ECONOMIC ROAD

INFRASTRUCTURE INVESTMENT

THROUGH INSITU STABILISATION

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ABSTRACT

This paper reviews a number of road pavements in Australia that have been rehabilitated using insitu stabilisation technology. The review has been undertaken mechanistically to evaluate structural design, construction achievement and field performance. In addition, the paper illustrates the manner in which insitu stabilisation technology was successfully adapted in India.

INTRODUCTION

The major component of Australian infrastructure both in size and capital value is the road network comprising 800 000 kilometres of sealed and unsealed pavement. Furthermore, as the largest single contributor to the transport industry, asset management authorities spend A$6 billion annually on maintaining and adding to the infrastructure network.

With the majority of the sealed network now well over 25 years old, particularly the rural arterial network, it is recognised that a major structural rehabilitation strategy needs to be put into place to preserve the asset.

By contrast, India has one of the largest road networks in the world comprising 163 000 kms of national and State Highways total and 2.7 million kms of major district and other roads. Since 1951, road freight has increases from 6 to 400 billion tonne-kms and passenger movement from 23 billion to 1500 billion passenger kms. Furthermore, these figures are expected to double by the year 2001.

In this context road infrastructure development in India demands economic technologies on a grand scale for both construction of new pavements as the network must be expanded and in rehabilitation of the existing network to meet increased traffic loading.

STRATEGIC BENEFITS OF INSITU STABILISATION

Strategic benefits of insitu stabilisation fall into the following categories:

Environment & Heritage

- Limits the demand for new materials to be extracted from pits and quarries.
- Obviates costs incurred in materials search for new pits and quarries.
- Obviates the impact of pits and quarries on the landscape and compromises with heritage issues.
- Facilitates incorporation of industrial waste and by-products like flyash and slag

Economics

- As a continuos process, rehabilitation costs are in most cases at least 40% lower in capital cost.
- As a stiffer pavement, life cycle costs are often much lower than granular pavements.

Road User Impacts

- Full width access is offered at the end of each day to reduce delay costs and increase safety.
- Project completion times are generally at least 30% quicker.
- Road safety is enhanced with improved unsealed road surfacings.

INSITU STABILISATION APPLICATIONS

In the early sixties and seventies, insitu stabilisation using bitumen emulsion or cement was used quite extensively using grader or harrow mixing. Then in 1986, as a result of local marketing by Brighton Stabilisers (now Pavement Technology Ltd) the technology was *re-discovered* particularly with the availability of *new* mixing machines and efficient cement spreaders. The next major advancement came in 1991 with the introduction of larger machines capable of deeper depths.

In 1993, such was the recognition of the impact of insitu recycling of road pavements, that the University of South Australia (SYMONS & POLI 1996) in collaboration with the Federal Government and others established a A$1.2 million three year research project. The outcomes have led to improved characterisation of stabilised pavement materials for mechanistic design.

Since 1986, Transport SA has rehabilitated over 800 lane kilometres of national and rural highways and the following lists a selection of projects undertaken during this period to illustrate the wide variety of applications which suit specific circumstances:

1. 1986 - The first recent major insitu stabilisation project was the full width rehabilitation of 16 kilometres of the Kalangadoo Glencoe pavement using Type GP cement and pavement depth of 250 mm.
2. 1990 - Full width stabilisation of 11 kilometres of the Flinders Highway using a two layer cement stabilisation process to achieve a depth of 300 mm and Type GP Cement.
3. 1991 to present - Selected full width rehabilitation of sections of the Eyre Highway between Lincoln Gap and Ceduna. incorporating either 4% or 2% blended cement at depths in excess of 300 mm.
4. 1995 - Two metre widening of 33 kilometres of the Eyre Highway (MM830 to 798) using lime and flyash to modify a high plasticity pavement material.
5. 1994 - Full width rehabilitation of 16 kilometres of the heavily trafficked Dukes Highway between Bordertown and the Victorian Border, heavily bound to a depth of 400 mm with 4.5% blended cement..
6. 1995 - Full width rehabilitation of three kilometres of the Lincoln Highway using lime flyash to achieve a fully bound pavement supporting a thin asphaltic surfacing with the expectation of reduced transverse shrinkage cracking commonly observed with cement stabilisation.
7. 1996 - Full width rehabilitation of eight kilometres of the heavily trafficked Angle Vale Road using 4% blended cement to produce fully bound 400 mm thick pavement incorporating a SAMI and 35 mm dense asphaltic surface.
8. 1993 to 1996 - Full width rehabilitation of Waterloo Corner Road, a heavily trafficked urban pavement constructed in three stages over five years and incorporating trial fabric interlayers beneath 35 mm asphalt to combat reflective cracking.
9. 1996 - Full width rehabilitation of Main North Road Clare using 4% cement to a depth of 350 mm and incorporating a cold overlay treatment to reduce surface roughness.
10. 1996 - Full width rehabilitation of Mallala main road using 2% cement modification to 250 mm depth in a residential area but subjected to heavy traffic with grain carting to adjacent silos.
11. 1997 - Full width reconstruction of 3 kilometres of Andamooka Main Street using foam bitumen and cement binders to a depth of 250 mm to combat periodic 1.5 metre deep flooding.
12. 1998 - Lane width rehabilitation using 1% lime to a depth of 250 mm of newly constructed overtaking lanes on Dukes Highway following shear failure of granular basecourse.

ADVANCES IN INSITU STABILISATION TECHNOLOGY

Over the past 12 years significant advances in machinery, quality control, binder selection, pavement design techniques and back analysis of constructed pavements have been developed and briefly described below

Binder Selection and Quantity Required

Application of insitu stabilisation to local government roads has predominantly been undertaken on residential streets using cement binder to a depth of around 150 mm. Many roads have been rehabilitated in this manner and are providing satisfactory performance.

