The importance of stabilisation techniques for pavement construction

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ABSTRACT

There has been a significant amount of well-documented research carried out in Australia and other countries into the processes of insitu stabilisation for pavement construction. However, despite this wealth of knowledge, many engineering consultants and indeed even pavement engineers often have a limited understanding of the applications and benefits of stabilisation techniques in pavement construction. This paper outlines the various applications where research into insitu stabilisation can be applied, ranging from improved subgrades through to total pavement construction. It looks at specific projects such as the widening of the runways at Changi airfield in Singapore, and the addition of an extra lane to the M4 motorway, Sydney, and a rehabilitation project on the Newell Highway, NSW. These examples illustrate techniques to fully utilise existing material, minimising the use of virgin materials while working under very restricted access and time restraints.

The paper provides guidelines as to when stabilisation techniques should be considered and suggestions on evaluation of the pavement structure. Evaluation of pavement designs should consider both economic and environmental outcomes. While economic evaluation is well understood, the paper explores factors that should be considered in the evaluation of a pavement structure to ensure compliance with the principles of sustainable development.

INTRODUCTION

For many years Australia has been considered a leader in the use of pavement stabilisation, primarily driven by necessity with our extensive road network, shortage of well graded materials, and a low taxpayer base in order to fund our roadworks. From many years of work, well proven design models have been developed for lime and cement stabilisation and further work is now being carried out on improving design models for foamed bitumen stabilisation and some chemical or blended stabilisers, in particular, dry powdered polymers [DPP]. However, despite this wealth of knowledge many engineering consultants and indeed even pavement engineers often have a limited understanding of the applications and benefits of using stabilisation techniques in pavement construction and reconstruction. In other parts of the world, in particular Europe, including the United Kingdom, the use of stabilisation for both road construction and for other ground improvement works has exploded in recent years driven primarily by environmental concerns.

The application of stabilisation techniques varies considerably between the regions and states of Australia. In Western Australia it is used primarily in base coarse construction to provide a modified pavement course of maximum unconfined compressive strength of 1 MPa. In Victoria subgrade stabilisation is used extensively, particularly in subdivisional work and pavement modification is often carried out using cementitious binders. In NSW hundreds of kilometres of highway have been recycled using deep lift heavily bound insitu stabilised pavements. Similar work has been carried out in South Australia and Queensland and Queensland has reintroduced extensive subgrade stabilisation projects following research into earlier projects and development of improved subgrade stabilisation techniques. Queensland also construct many roads using insitu stabilisation to modify pavement materials. Very few regions fully utilise all the applications of pavement stabilisation and few pavement engineers either understand or take advantage of the vast range of opportunities that stabilisation can provide to produce both economic and environmentally friendly pavements.

ENVIRONMENTAL CONSIDERATIONS

Conventional road construction depends on quarrying non-renewable resources; the process of stabilisation has developed primarily in areas where these resources are difficult to obtain. Little recognition has been given in the past to the preservation of these resources particularly where they appear to be readily available. It is surely the responsibility of engineers and designers involved in all forms of construction, and specifically in road construction, to give due consideration to the preservation of these valuable non-renewable resources for future generations. Countries such as the UK have imposed levies on quarried materials and the movement of soil from site to site, thereby, encouraging the conservation of materials and the reduction of the detrimental effects of trucking, resulting in far greater use of existing materials. No such incentives apply in Australia, although the association of Australian and New Zealand road transport and traffic authorities (Austroads) are committed to an environmental strategy, which among other objectives is aimed to reduce resource consumption and reduce green house gas emissions from the transport sector. Both of these, and other objectives are significantly obtained with the use of stabilisation techniques (Wilmot 2003). Preliminary work has been done on quantifying the costs of environmental factors of different roadwork designs (Smith 2005) and more attention needs to be paid to the introduction of these costs when evaluating pavement design options.

