected for assessment and the roads were constructed by Council with the aid of specialist stabilisation contractors. The pavement material was gravel from a local quarry owned and operated by Lake Macquarie City Council.
- All roads were stabilised with a blend of GP cement (80%) and fly ash (20%) at an additive rate of between 4 and 5% by weight of soil.
- The depth of stabilisation was 150 to 200mm.
- The predicted cumulative design traffic for a 20 year life of each pavement fell within the limits of  $3 \times 10^3$  and  $4 \times 10^5$  ESA's.
- Benkleman beam deflection bowls were used along with EfromD2 to back calculate the modulus of each road.

Whilst Pike had recognised the limitations of the Benkleman beam to provide reliable results for the determination of soil parameters, it was a relatively inexpensive method of establishing the existing pavement properties, especially in terms of stiffness. In addition, CIRCLY was used to determine the maximum base and subgrade strains in order to predict the allowable axle loads before failure.

Pike's study looked at the performance of the pavement in terms of the traffic on the pavement and Benkleman beam results in both lanes and wheel paths. The roads selected in the study are listed in Table 2 and are constructed on a clay subgrade varying in strength from CBR 2 to 13, and in some instances as high as 32.

The calculated traffic data indicates that the pavement traffic is similar to the period after construction in terms of a reference to the 20-year design life. The Benkleman Beam data in Tables 2 and 3 indicates that after several years of service the mean deflection over the four wheel paths is less than 1.0mm with the exception of James Street.

The conclusion presented by Pike may be summarised as follows:

- Adequate site investigation is to be undertaken prior to any stabilisation works. It was found that

the depth of various layers of the existing pavement varied markedly over the length of each inspected road.

- Pavements that are insitu stabilised with 80/20 blend of GP cement and fly ash exhibited some reflective cracking. However there was no indication, based on Benkleman Beam readings from the roads investigated that had reflective cracking, that this form of cracking would lead to lower life expectancy of the pavement.
- The desirable range (i.e. 1.5 – 2.0 MPa) of the UCS for insitu stabilised pavements is reasonable and should be the target for future stabilisation works.
- Insitu stabilisation of granular pavements considerably improves the Benkleman Beam deflection readings. It was found that after insitu stabilisation, the Benkleman Beam deflections of all roads tested except one, reduced substantially by between 14 and 66%. The standard deviation of results also reduced markedly, resulting in more homogeneity of deflections over the length of each road. Resulting curvature functions were also particularly low. It was found that these favourable beam readings could be sustained over long time periods, at least in excess of five years. It was concluded that the process of insitu stabilisation does substantially add strength and stiffness to the stabilised layer, even for relatively thin stabilised layers.
- The AUSTRROADS recommended value of 2,000 MPa for stabilised marginal materials, appears too high for pavements insitu stabilised in the city of Lake Macquarie. The typical range of stabilised base course moduli for the subject roads studied, each with a stabilised base depth less than 200mm, was 1100 – 1800 MPa, although two of the roads had average moduli exceeding 2800 MPa.
- Pavement moduli results back-calculated from Benkleman Beam readings and EfromD2 software should be considered as indicative only, not absolute. Variations in curve fitting between measured beam readings and the synthetic generated curve of EfromD2 were present to some degree in most of ten roads analysed.
- It appeared that the fatigue relationships in the Austroads, Queensland Department of Transport, and VicRoads design guides are inappropriate for estimating the fatigue life (ie repetition of axles to failure) of stabilised pavement layers less than 200mm thick. Using the strains from the CIRCLY analysis the life of shallow depth cemented pavements were  $7 \times 10^0$ ,  $8 \times 10^2$ , and  $5 \times 10^4$  ESA's as predicted by fatigue relationships in the Austroads, Queensland Department of Transport, and VicRoads guides respectively. These values were based on a pavement depth of 200mm, base course  $E=2000$  MPa, and subgrade modulus  $E=80$  MPa.

It was found in this study that some of the roads surveyed with similar characteristic values as just given, have had cumulative traffic far exceeding the predicted values yet show no signs of fatigue pavement failure. It is felt that for the roads that have not experienced this degree of traffic to date, the pavements will also exceed the life as predicted by the given fatigue relationships.

experience and history should dictate the appropriate design life.