These types of pavements are classified as rigid in the sense that they are subject to tensile stresses on the underside of the layer and as such tensile fatigue cracking is the governing design factor. Stabilisation mix design is carried out by determining the unconfined compressive strength characteristics over a range of binder contents. Typically a target UCS of 2.0 MPa is adopted to ensure sufficient pavement stiffness for a 150mm thick layer.

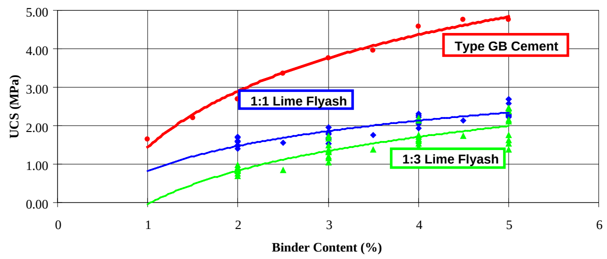


Figure 1 UCS & Binder Content

Figure 1 gives an example of the relationship between UCS and binder content for 20mm Class 2 Crushed Rock.

Whilst UCS (AS1141. 51) can be used for mix design it does not provide the mechanistic design parameters of Resilient Modulus and Poisson Ratio. These two parameters can be determined from modified repeated load tests developed for granular materials and described in AS 1289 6.8.1and illustrated in Figure 2.

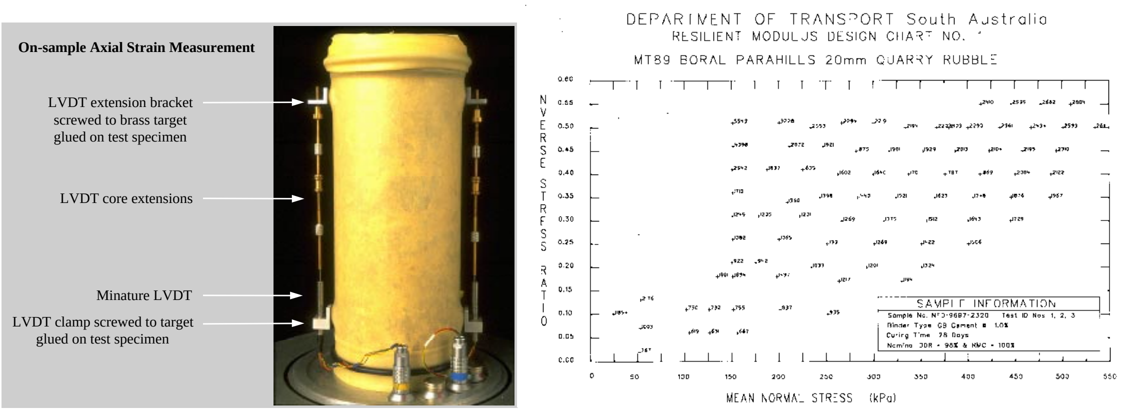


Figure 2 Repeated Load Testing

The results of the test are direct input into the Austroads mechanistic design procedure which considers the pavement as a load bearing structure. The analysis calculates critical strains at specific locations in the pavement and then relates it to an empirical fatigue model.

Alternate Dry Powder Binders

Addressing the improvement of insitu stabilised pavements using dry powder binders has resulted in experimentation and adoption of slower setting binders with lower shrinkage characteristics. These types of binders also provide for increased working time because of the slower set. However it must always be recognised that the hydration of cementitious binders is temperature dependent. In conditions colder than about 20^0C very little stiffening will occur and subsequent overnight trafficking will induce some surface ravelling.

Other dry powder type binders used are :

- Lime and fly ash combinations where fly ash is readily available from coal burning power stations as a saleable product. These binders are particularly suited to high plasticity pavements and situations where the subgrade needs to be incorporated.
- Lime and slag combinations (generally proportions 15/85) where slag originates from the iron and steel industry and processed to a granular form. These binders are also suited to high plasticity pavements
- triple blends of cement lime and flyash or slag, where advantage is taken of the more rapid strength gain from the cement portion.

Figure 3 illustrates strength gain of two lime fly ash blends as compared to Type GB Cement

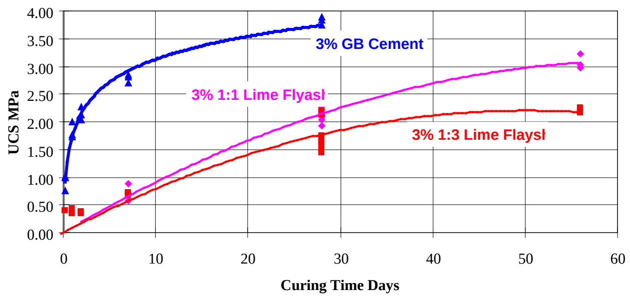


Figure 3 Gain in Strength with Time

Lime slag binders display even slower setting times as shown in Figure 4.