This work has indicated that we should be giving far greater regard to the environmental costs of different pavement designs. **Fig. 1** illustrates the very significant environmental and social costs associated with 5 alternate forms of pavement construction for an Australian case study (Smith Southey Wilmot Wilmot 2004). Similar results have been presented for other case studies including Whangaparaoa Rd. New Zealand (Kett, Browne, Quickfall 2006). These studies all demonstrate that the use of insitu stabilisation and where possible the use of recycled materials lead us a great deal closer to constructing pavements which may be considered as complying with a sustainable development.

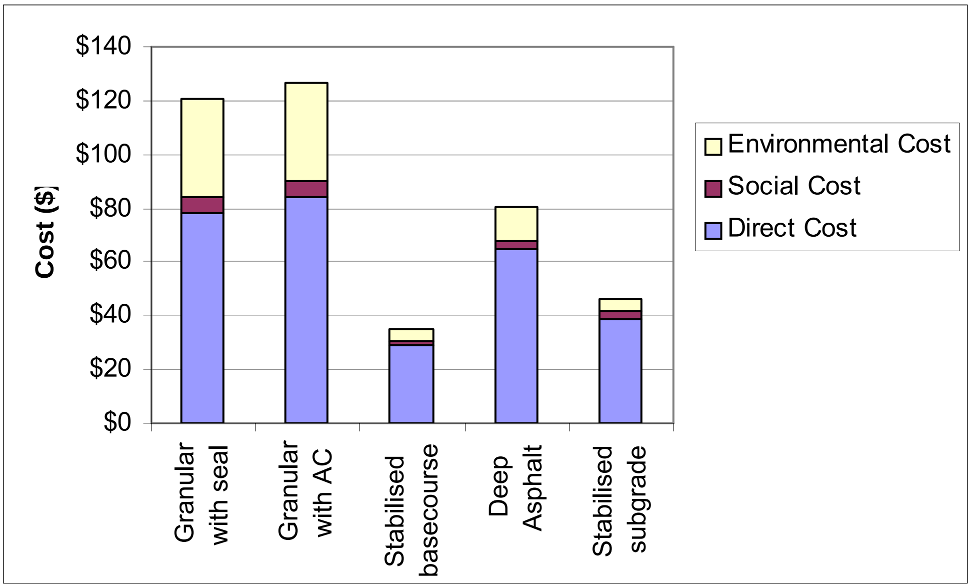
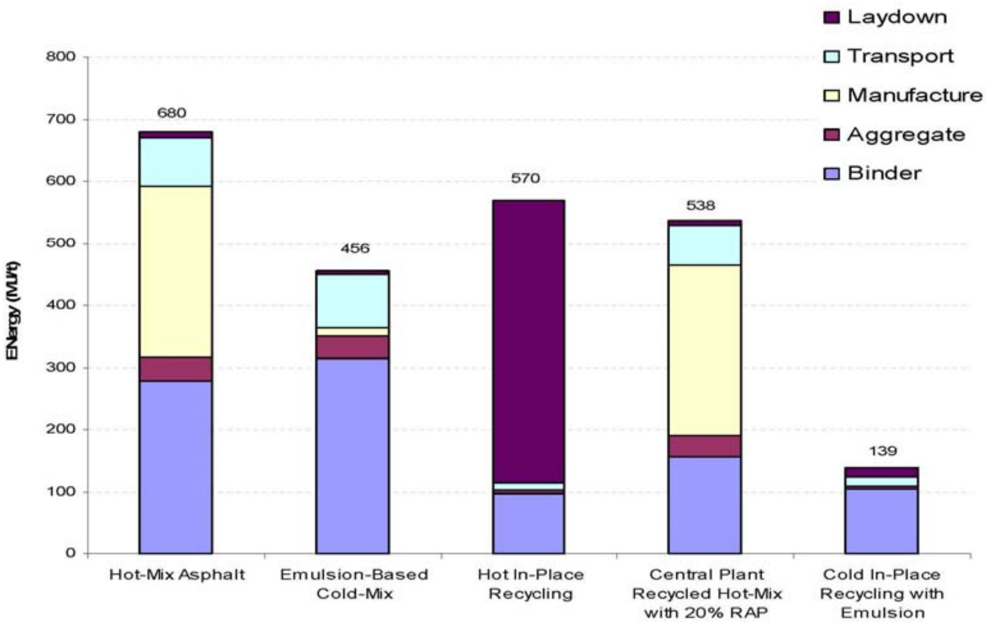