- It is not possible to assess the design or remaining life of an insitu stabilised pavement with a cemented base layer less than 200mm using current mechanistic design principles. Rather, past

- Thin insitu stabilised pavements are capable of achieving a 20 year design life based on the Benkleman Beam readings, with regards to tolerable deflection and characteristic deflection as proposed by Mulholland [Ref. 7], and Austroads [Ref.8] respectively. Nine out of the ten roads studied are expected to perform adequately over a design life of 20 years.

**Table 2** Description of streets and traffic and Benkleman data [Ref.6].

Street Name	Pavement Age (years)	Stabilised Depth (mm)	Cumulative Traffic to Date (ESA's)	20 Year Design Traffic (ESA's)	Ratio of actual to design traffic	Benkleman Beam Deflections <sup>1</sup>	
						Before <sup>2</sup>	Jun-97
Gradburn & Curdie St	6.7	180.0	9.70E+04	2.80E+05	0.35	0.62	0.45
Statham St	6.2	180.0	5.90E+04	1.90E+05	0.31	0.78	0.48
The Groves	6.2	180.0	1.20E+05	3.90E+05	0.31	1	0.22
Ian Street	5.4	150.0	6.00E+04	2.20E+05	0.27	1.03	0.72
Dalwood Cl	4.7	180.0	3.80E+03	1.60E+04	0.24	N/A	0.61
Tahlee Cres	2.9	180.0	4.20E+02	2.90E+03	0.14	N/A	0.51
James St	2.9	180.0	3.70E+03	2.60E+04	0.14	1.21	1.13
Tennent Rd	2.2	200.0	1.70E+04	1.60E+05	0.11	N/A	0.38
Albert St	1.4	200.0	4.60E+03	6.70E+04	0.07	N/A	0.36
Robina Dve	0.3	180.0	2.60E+03	1.60E+05	0.02	0.72	0.49

Note: 1. The deflections represent the average deflection of four sites across the two lanes.

2. Existing road data before construction.

Refer to Table for full details. N/A refers to no data collected before construction of the existing road.

**Table 3** Mean deflection (mm) from Benkleman beam results in various wheel paths.

Street Name	Before construction				Jun-97			
	1m (L)	3m (L)	1m (R)	3m (R)	1m (L)	3m (L)	1m (R)	3m (R)
Gradburn & Statham St	0.63	0.75	0.54	0.54	0.41	0.54	0.39	0.46
The Groves	0.77	0.81	0.76	0.78	0.51	0.47	0.5	0.42
Ian St	0.85	1.15	0.78	1.21	0.21	0.21	0.2	0.26
Dalwood Cl	0.88	1.16	0.9	1.19	0.53	0.72	0.77	0.87
Tahlee Cres					0.48	0.85	0.55	0.54
James St					0.28	0.67	0.36	0.72
Tennent Rd	1.08	1.26	1.19	1.3	1.26	1.52	0.84	0.88
Albert St					0.25	0.46	0.3	0.51
Robina Dve					0.27	0.42	0.34	0.41
	0.65	0.87	0.6	0.76	0.42	0.63	0.41	0.49

Note: No data collection for "before construction" for Dalwood, Tahlee, Tennent and Albert streets.

### 3 Design

#### 3.1 History

In 1986 the NAASRA Guide to Stabilisation of Roadworks [Ref.9] was published and was then the state-of-the-art information on stabilisation. Unfortunately, it did not cover the design of stabilised pavements for strength as it relied on the NAASRA Guide to the Structural Design of Pavements. Two years later the Cement and Concrete Association of Australia published a guide on stabilisation [Ref.9] and noted that UCS testing yields cement contents which have been shown to correlate very closely with those which give good field performance. This publication suggested that the target binder content for local government roads should yield a 7-day UCS value in the range of 1.5 to 2.0 MPa. Also, these roads were typically 150-mm in thickness due to the low traffic volumes.

In the late 1980s CIRCLY by Mincad systems had proven to be a great software package for flexible pavements. The program allowed the designer to input wheel loads, and layered properties of the base, subbase and subgrade. The analysis was quick and engineers found the task of finding the maximum strain in each layer with some ease. CIRCLY only questionable assumption was the use of infinite layers in the model.

The Road Rehabilitation by Recycling Project produced the next generation of flexible pavement computer software using a finite element (FE) approach. The program uses the STRAND6 FE engine designed in Australia and currently available in many consulting engineers offices. This program is still currently undergoing development and it may complement CIRCLY in design offices.

#### 3.2 Design Issues

Stabilised pavements have generally been designed in a very conservative manner and over the last five years the empirical factors have been adjusted based on the results of several ALF Trials, in particular the Cooma Trial in 1994 [Ref.10].