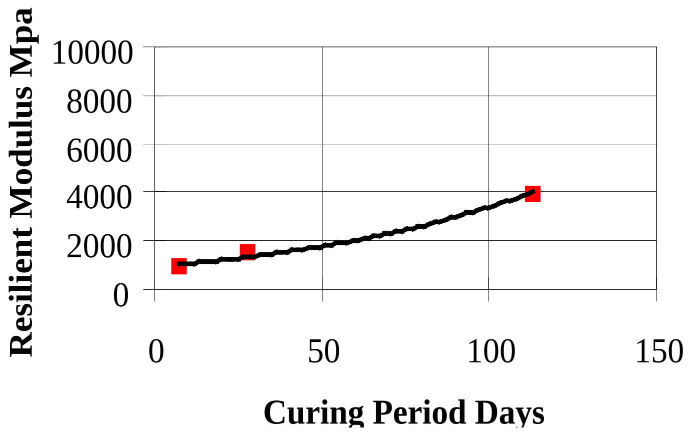


Figure 4 Strength Gain for Lime Slag (15/85)

Chemical Stabilising Agents

Over the years a myriad of these types of products have been marketed but all have suffered from a lack of quantitative analysis to provide a measure of benefits or support manufacturer claims.

Products generally are ligno sulphonates which have an adhesive action, electro chemicals with an ionic action or salts which crystallise. The majority of products activate the clay particles by breaking down their chemical plate type bonds and reconstituting them into a lattice type structure. Consequently they require a minimum plasticity index of about 10 to be effective. In addition, some products dissolve when wet eg salts, or leach out with time and consequently may only be of a temporary measure.

Table 1 gives an indication of what is available on the market.

Table 1 Chemical Stabilisers

Product Name	Type	Base
Roadbond EN- One	Liquid Stabiliser	Ligno sulphonate
Roadbond SS 2-3-5	Liquid Stabiliser	Ligno sulphonate
Road Tech 2000	Liquid Stabiliser	Electro chemical
Reynolds RT 12	Liquid Stabiliser	Electro chemical
Reynolds RT 20	Liquid Compaction Aid	Electro chemical
Bitumen Emulsion	Liquid Stabiliser	Petroleum
Dustmag	Liquid	Magnesium salt
Paczyme	Liquid	Electro chemical
Magchlor	Liquid dust suppressant	Magnesium chloride salt
Endurazyme	Liquid	Electro chemical
Dustex	Powder Stabiliser	Calcium Ligno sulphonate
Weslig 120	Powder	Ligno sulphonate

Over the past two years, a greater interest in the quantitative evaluation of these products has developed for unsealed roads in an attempt to address efficient management of this large portion of the Australian road network

Such evaluations have centred on field trial sections rather than laboratory tests like CBR.

Of the laboratory tests that may indicate some field performance is the Transport SA *Drip Test* illustrated in Figure 5 with results illustrated in Figure 6. This test is simple and provides an immediate indication of whether a product is worthy of further expensive evaluation.

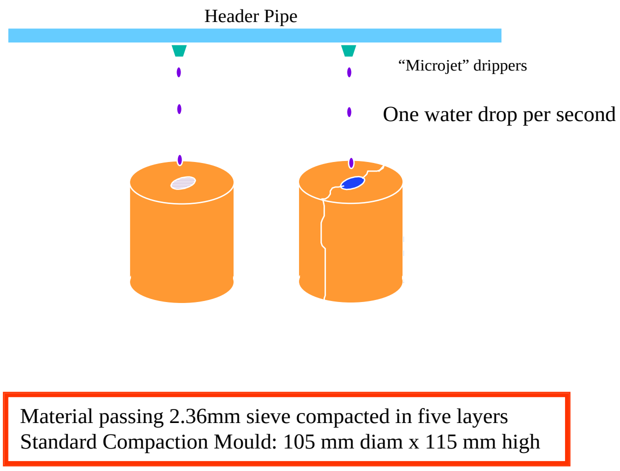


Figure 5 Drip Erosion Test

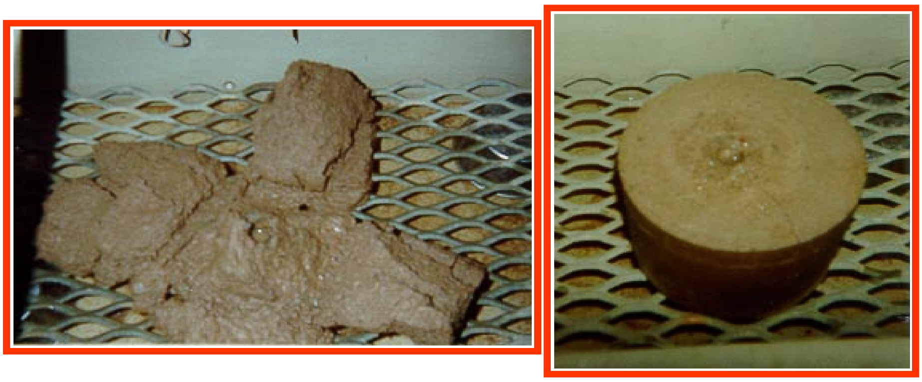


Figure 6 Untreated (left) Roadbond EN-1 Stabilised (right) after 24 hours

Construction Equipment

Controlling binder spread rate has improved by the use of electronic weighing and automated flow adjustment of binder discharge. In addition, carrying capacities have increased to more economically transport binder to construction sites as shown below:

Figure 7 Spreaders 1986 and 1998

Reclaimer/recyclers have undergone dramatic change in terms of increased depth capability allowing single deep lift construction to be adopted on much higher trafficked roads. Typically 400mm capacity is normal with Transport SA adopting two mixing passes for depths in excess of 250mm.

Figure 8 1986 Raygo Reclaimer/Recycler and 1993 CMI RS 500

Because of increased mixing depths, compactive effort has had to subsequently increase. This has been achieved not only by using heavier vibrating rollers but incorporating the benefits of kneading compaction gained from pad foot configurations.