Figure 1 Graphical comparison of direct, social and environmental costs for example site. Source (Smith, Southey, Wilmot, Wilmot 2004)

Other studies have demonstrated that enormous savings in energy use can be achieved by using stabilisation. **Fig. 2** shows a comparison of the energy used for five alternate pavement designs indicating the enormous savings of using emulsion stabilisation (Chappal & Bilal 2003). Similar savings can be achieved with foamed bitumen and probably even greater with other binders.



Source: *The Environmental Road of the Future, Life Cycle Analysis* by Chappat, M. and Julian Bilal. Colas Group, 2003, p.34

Figure 2 Energy use per tonne of material laid down.

APPLICATIONS

Subgrades

Almost all subgrades can be improved by the application of a stabilising additive. Most advantage can be obtained for poorer subgrade values of less than CBR 8%. In these cases stabilisation with lime, should it be applicable, or lime plus cement, or cement alone, or in some cases with dry powdered polymers (DPP's), can substantially increase the value of the subgrade CBR. This will enable a reduction in the thickness of the imported pavement material. Guidelines for this can be found in Vorobieff & Murphy (2003) and The Australian Stabilisation Industry Association (AustStab) publications. The economical benefits of such work are usually very significant and the environmental benefits are even greater. The material which may have otherwise have been unsuitable does not need to be transported off site, and the amount of material quarried for replacement, and for the extra thickness of pavement, is significantly reduced, or in some cases entirely eliminated. Subgrade stabilisation should not be limited to new construction, in many rehabilitation projects the base course can be readily removed by milling and side casting, exposing the subgrade, which can then be stabilised prior to replacing the previous base course material. Many pavement problems can be attributed to subgrade rather than pavement failure, temporary removal of the base followed by stabilisation of the subgrade provides a rapid and economical solution to these problems.

Subgrade stabilisation should not be restricted to roads or pavement construction. It is an ideal base for the underside of concrete slabs and for general broad area factory floors and other similar constructions requiring ground support.

Stabilisation of Selected Fill

Similarly to subgrade stabilisation the treatment of select fill can enable the use of on site materials, which would not otherwise have been classified as suitable for select fill layers. Generally stabilisation of select fill takes the form of modification or lightly bound in the case of cementitious materials. The treatment not only makes substantial savings on imported materials but it can provide an all weather platform to protect the subgrade and provide all weather access for the placement of base course materials.

Base and Subbase Stabilisation

When considering stabilisation of base and subbase materials a large range of additives and design procedures are available. These range from modified materials using lime or small quantities of cement through to lightly bound cementitious pavements and heavily bound pavements using cementitious binders. Also available are binders providing more flexible design options, including foamed bitumen which can produce excellent quality base course materials at a fraction of the cost of full depth asphalt. Other options include dry powder polymers which are ideally suited to treating a wide range of natural gravels, particularly those susceptible to moisture ingress and subsequent degradation (AustStab Technical Note No.3).

With this wide range of binders available it is possible to design a base course from almost any naturally occurring material to achieve suitable properties for any form of pavement construction. No one binder will be a panacea to all our needs, however we are fortunate in having available to us such a large range that any required design requirements can normally be met.

Recycling Pavements

Recycling by insitu stabilisation is probably one of the best known applications of the stabilisation process. It enables the upgrading of existing roadways without the removal of any of the existing road material and being able to realise a high value for all the material in the existing roadway. The simplest forms of recycling are base course recycling where the top 200 mm to 350 mm of the pavement are stabilised and then a wearing course applied.