The five main design variables for insitu stabilisation are:

- Design traffic over a specified period, such as 20 years
- Binder type and content in terms of the weight of the soil
- Pavement thickness
- Properties of the stabilised material over time.
- Strength of the subgrade

Whilst the weather and locality play an important role in the decision making process they are not used in any of the current design models for stabilised pavements.

#### 3.3 Design Approaches

There appears to be three approaches to the design of insitu stabilised local roads. The first is the traditional selection of a binder content that will provide a 7-day UCS of about 1.5 to 2.0 MPa and 150, 180 or 200-mm in thickness is chosen according to the traffic volume and local experience [Ref.17]. The binder commonly used with this approach is either a GP or GB cement.

The next approach is to use design charts that require the design ESAs, the subgrade strength in terms of CBR and the appropriate modulus of the stabilised pavement material. Using these design variables the determination of the pavement thickness is read off a chart. Similar to the previous method the binder is tested at various values to achieve a target UCS at 7-days of 1.5-2.0 MPa.

The final and refined approach is to analyse the pavement using CIRCLY and test the stabilised pavement with various binder content to determine Poissons ratio, modulus and UCS. Using the various fatigue relationships the allowable number of axle repetitions may be determined and compared with the estimated design traffic. Section 3.5 of this paper discusses these methods in more details and limits the discussion to blended cementitious binders, and does not cover lime only or cement/bitumen binders. It is suggested that the designer refers to the AustStab Guideline on Binders [Ref.11] to select an appropriate binder for various soil types.

#### 3.4 Traffic Data

It is difficult to estimate the traffic on local government roads as the design vehicles, that is commercial vehicles exceeding 3 tonnes, are small in number compared to the average annual daily traffic. The recent Austroads publication [Ref.12] on light traffic is the best guide to estimate traffic volumes and Figure \* shows the indicative ESAs for a 20 year design life for various street types. Construction traffic during the development of the estate has been taken into consideration in the final ESAs.

The Austroads Guide [Chapter 7, Ref.8] may also be used to determine the design traffic on the pavement and a *National AustStab Guideline* titled *Traffic Estimate* [Ref.13] was published in 1996 to assist designers with the calculations. It is noted that Chapter 7 of the Guide is under review and it is likely that a different approach will occur for traffic estimates for flexible pavements.

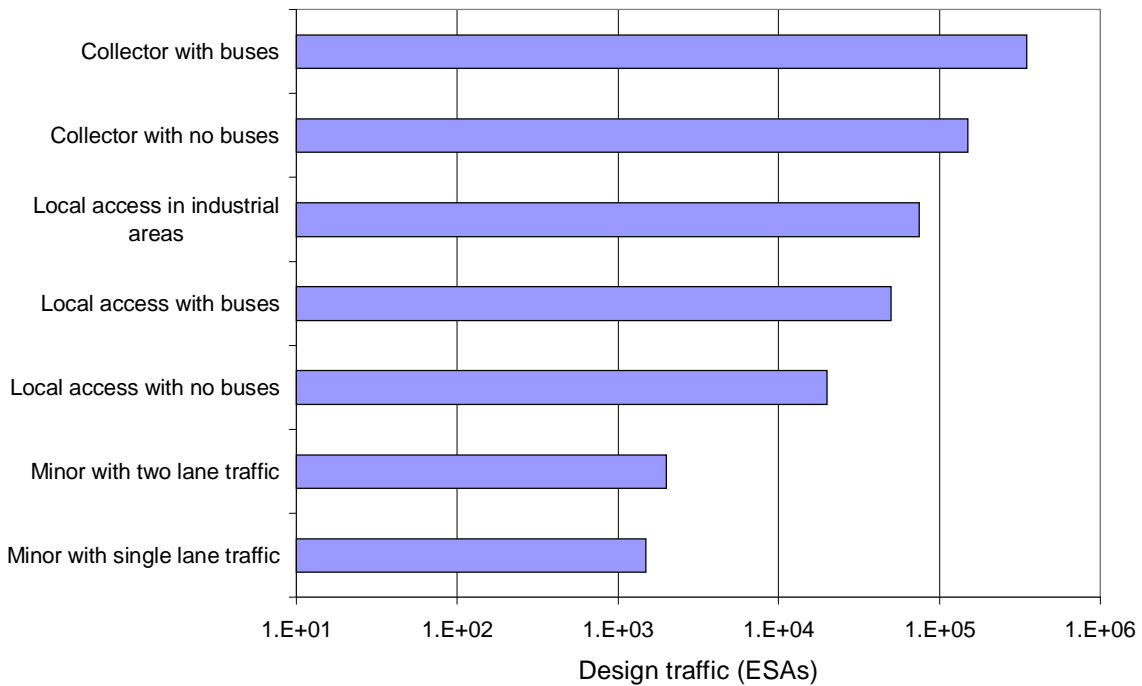


Figure 5 Indicative values of design traffic for flexible pavements [Ref.12].