Figure 9 1986 12 tonne vibrating & 1998 17 tonne vibrating rollers

PERFORMANCE OF CEMENT STABILISED PAVEMENTS

Whilst the performance of cement stabilised pavements has been satisfactory in consideration of the cost savings offered by the process very occasionally they suffer from the following defects :

- transverse shrinkage cracks requiring periodic crack sealing which whilst being structurally competent can detract from the pavement aesthetics.
- random fatigue failures due to changes in subgrade stiffness cause by say leaking water pipes.
- selective fatigue failure due to changes in road function by say incorporating bus stops.
- on old pavements constructed from pit materials and carrying higher speed traffic, large sized stones can produce a rough surface.

Examples of fatigue and shrinkage defects are shown in Figure 10, however it should be noted that these attributes represent less than 5% of all stabilisation undertaken in South Australia.

Fatigue

Shrinkage

Figure 10 Typical Cement Stabilisation Defects

INSITU STABILISATION CASE HISTORIES

Eyre Highway Iron Knob - Lime Flyash Stabilisation

The features of this project are the selection of a lime flyash binder in lieu of cement.

In 1994, a 35 kilometre section east of Kimba was stabilised to a depth of 325 mm using 3% fly ash and 1% lime to counter plasticities around 16 to 20**)**. The composition and type of binder was selected from an extensive laboratory testing program in the knowledge that nearly half the total project cost is taken up in the cost of binder.

Results from the laboratory test program are shown in Table 2 together with binder costs for the total project (rounded to nearest $1k)

Table 2 Laboratory Testing for Binder Selection Eyre Highway Kimba East)

Binder	UCS @ 7 days	Resilient Modulus @ 7 days	Total Binder Cost
Untreated	N/A	250	N/A
2% GB Cement	0.83	550	$278 000
3% GB Cement	1.20	700	$417 000
1.5% Fly ash, 0.5% Lime	0.50	370	$164 000
2% Fly ash, 1% Lime	0.70	470	$295 000
2.5% Fly ash 0.5% Lime	0.80	440	$258 000
Roadbond EN-1	**N/A**	**400** *	**$158 000**

* *Whilst the chemical stabiliser Roadbond EN-1 offers the lowest cost, this information has been added to the Table retrospectively as the product was not available in Australia at the time. The opportunity to trial the product was subsequently available towards the end of the project.*

The poor quality of the material is reflected in the low strengths offered from stabilising, however, the option still represented the most economical method. On the basis of the above a 2.5% flyash and 0.5% lime binder composition was selected.

Table 3 shows the structural pavement response and back-calculated moduli one month after construction.

Table 3 Deflection & Stiffness Characteristics Kimba East (Age one month)

	Deflection	Curvature	Pavement Modulus	Subgrade Modulus
Mean	0.471 mm	0.168	550 MPa	133 MPa
Standard Deviation	0.235 mm	0.105	368 MPa	58 MPa

Comparison of moduli in Tables 9 (laboratory determinations) and Table 10 (field achievements) indicate good agreement.

Recognising the slow setting characteristic of the binder and its continued strength gain (particularly during the cold construction weather, FWD testing was undertaken three years after construction (June 1997). The measured deflections and back-calculated curvatures are shown in Table 4.

Table 4 Deflection & Stiffness Characteristics Kimba East (Age 4 years)

	Deflection	Curvature	Pavement Modulus	Subgrade Modulus
Mean	0.506 mm	0.207	600 MPa	175 MPa
Standard Deviation	0.209mm	0.092	404 MPa	81 MPa

Figure 11 (clockwise) Spreading binders, double mixing, heavy compaction, final surface

Eyre Highway Lime Flyash & Chemical Stabilisation

To gain better understanding of lime fly ash stabilisation a 700 metre long trial section was constructed comprising six 100 metre lengths of half width stabilised pavement with various combinations of binder and one untreated control. This trial was incorporated into the GIRD project.

These sections have been monitored at six monthly intervals (summer / winter) for the past three years (Andrews 1997) using the Falling Weight Deflectometer. During this period no seasonal variation has been noted. The most recent (January 1998) results of back-calculated moduli for a single layer pavement model are summarised in Table 5 and Figure 12

Table 5 Lime Fly ash Trial Sections Resilient Modulus Kimba East

	Binder Type & Content	Modulus MPa
Section 1	Untreated Control	280
Section 2	Roadbond EN-1	400
Section 3	3% Lime Fly ash (1:3) + Roadbond EN-1	1400
Section 4	3% Lime Fly ash (1:3)	1000
Section 5	4% Lime Fly ash (1:3)	1500
Section 6	3% Lime Fly ash (1:1)	2300
Section 7	4% Lime Fly ash (1:1)	2500

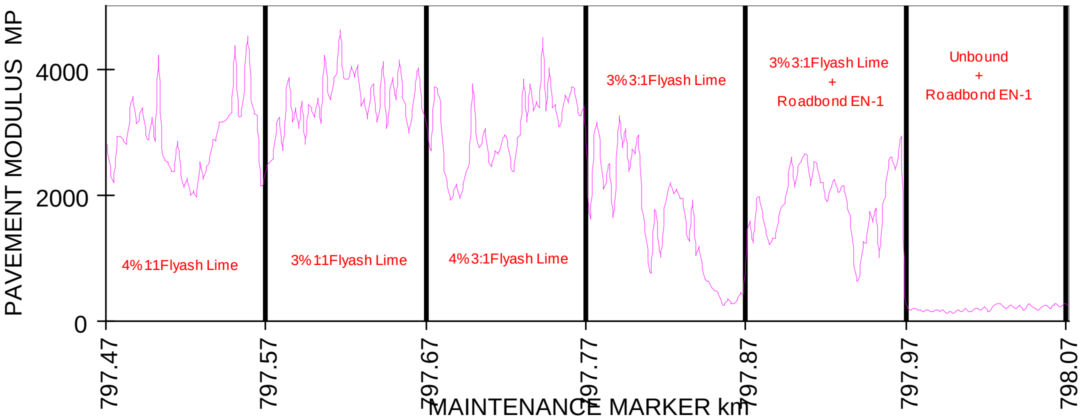


Figure 12 Pavement Modulus Kimba Trial Sections

Whilst the selection of an appropriate binder will continue to be determined from laboratory evaluation on major projects, the outcomes of this trial provide the following indicative observations:

1. The use of Roadbond EN-1 offered a cost effective solution to stabilising moderate to high plasticity pavement materials.
2. Comparison of Sections 2 and 3 suggest the use of a Roadbond EN-1 (in this instance) added in addition to a dry powder binder may offer a reduction in binder content and/or improve the efficiency of the cementitious binder by mobilising the clay fractions.
3. For the same binder contents, a 1:1 lime flyash binder will provide an equivalent long term strength to cement.

Eyre Highway Chemical & Cement Stabilisation

The features of this example display the benefits of chemical additives to reduce the amount of cement binder required.

As part of a 35km long widening project on the Eyre Highway, stabilisation using low quantities of cement were trialed in attempt to provide a stiff pavement without inheriting the cracking characteristics of heavily bound pavements. The use of cement in this project was preferred in that it provided immediate pavement stiffness in order for the road to be opened full width overnight. By allowing overnight trafficking, road safety is significantly enhanced however with slower setting binders rutting adjacent to the boxed out widening has often been experienced.

Figure 13 illustrates the deflection characteristics for the 35 km length of pavement and

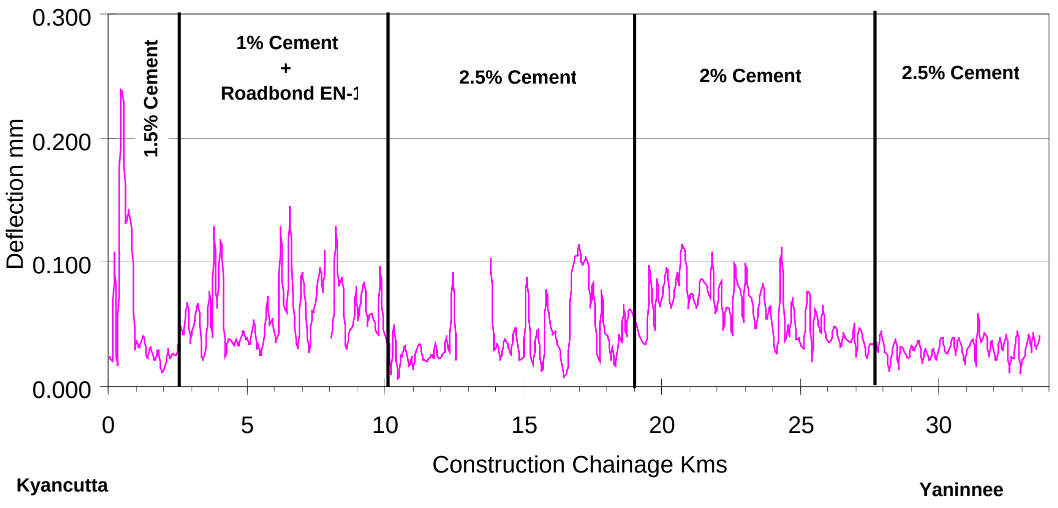


Figure 13 Deflection Characteristics Low Cement Contents

The corresponding pavement stiffness is illustrated below:

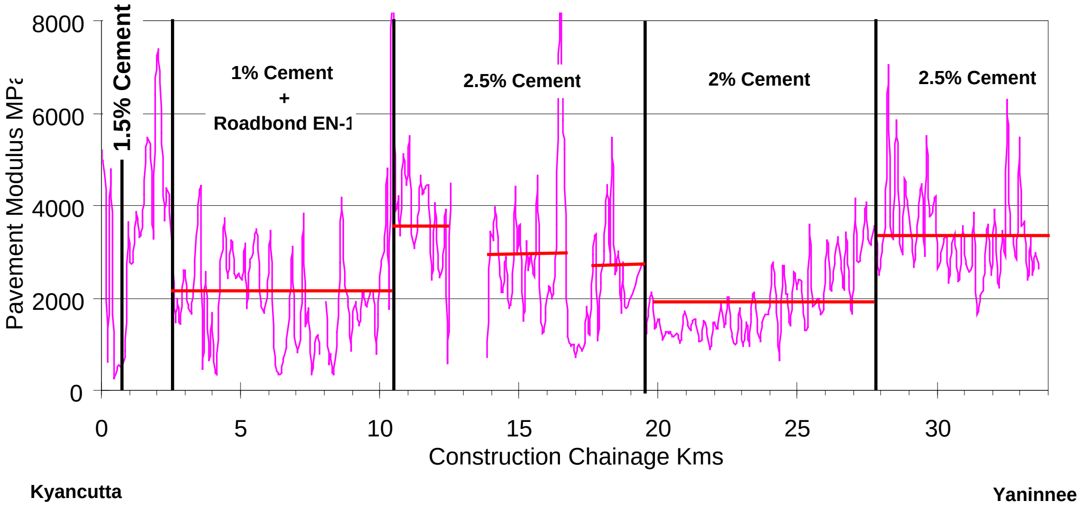


Figure 14 Pavement Stiffness Low Cement Content

The above illustrates that the inclusion of Roadbond EN-1 chemical effectively replaces 1% cement in terms of stiffness. As a result, shrinkage potential is reduced and subsequent cracking typical of cement stabilised pavements generally avoided.