Many pavements require more specialised attention, this may include the lowering of the surface by milling out some of the existing pavement and storing for re-use on other parts of the project. It can include milling & sidecasting of the base course and stabilising in two separate layers to obtain sufficient depth of recycled pavement. It may involve removing the pavement all together and either treating or removing some of the subgrade before replacing and stabilising the base. With modern equipment and efficient techniques all these processes can be carried out with a minimal disruption to traffic and a minimum exposure to the elements. All these techniques optimise the use of existing materials significantly reducing or eliminating the need for imported materials. This brings us a great deal closer to sustainable development and almost always at significant cost savings.

DESIGN CONSIDERATIONS

All too often environmental concerns and the concept of stabilisation are considered later in the design process. If we are to continue to strive for sustainable development, the concept of using as much as possible insitu materials and absolutely minimise the percentage of imported materials must be paramount from the design concept stage.

The following check list is proposed as a useful tool to assist with design concepts.

Pre Design Check List

- Could the subgrade be improved by stabilisation and could this lead to a reduction in pavement thickness
- In heavy pavements could the existing subgrade material be improved to use as select fill
- Is there existing road material, gravel or asphalt which could be recycled and introduced into the base or subbase course
- Is there Recycled Asphalt Profilings (RAP) or other reclaimed materials available nearby which could be incorporated into the pavement with or without further treatment
- Is there a locally available lower grade gravel which could be stabilised in preference to sourcing high grade crushed rock
- Could bitumen stabilised material be used in lieu of deep lifts of asphalt
- Could a thinner pavement or use of a poorer material be considered by stabilising with a DPP.

Selection of Binder

The pavement designer now has a wide range of binders to select from and it is possible to provide a suitable binder for almost any soil or pavement material to enhance its properties for pavement construction. Further details can be found in Wilmot (1994) and Wilmot & Rodway (1999). Generally lime and cement are the least expensive and readily available while chemical mixtures, foamed bitumen and DPP's have significantly increased the range of materials we can treat and have provided challenges to apply conventional design techniques. In the case of foamed bitumen many projects over the last 5 to 10 years have been well documented and correlated with design procedures (Jones & Ramanujam, 2003). Similarly work with DPP's has been well documented over the last 10 years indicating a very good performance from stabilisation of existing relatively thin pavement.

EXAMPLES

Following are some examples of projects, which have been constructed using insitu stabilisation with descriptions of the procedures and the benefits achieved.

M4 Motorway Upgrade

The M4 Motorway West Upgrade was carried out over a length of 20 km between the twin Service Centres at Prospect and Mulgoa Rd at Penrith.

The existing highway consisted of two lanes each way and a shoulder. It was required to construct a third lane each way and re-sheet the whole road with a new wearing course. The third lane was constructed using the millings from the old wearing course and the existing shoulder material thereby reducing the need for imported material to 25% of the total material used. In addition, this imported material was of a lower standard and could be obtained locally rather than a first grade crushed rock, which would have needed to be imported from a far greater distance (see Fig. 3).

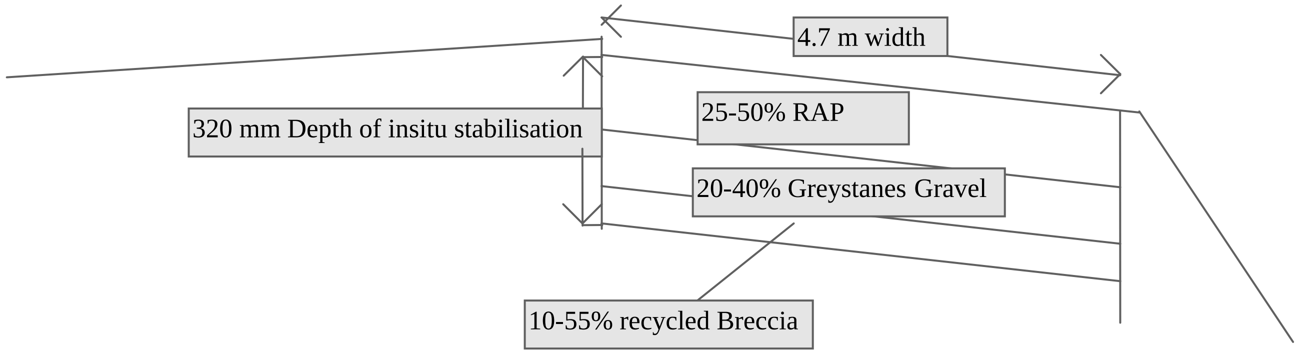


Figure 3 M4 Motorway Pavement Cross-section.