Whatever method is used to derive the design ESAs, it must be noted that the design traffic should reflect the growth in commercial traffic and not the AADT over the design period. The initial estimate of AADT should also be carefully collected or selected.

In the determination of the pavement thickness using the CIRCLY the number of axle repetitions should be factored by 10 and not 20 for use in the design method described in Chapter 8 (ie as noted in Section 7.5.3) of the Austroads Guide. This factor adjusts the data to allow for the 4<sup>th</sup> and 12<sup>th</sup> power damage law.

### 3.5 Pavement Thickness

In 1992, the Austroads Guide [Ref.8] provided fatigue relationships and complex thickness design charts for the design of stabilised pavements using cementitious binders. The RTA reorganised these charts to provide a simple approach where the pavement wearing surface is thin, and does not contribute to the strength. Figure 6 shows one such chart where the designer selects the appropriate CBR subgrade strength and the E value for the cement material. Using the design ESAs, the minimum thickness for the layer can be determined. These charts were based on equation 1 below.

$$N = (K/\mu\epsilon)^{18} \tag{Eqn 1}$$

Where K = 280 for Base E = 2,000 MPa, and  
K = 200 for Base E = 5,000 MPa

For example, if the strain at the bottom of the stabilised layer was 150 microstrain ( $\mu\epsilon$ ), then N = 1,790.

After the Beerburrum and Cooma ALF Trials the equation was modified to:

$$N = (K/\mu\epsilon)^{12} \tag{Eqn 2}$$

Where K = 440 for Base E = 2,000 MPa, and  
K = 310 for Base E = 5,000 MPa

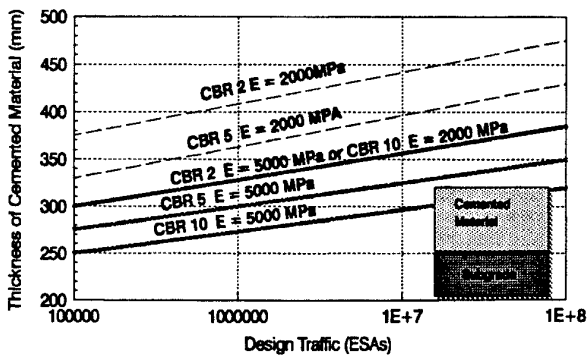
Using Equation 2 (also refer to reference 14) with a strain at the bottom of the stabilised layer at 150 microstrain ( $\mu\epsilon$ ), then N = 406,000. Therefore, the refined Austroads equation from the ALF trial has a dramatic change on N. Hundreds of kilometres of main roads have been designed and constructed to this new fatigue relationship and discussions with engineers indicate that the pavements are performing very well.

In the determination of N in equations 1 and 2, the designer needs to select an appropriate value of E. The traditional or empirical values [Ref.8] of E have been based on the content of the binder, that is:

$$E = 1814 UCS^{0.88} + 3500 \text{ for cemented crushed rock} \tag{Eqn 3}$$

$$E = 2240 UCS^{0.88} + 1100 \text{ for cemented natural gravel} \tag{Eqn 4}$$

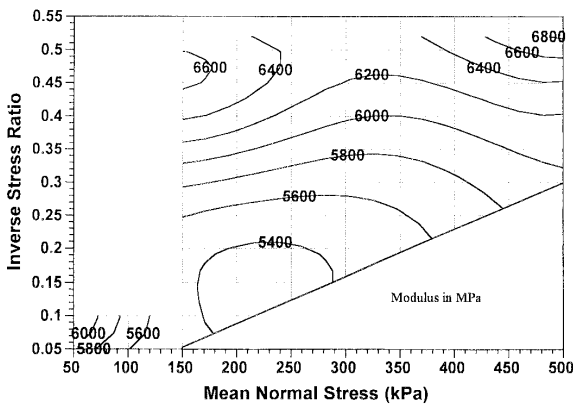
The UCS is based on the unconfined compressive strength to the Queensland Main Roads Department test method (1982).