Andamooka Main Street Foam Bitumen & Cement Stabilisation

The features of this project are to illustrate the use of a bituminous binder as reducing permeability characteristic whilst combing with cement to improve strength and erosion resistance.

The main street of Andamooka was an unsealed road in the bottom of a creek bed and as such was subject to occasional flooding by up to two metres of water. Whilst his volume of water could not be controlled, the project brief called for a *waterproof* pavement.

In considering binders, cementitious binders were not favoured because a high binder content would be required to prevent erosion and as a consequence cracking will occur. Based upon the success of the cement bitumen stabilisation in the Dandenong ALF Trial this binder was considered most suitable.

Laboratory evaluation of binder content was established by moulding specimens in a marshal compaction mould (gyratory compaction) and immersing in water to determine integrity. In addition MATTA indirect tensile resilient modulus were determined and expected to be over 10 000 MPa. However, this value is never realised in the field (Table 6) due to the different orientations of loading. It is the authors opinion therefore that indirect tensile testing of these materials to determine a design modulus is not appropriate and needs further development through Austroads and industry.

The final binder combination chosen was 3% residual bitumen (either as emulsion or foam) and 3% GB cement stabilised to a depth of 250 mm (material modulus 2500 MPa). Because of large boulders in the creek bed, it was decided to box out full width and replace with a 20 mm crushed quarry product form Roxby Downs. Figure 15 illustrates some of the construction process.

Figure 15 Foam Bitumen + Cement Stabilisation Andamooka

Construction was undertaken using a foam bitumen dry cement spread process working full width in one day. It was noted that some difficulties were experienced by the contractor in achieving uniform bitumen application due to frequent jet blockages.

A FWD survey conducted six months after construction is summarised in Table 6

Table 6 Deflection & Stiffness Characteristics Andamooka (Age six months)

	Deflection	Curvature	Pavement Modulus	Subgrade Modulus
Mean	0.132 mm	0.040	4558 MPa	353 MPa
SD	0.043 mm	0.023	1686 MPa	103 MPa

A final seal comprising a two coat SAM seal was applied and to date minimal exposure to rain has been experienced.

The cost of this project was $16 per sq metre for stabilising plus approximately $4 per sq metre for sealing. An comparative alternative is not suggested in this instance as selection of stabilisation was based upon operational requirements rather than cost.

Foam Bitumen & Cement Urban Corridor

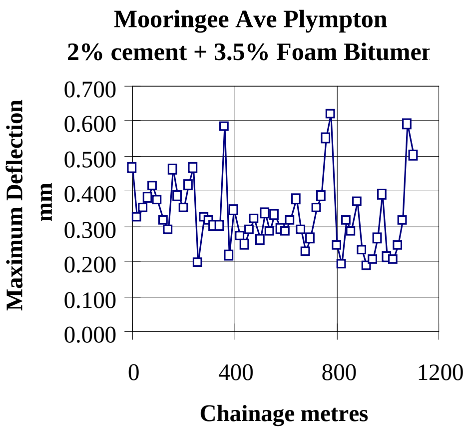
The features of this example illustrate a typical achievement in rehabilitation of a moderately trafficked asphalt surfaced urban pavement. The selection of foam bitumen and cement being made to produce a flexible pavement characteristic with lower sensitivity to moisture environment.

In April 1988, the City of West Torrens stabilised a 1.1 km length of pavement was stabilised to a depth of 250mm using 3.5% foam bitumen and 2% cement with a 35mm asphalt surfacing.

Figure 16 illustrates the deflection and curvature characteristics of the stabilised pavement form which:

- Deflections below 20 year tolerable (1.0 mm for traffic loading 3 x 10^6 ESA) suggest that adequate pavement thickness exists to meet subgrade rutting life.

- Curvatures below 10 year tolerable (0.17 mm for traffic loading 1.5 x 10^6 ESA) suggest that the pavement has adequate stiffness to meet asphalt tensile fatigue life.



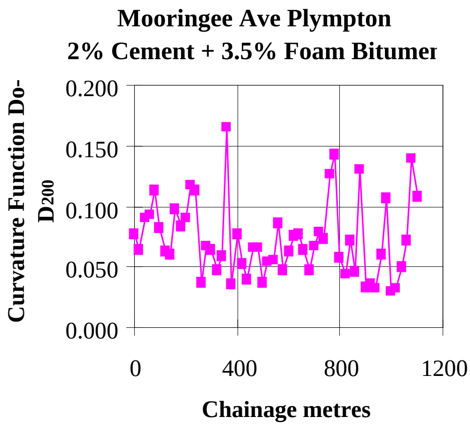


Figure 16 Deflection & Curvature Foam Bitumen & Cement

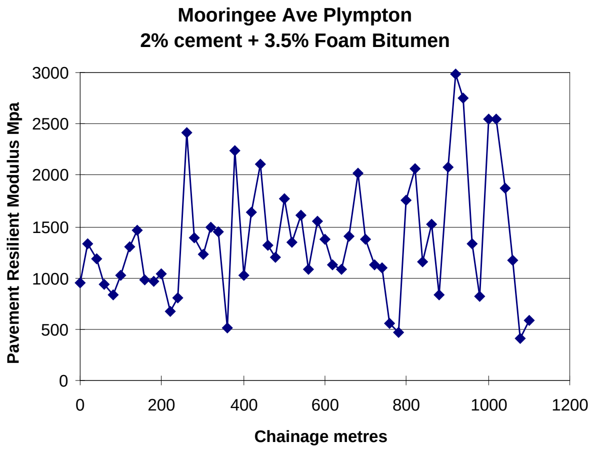


Figure 17 Back Calculated Modulus

National Highway 10 New Delhi India

The features of this example are to illustrate the use of a chemical stabilising agent [Roadbond EN-1] in producing a high quality granular basecourse from marginal materials. In addition, the example illustrates an opportunity offering improved and more economical pavement configurations over conventional macadam pavements with thick asphalt surfacings.