Prior to design the existing shoulder was cored to determine subgrade CBR's for the additional lane. The pavement design was modelled in CIRCLY using a modulus of 2000 MPa for the stabilised layer. This modulus was similar to that of the adjoining pavement and now after 8 years use there is no apparent difference in the behaviour of the two pavement sections.

After earthworks, the shoulder of the Motorway was milled. This shoulder material contained a varying combination of breccia and asphalt. A specially adapted profiler carried out the milling works, which was able to reach the full depth (up to 400 mm) and width (2.6 m) of the existing material in just one pass. This material was then taken along the Motorway to a temporary storage site.

Between the milling and preparation operations, the existing subgrade was then inspected for strength and suitability. In locations where the subgrade CBR did not meet the design criteria, insitu lime stabilisation of the subgrade was carried out.

Preparation involved placing a combination of RAP (Recycled Asphalt Profilings) from the motorway, Greystanes Gravel (a poor, sandy and slightly plastic local gravel) and the reclaimed base material from the shoulder within the specified envelope. The proportions were confirmed by extensive laboratory testing of a matrix of mixes which defined an envelope of acceptable mixes over the following ranges; 25-50% RAP, 20-40% Greystanes Gravel and 10-55% Breccia. The criteria for the mixing envelope was to obtain a consistent UCS of between 1.5 MPa and 2 MPa. 7 days accelerated at a constant binder add, in this case of 3% by mass. As the breccia and some of the RAP already existed in the millings, the process involved placing the millings from the profiler, a predetermined thickness of Greystanes Gravel, and finally topping up to level with more RAP.

Now the pavement was ready for stabilisation. The additive used was 25% Slag, 25% Lime and 50% Fly Ash, and preliminary testing showed this mix, at 100% standard compaction, would reach the required 7 day accelerated unconfined compressive strength (UCS), (which was found to correlate well with a 28 day moist cured test) of 2 MPa with an addition rate of only 3% by mass. This particular mix has an extended working time, which was considered necessary to allow time to correct levels and improve compaction.

The subbase layer was stabilised to a compacted depth of 320±10 mm. This was surveyed daily at a frequency of 1 level per 15 m^2. The compaction (97% standard for the lower 150 mm and 100% for the upper 150 mm) was measured at a frequency of 4 tests per 600 m^2, and in addition to this, progressive UCS samples were taken at least daily to ensure that 2 MPa was always achieved.

Result

The widening of the subbase layer of the Motorway was completed in approximately 150 working days and involved a total of approximately 110,000 m^2 of stabilised subbase, as well as many more square metres of subgrade and bridge approaches. After provision of a multilayered asphalt base over the stabilised subbase and a similar multilayer asphalt rehabilitation of the existing traffic lanes, the M4 is now a three lane (in each direction) Motorway from Concord to the Blue Mountains.

This work was carried out in 1998 and 8 years later the pavement is in very good condition.

Savings achieved:

- Saved 50,000 tonne of landfill
- Reduced construction traffic
- Reduced truck generated pollution
- Reduced damage to local roads due to trucking operations
- Saving of 50,000 tonne of quarried material
- Significant unspecified energy savings
- Lower costs estimated to be 2/3 of next best alternative.

Chemical-Soil Stabilisation for Runway Shoulder Widening at Singapore Changi Airport

To support the operations of the Airbus A380, the runway shoulders at Singapore Changi Airport have to be widened to prevent soil erosion and Foreign Object Damage (FOD), arising from the more powerful jet blast exerted by the Airbus A380 outboard engines, as well as to provide a safe area that can withstand runway excursion by aircraft (**see Fig. 4**).