**Figure 6** Design thickness of cement stabilised layers for various subgrade strengths and material stiffness. Curves based on CIRCLY analysis using the Austroads 1992 fatigue relationship.

Alternatively, the RTA has defined  $E = 5,000$  MPa for heavily bound layers consisting of about 4% of binder which results in a UCS after curing of 4 MPa. For lightly bound pavements with about 2% of binder,  $E = 2,000$  MPa is used.

It has been well documented now that  $E$  is a function of the applied load. The Road Rehabilitation by Recycling Project in SA approached this issue by establishing a test method that could provide a better estimate of  $E$  for use in the CIRCLY analysis [Ref.15]. A laboratory procedure was devised and a chart showing the modulus for varying loads shows how  $E$  can vary significantly in the design procedure (refer to Figure 7).

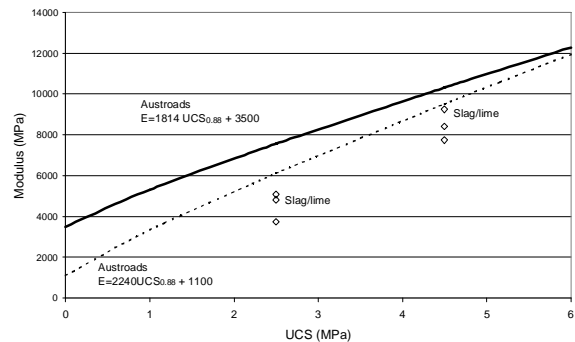


**Figure 7** The resilient modulus at 28 days for the stabilised Mount Pine quarry gravel with 4% GP cement [Ref.15].

Cores taken from the field trials on the Sturt Highway, SA indicated that the resilient modulus of elasticity varied from 5,500 to 19,400 for 4% blended cement of 80% GP cement and 20% fly ash [Ref.4]. It is important to note that the modulus will vary according to the variations in the soil along the road and the curing adopted during construction.

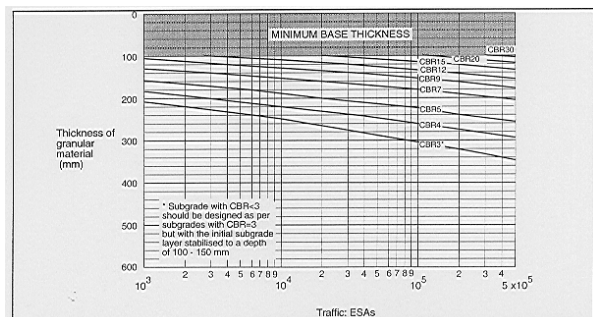
The project also established the soil properties of stabilised material consisting of a well-graded gravel from the Mt Pine Quarry in the Brisbane region. These properties are listed in table 4.

The recent ALF trials at Dandenong in Victoria [Figure 10, Ref.16] indicated that the  $E$  value from core samples under the loaded trial pavement consisting of the 5% slag/lime binder, with the marginal sandstone material, showed a close approximation to the Austroads equation for cemented natural gravels (Eqn 4) as noted in Figure 8. The UCS values of 2.5 MPa and 4.5 MPa are at 69 and 488 days respectively.



**Figure 8** Comparison of resilient modulus and UCS of slag/lime cores of similar age from Dandenong ALF trial [Ref.16]

Finally, Chapter 13 of the Austroads Guide [Ref.8] provides design charts for various levels of reliability for granular materials (see Figure 9). This document notes that the charts are satisfactory for materials stabilised with about 2% of a cementitious binder. Using the design charts for various confidence levels and street types, tables can be constructed for various confidence levels and subgrade CBR values such that a catalogue of designs will occur as shown in Table 5.