At the invitation of the Engineer - in - Chief New Delhi Public Works Department, two trial sections of contemporary pavement were constructed as lane expansion to contrast against traditional Indian construction.

Conventional road pavements in India comprise up to 500mm or more granular and macadam layers supporting a bituminous surfacings of up to 150mm. In contrast, a contemporary stabilised pavement was offered incorporating a stabilised pavement layers up to 350mm thick with a thin asphalt surfacing as shown below.

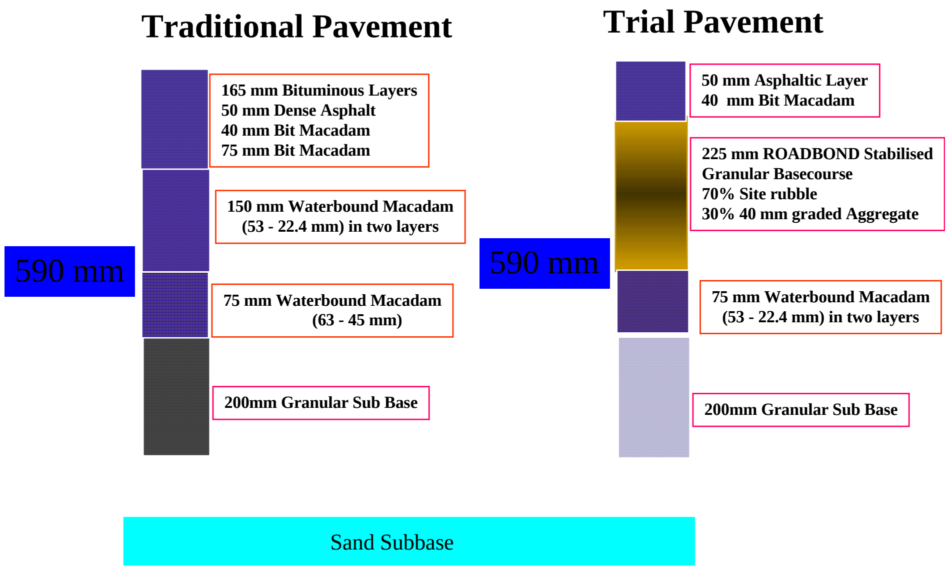


Figure 18 Trial pavement Configuration

The perceived benefits of this trial were based upon expectations from the Australian experience enabling marginal material to provide high performance and also introduce a simple but economical construction process and efficient pavement configuration. Therefore in the words of the Engineer in Chief, *The medicine must be tried on the worst patient*, with NH 10 being a two lane dual carriageway subjected to heavy traffic (at least 10^8 ESA) and displaying significant fatigue failure, cracking and surface roughness.

The basecourse was manufactured volumetrically using 65% insitu rubble from the boxed out formation and 35% discarded (flaky) hand broken macadam stone. In the first trial the chemical was added to a water tanker and added to the pavement by hand held hose. In the second trial a *conventional* spray bar was used. Mixing was undertaken using farm implements and compaction simply undertaken with a heavy static roller.

Post construction analysis of the conventional and stabilised pavements revealed characteristic Benkelman Beam deflections (moisture corrected) of 0.707mm and 0.537mm respectively. In terms of pavement life this improvement in deflection can be illustrated as follows using mechanistic analysis:

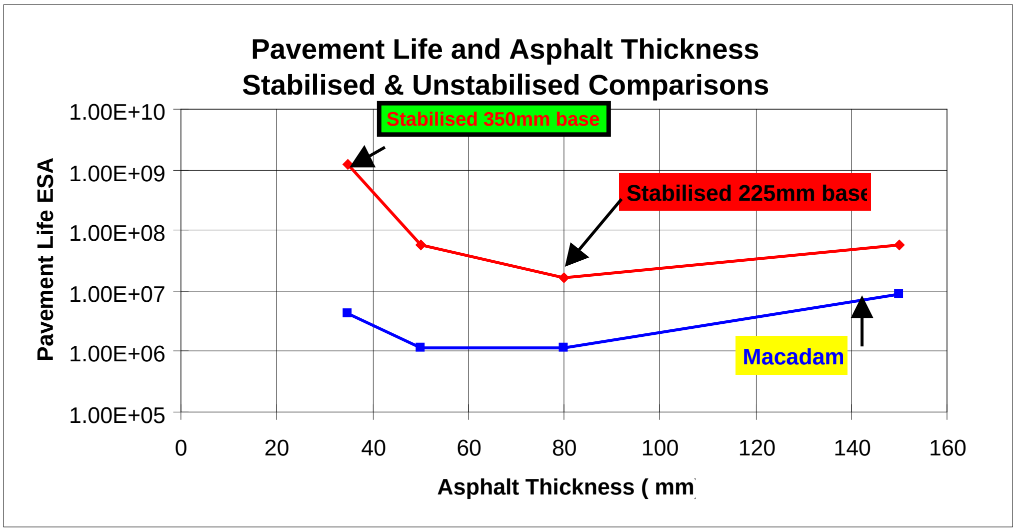


Figure 20 Pavement Life Expectations New Delhi NH 10

Unsealed Road Trials Copley

The unsealed road network contains significant freight and tourist transportation routes and the cost of maintaining these roads in the Northern & Western Region of Transport SA, exceeds $10 million per annum.