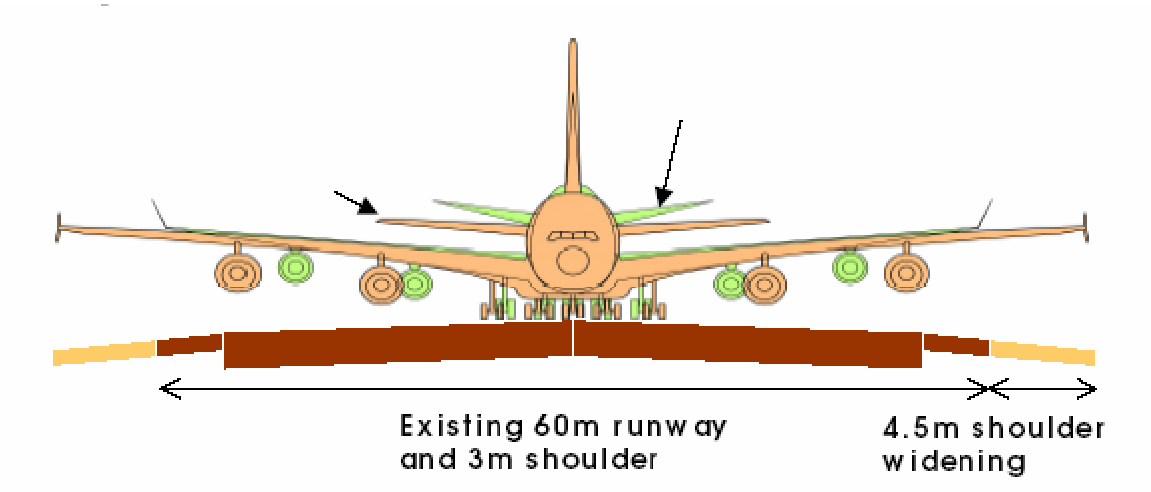


Figure 4 Runway shoulders widening at Singapore Changi Airport.

The proposed construction methods can be classified into two categories, replacement and non-replacement, the latter of which allows insitu soils to be re-used as a source of construction material. Considerations included the rate of construction, safety on the airfield, speed to make safe for emergency landings, construction costs and environmental costs. The non-replacement method of strengthening insitu soils with polymer modified cementitious chemical stabilising agent for the base course, topped by asphalt concrete as a wearing course was selected (see Fig. 5).

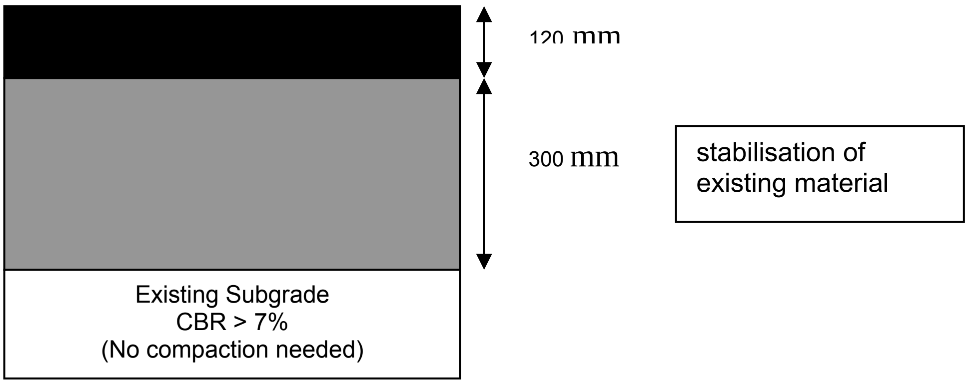


Figure 5 Cross-section of runway widening.

The selection criteria were:

- Ability to meet airport operational restrictions
- Construction speed
- Shoulder pavement structural design
- Environmental impact
- Cost effectiveness.

Selection of binder

The design criteria of the 300 mm thick stabilised soil base course for the new runway shoulders were

- 7 day unconfined compressive strength (UCS) not less than 1.5 MPa
- 7 day California bearing ratio (CBR) not less than 90%
- Resilient modulus (at 28 day) not less than 3,000 MPa.