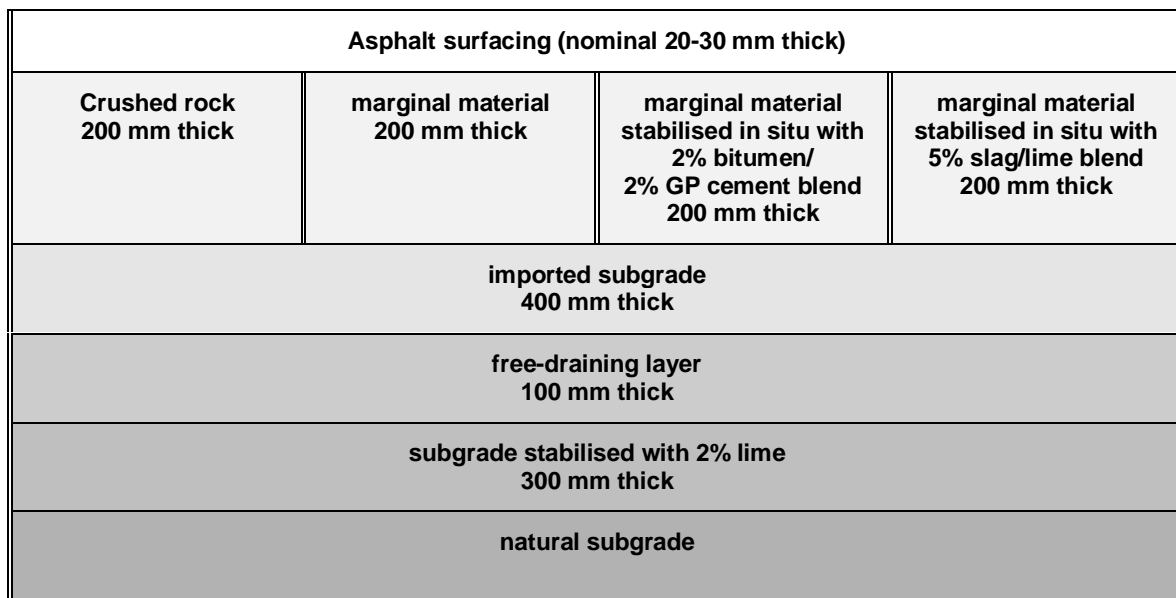


**Figure 9** Design chart for granular pavements with thin bituminous surfacing. This chart is suitable where the confidence level is at 80% [Ref.12].

**Table 4** Stabilised soil properties from Brisbane region with various binders [Ref.15]

Binder	UCS <sup>1</sup> (7 days)	UCS (28 days)	Wet-Dry Durability Test <sup>2</sup>	Average Modulus of Elasticity <sup>3</sup> (MPa)	
				(7 day)	(28 day)
GP cement/FA (70/30)	1.5	2.1	3.5	3750	5150
GP cement/FA (75/25)	1.8	2.1	3.5	2950	5500
GP cement/GGBFS (40/60)	1.4	2.9	2.8	1550	2600
GP cement	1.7	1.9	2.8	-	-

**Note:** 1. UCS to AS 1141.51 – 1985. 2. % soil loss to ASTM D559-89. 3. Average of minimum and maximum values using AS1289.6.8.1-1995.



**Figure 10** Cross-section of test pavements for trial.

**Table 5** The minimum stabilised base layer (mm) for local roads with various subgrade CBR values for an 80% confidence level. The shaded area indicates that a minimum base thickness of 150-mm is recommended by AustStab.

Street type	Subgrade CBR		
	3	5	12
Minor with single lane traffic	215	160	100
Minor with two lane traffic	220	170	100
Local access with no buses	270	200	120
Local access with buses	290	220	130
Local access in industrial areas	300	220	140
Collector with no buses	320	230	140
Collector with buses	340	250	150

#### 4 Summary

The design methods of insitu stabilised pavements for local government road are developing as further work on research and performance assessment continues to be published and scrutinised by practitioners. This paper has shown that there are at least three design methods for insitu stabilised pavements up to about 200-mm in thickness. One of the important elements in the design model is the overall selection of an appropriate binder and consideration should be given to stiffness of the pavement.

The qualitative performance study by Hodgkinson in 1991 confirmed that the simplified design models in the 1970s and 1980s resulted in stabilised pavements reaching their desired 20-year life.

Recent quantitative studies by local government engineers highlight some of the shortcomings of using linear elastic analysis to assess the performance of stabilised pavements based on accelerated performance data from ALF trials on thicker pavements.

The Road Rehabilitation by Recycling project broke new ground by developing a test method to provide more reliable predictions of the stabilised layer modulus in order to give more accurate material fatigue prediction models. In addition, the field trials outlined the methods that may be employed to monitor the performance of stabilised pavements.

With the recent use of various slow setting cementitious binders for deep-lift construction which are now being specified for local government projects, the construction and design decisions must be complemented to allow the pavement to perform as intended.

The new Austroads publications due in 1998 on Stabilisation and Lightly Trafficked roads will provide pavement engineers with a new suite of design models in order to carry out simple and refined pavement analysis.

#### 5 References

Papers noted with [WEB] are available on the AustStab web site at [www.auststab.com.au](http://www.auststab.com.au)

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