Traditional maintenance of these roads is seasonal grading and resheeting approximately every ten years. Over the past three years a network of bores have been established along the major unsealed roads in order to undertake wet maintenance in an arid environment. Wet maintenance is preferred as the material is easier to work and a tight compacted surface is generally achieved.

With this infrastructure in place, the opportunity to enhance wet maintenance by addition of chemical stabilising agents into the water cart became possible with no changes to work practices or additional equipment requirements. In addition, the success of these stabilising agents may offer opportunities to extend the period between resheeting interventions (less dust loss) and grading maintenance (less corrugations).

For the road user, the success of chemical stabilisation may provide opportunities to enhance road safety by reducing dust levels and the amount of loose material on the road.

The Copley trial was established in January 1998 by incorporating a number of products into resheeting the Copley Balcanoona road.

Figure 21 Copley Unsealed Roads Stabilisation Trial

Evaluation of the trial is being undertaken by scientific measurement of various parameters in addition to **road user assessments** of road condition, safety and dust levels. In addition an economic cost benefit analysis will be undertaken to establish the implications on managing the asset.

Scientific testing has included strength determinations using the FWD, surface roughness using the Two Laser Profilometer and physical removal and measuring loose material on the surface.

Figure 22 indicates the results of measuring loose material on the road in each test section after five months trafficking.

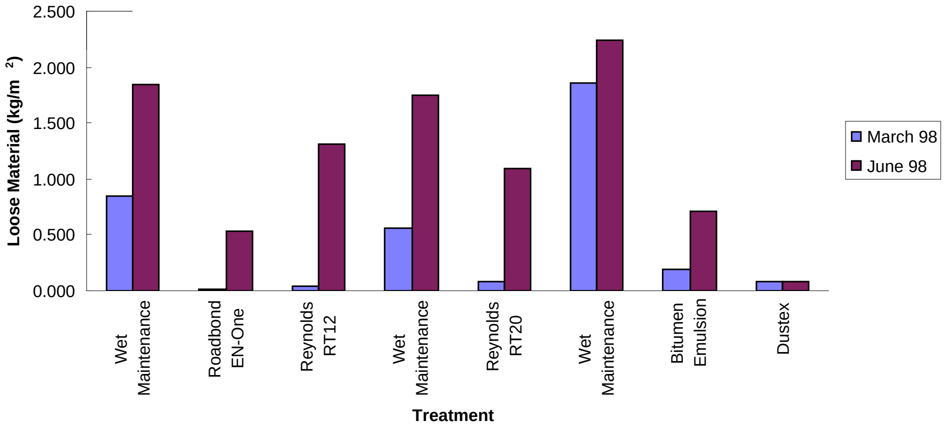


Figure 22 Loose Material after two and five months

The results in Figure 22 speak for themselves, and continued monitoring will provide a first base deterioration model upon which to undertaken the economic analysis.

It is also proposed to incorporate the products at other locations particularly targeting bends and intersections in an effort to enhance road safety, and at grid approaches to reduce corrugations forming.

The two laser profilometer was used on this project to evaluate its potential as a road condition measuring tool that could input into an unsealed roads management system. The first results undertaken after six months trafficking are shown in Figure 23.

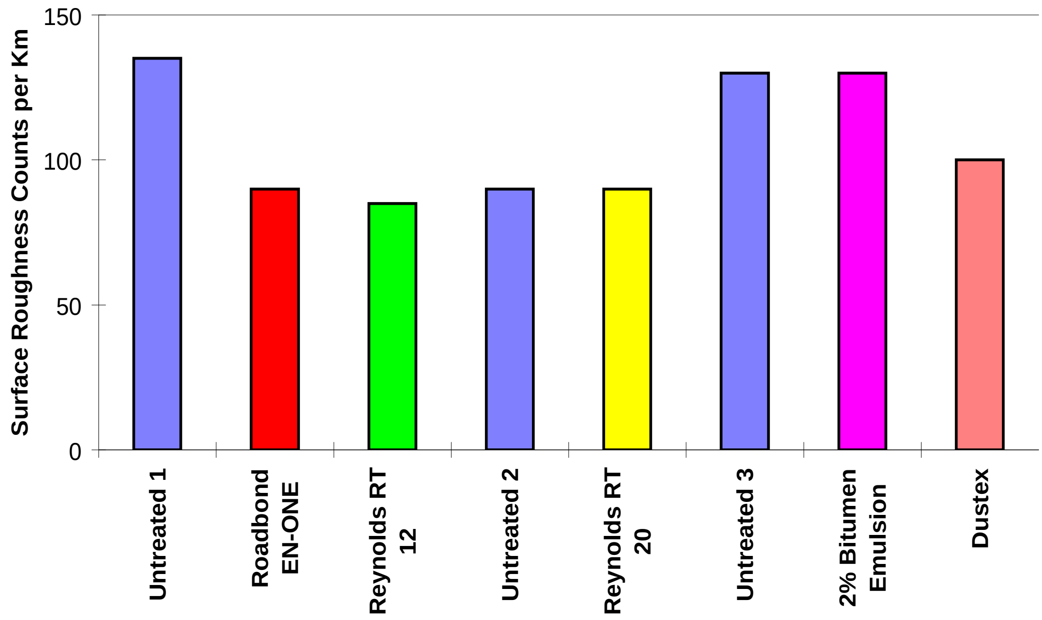


Figure 23 Two Laser Profilometer results

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