As the insitu material was variable both in grading and plasticity, testing with cement could not produce consistent results. The selected binder was a polymer modified cementitious soil stabilising agent that has been successfully used in tropical regions for more than ten years with numerous project records (Suhaimi & Wu, 2003). Non-homogeneity of soils, which includes stone, beach sand, silt and clay or their mixtures, along the longitudinal profile of the runways, coupled with the limited construction time window, meant that the ideal application of using different stabilising agents for different soil types is not practical. Therefore a special version of the stabilising agent, which is able to treat a wide range of soils from gravel/sand to silt/clay, as well as their mixtures, was used.

Runway shoulder widening process

The runway closure was limited to 6 hours per night with an effective construction period of 4 hours due to safety procedures and housekeeping requirements. Major construction activities were:

- Excavation and removal of the topsoil
- Spreading of the chemical agent on the surface of the soils to be stabilised
- Mixing of the chemical with the insitu soil
- Compaction of the chemical-soil mixture
- Paving of a layer of asphalt concrete
- The final layer of asphalt concrete is laid during the following closure.

The peak hourly and daily construction rates for the new shoulder pavement are about 280 m²/hour (62.5 m length by 4.5 m width) and 1,125 m²/day (250 m length by 4.5 m width) respectively, which is significantly faster than the initial planned daily rate of 166 m length by 4.5 m width. A comparison of the actual construction time versus planned timings, and average daily rates for the shoulder pavement construction by chemical-soil stabilisation method is shown in Table 1.

Table 1 Comparison of Planned and Actual Construction Period for Runway Shoulders Construction using Chemical Soil Stabilisation Method.

Runway	Planned Construction Period	Actual Construction Period	Actual Working Days	Remarks
I	90 days	(31/05/05-11/07/05) 42 days	31 days	Ave. 208 m/day
II	90 days	(08/03/05-29/04/05) 53 days	29 days	Ave. 226 m/day
I & II	180 days	95 days	60 days	Ave. 217 m/day (Total: 13 km x 4.5m)

Result

Comprehensive early project planning and methodology evaluation by the airport authority was critical in the smooth and on-time completion of the shoulder widening works.

The chemical-soil stabilisation method is applicable under the restricted operating conditions in the airport environment, and effectively minimized unnecessary disruption to airport operations and any risks associated with the works. The process is environmentally friendly and expeditious. Assurance on quality of the completed works can be controlled through sample testing to specifications. Technical performance to-date is satisfactory.

Savings Achieved

- Reduction from 100 to 20 truck movements per shift, significantly reducing airport security risks.
- Ability to comply with a demand to be able to re-open the runway within 30 minutes for emergency operational procedures
- Saving of disposal of 21,000 tonne to landfill
- Saving of 21,000 tonne of imported material
- Reduction of construction time by 2/3 of alternate methods
- Substantial cost savings.

Insitu Stabilisation of Newell Highway, 28 KM North of West Wyalong, NSW

Insitu stabilisation of existing pavements using dry powdered polymers has been a common practice in southern NSW for State and National Highways since the mid nineties. This particular example is but one of many pavement rehabilitation projects carried out by public and private sectors in the region using dry powdered polymers.

The local geography is relatively flat with minimal opportunity for longitudinal drainage. Typically throughout this area the road formation is often no higher than 300 mm above the surrounding terrain.

This section of the Newell Highway has an approximate 20 year design life of up to 5×10^7 DESAs and currently carries approximately 1700 heavy vehicles a day, the majority of which occurs during the night. Back calculated traffic loadings using Vehicle Classification Surveys indicates the pavement has experienced approximately 1×10^7 ESAs to date since its construction in December 1998.

The project involved minor shape correction, typically a nominal 50 mm depth, before insitu stabilisation to a depth of 200 mm for a total length of approximately 3.2 kilometres. The project also contained floodways, which were similarly stabilised to a depth of 200 mm. A spread rate of 1.5% by mass of dry powdered polymer was incorporated. Underlying the stabilised pavement is approximately 100 mm of existing subbase material on a poor quality expansive subgrade.

Design considerations

For this particular project site, sufficient pavement thickness existed to enable stabilisation.

The selection of binder for the project was based on satisfying the following criteria:

- The stabilised insitu pavement material must result in a modified pavement due to the minimal pavement thickness available, the low strength expansive subgrade and the financial constraints of importing base quality gravels i.e.; ≤ 1.5 MPa unconfined compressive strength (UCS)
- Due to the insitu pavement material being highly moisture sensitive the binder must significantly inhibit moisture ingress to avoid wetting up of fine grained particles that has typically resulted in permanent plastic deformation of the untreated insitu material –tested using Australian Standard test method AS 1141.53 or equivalent road authority test method
- 10 day soaked CBR values of the stabilised pavement material shall be at least the same dry strength CBR value of the untreated insitu pavement material.

Extensive testing has been carried out in southern NSW using dry powdered polymers since the early nineties. The results have consistently confirmed the binder has been highly effective in reducing moisture ingress producing a modified pavement with UCS strengths ranging from 0.5 MPa to 1.2 MPa for poor to moderate quality pavement materials. Similarly soaked CBR results using the dry powdered polymer range from two (2) to four (4) fold increases over the untreated insitu pavement material.

While a limited number of thinner (150 mm) and significantly thicker (325 mm) stabilised pavements have been carried out, the selection of a 200 mm stabilised pavement was based on successful performance to date of an extensive number of equivalent stabilisation depths using the dry powdered polymer within the region.

Results

Prior to stabilisation works, formation widening to provide 1.2 m wide shoulders had been previously carried out. Stabilisation was then carried out for an approximate width of 9.2 m which provided 2 lanes of 3.5 m width with 1.2 m wide shoulders.

Because of the depth of stabilisation, outputs of up to approximately 4000 m² per day were easily achieved. As a result of the shape correction and competent construction, excellent ride quality was also achieved.

Alternatively, rehabilitation of pavements in the region along State and National Highways would typically receive a minimum of 200 mm overlay of base quality gravels particularly where the existing pavement thicknesses were considered deficient.

As a result of many rural highways being theoretically deficient in pavement thickness and remote from affordable high quality quarried sources, the financial constraints from within a typical modest maintenance budget has required innovative and affordable treatments to minimise the rate of deterioration and maintenance requirements of a large rural road network.

The performance of the dry powdered polymer over the last 10 years has satisfied the technical performance requirements of the available local materials, reduced rehabilitation costs relative to other more expensive options and has delivered effectively a maintenance free regime to date.

Savings achieved

- Saving of approx. 15,000 tonne of imported quarry material
- Reduced construction traffic
- Reduced truck generated pollution
- Saving of approx. 40,000 truck kms
- Reduction of construction time by approximately half of the alternate method
- Substantial cost savings
- Reduced damage to local and state roads due to trucking operations.

Based on just the use of dry powdered polymer stabilisation within this region over the last 10 years, the decision to insitu stabilise with the polymer over alternative granular overlays has generated environmental savings of up to 200,000 tonnes of imported quarry material and over 1 million truck kilometres.

CONCLUSION

The experience, design technology and construction resources are available to design & construct stabilised pavements so as to minimize our reliance on imported material and preserve our non-renewable quarry resources. By following guidelines to ensure the full utilisation of existing materials we can more closely establish a road to sustainable development.

Pavement design engineers have a responsibility to evaluate not only the direct costs of a pavement construction but to also consider the social and environmental costs associated with its construction. In the absence of government or Austroads guidelines, designers need to make their own judgement of these values and should make mention of these considerations in their design report.

When reporting on environmental progress, road authorities, local government and companies should consider the environmental impact of their pavement design along with other environmental measurements.

Consideration should be given by bodies such as Austroads to formulating guidelines for pavement designers to use in order to incorporate the social and environmental costs of alternate pavement designs. In particular Austroads could extend their environmental strategy to provide specific methods of assessing environmental impact of pavement structures.

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