# STABILISED PAVEMENTS - SELECTING THE ADDITIVE: CEMENTITIOUS, POLYMER OR BITUMEN.

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## ABSTRACT

Recycling of roads by stabilising with cement and more recently with other cementitious additives is a well-documented and proven process. Two alternative additives, foamed bitumen and an Australian-developed polymer-based material are now finding wide acceptance in the market place. They broaden the range of materials and situations for which insitu stabilisation is suitable.

Polymers are especially suited for treating poorer quality gravels that lose considerable strength if they wet up in service. They have particular application in regions of high water table and where periodic flooding of shoulders occurs. They preserve dry strength by ‘external and internal waterproofing’. The treated material remains flexible and is not subject to either shrinkage or load-induced fatigue cracking. Foamed bitumen, too, reduces water susceptibility but is better suited to well-graded crushed rock of low plasticity and to recycled asphalt and concrete.

Increases in pavement rutting life that result from the increased stiffness of a stabilised layer are commonly calculated using the Austroads subgrade failure criterion. This life estimate is conservative for stabilisation additives, such as polymer and foam, which improve pavements in ways other than by increasing stiffness. Specifically the design method cannot factor in the benefits of reduced plastic deformation of the stabilised layer itself, and also the benefits of any waterproofing produced by the stabilising additive. Consequently designers must currently largely rely on the accumulating field evidence to assess the effectiveness of these treatments. Continuing efforts to document the performance of pavements that contain new stabilising additives are required.

**Key Words: pavements, stabilisation, recycling, foamed bitumen, polymer.**

## INTRODUCTION

In recent years large stabilising machines capable of efficient and thorough insitu remixing of existing pavements to depths of 400mm have become available in Australia. This has opened the way to economically improve roads to cater for heavy traffic. Many have been successfully recycled, commonly using cementitious additives.

When unbound gravels are strengthened by cementing the particles together to produce significant tensile strength, unavoidable shrinkage accompanies the cementing process and causes cracking of the newly strengthened pavement. Sealing of the cracks is then necessary as pumping of fines can lead to premature failure. In practice the potential problems arising from shrinkage can be effectively managed. The potential for fatigue cracking that accompanies the new rigidity of the strengthened layer is of greater concern. The bound pavement is much more sensitive to vehicle overloads and to localised deficiencies in thickness or stiffness of the treated layer. In some Local Government situations it may not be feasible to construct cement-stabilised basecourses of sufficient thickness to prevent fatigue cracking for the required design life. This may be due to limited funding or to limited depths of existing pavement suitable for insitu stabilisation. Treatment depths of 150mm to 250mm are common. Also, practical limits to site investigation often means that the variation in quality of the insitu material along the road is not well defined, so design stiffnesses might not be consistently achieved. In these circumstances, bitumen and polymer treatments, which do not produce fatigue cracking and whose performance is less sensitive to vehicle overloads and to deficiencies in thickness may be attractive alternatives. When these flexible treatments are used, no special surfacings are needed to combat reflection cracking. Thus the additional expense of stress absorbing membrane interlayers (SAMIs), rubberised seals, geofabrics, modified binder asphalts, thick asphalt overlays or granular overlays may be avoided. These savings should be taken into account when comparing the treatments with cementitious alternatives.

All insitu stabilisation methods provide considerable savings compared with new construction, but it is difficult to be specific because cost relativities are project-dependant. Cementitious additives and polymer are less expensive than bitumen. Initial costs are affected by factors such as location, different stabilisation depths required for each additive, and the designer’s judgement on the need for special surfacings to combat reflection cracking if applicable.

Pavements are now usually designed using the mechanistic pavement design procedures detailed in the Austroads Guide to the Structural Design of Road Pavements (Austroads, 1992). Surface rutting is controlled by limiting the vertical compressive strain at the top of the subgrade. Calculations of increases in pavement rutting life are based only on the additional protection given to the subgrade due to increased stiffness of the stabilised layer. Consequently the estimates of pavement life are conservative for additives that also improve pavements in ways other than by increasing stiffness. Specifically the design method cannot factor in the benefits of reduced plastic deformation of the stabilised layer itself, and also the benefits of any waterproofing produced by the stabilising additive. For example a higher design CBR may be warranted by the resulting drier subgrade. This inherent conservatism may be of no practical significance for cemented layers that achieve significant tensile strength, because the design is inevitably governed by fatigue cracking considerations, not rutting. However, this conservatism is critical for polymers, significant for foam in some cases, and can act as an impediment to the use of these additives. The mechanistic design procedures cannot fully value the benefits of these materials so designers must largely rely on the accumulating field evidence to assess their effectiveness.

## CEMENTITIOUS STABILISATION

The processes and criteria for use of cementitious stabilisation are well covered in the technical literature including (Wilmot, 1994) and the recently published Austroads Guide to Stabilisation in Roadworks (Austroads, 1998).

The high stiffnesses readily produced by cementitious stabilisation mean that, theoretically, the need to protect the subgrade against rutting is met by very small depths of stabilisation. Much greater depths are needed to protect the stabilised layer itself against fatigue cracking. That is, the design is governed by a fatigue criterion not by the subgrade rutting criterion. For example, consider an existing 250mm thick unbound gravel pavement over CBR 5 subgrade and design traffic of 100,000 ESAs. CIRCLY calculations indicate that stabilisation to a depth of only 55mm is required to protect the subgrade against rutting failure, assuming that a stiffness of 3500 MPa is achieved in the stabilised layer. But to prevent fatigue cracking for 100,000 strain repetitions, a stabilised layer of 290mm is needed. In this case the stabilisation depth is limited to 250mm by the thickness of the existing pavement, which CIRCLY indicates would have a fatigue life of 7,000 ESAs, only 7% of that required. This high sensitivity to achieved thickness has been noted earlier in this paper. However, in practice 200mm thick gravels moderately bound to achieve moduli of around 1000 MPa have often performed considerably better than predicted by the current fatigue criteria for cemented materials. This suggests that they are functioning as improved, or ‘modified’ unbound materials rather than as truly cemented materials.

## FOAMED BITUMEN STABILISATION

The addition of small amounts of cold water, typically 2%, causes hot bitumen to foam which increases its volume 10 to 15-fold. In this expanded state, which persists for about 10 seconds, it can be very effectively mixed with cold, damp aggregates and soils. The foam preferentially coats finer particles to form a cohesive, water-resistant matrix that bonds the larger particles together. This contrasts with asphalt production and with emulsion and cutback stabilisation, all of which involve coating of both coarse and fine fractions. Once mixed, the treated material remains workable for an extended period that is ample for compaction and trimming. Despite the extended working time, the road can usually be opened to traffic immediately. In cases where deformation has occurred it has usually been attributed to high compaction moisture and/or to low-stability plastic materials deficient in granular interlock. Compacting somewhat dry of optimum is appropriate and, when required to function as a basecourse, foam is best suited to well-graded crushed rocks of low plasticity (PI< 10 or 12) and to recycled asphalt and concrete. Hydrated lime (1 to 2% by mass of treated soil) is often added to counter the adverse effect of plastic fines.

The foamed bitumen process is the most economical way of adding bitumen. The considerable cost of aggregate heating that is involved in asphalt production is saved. Also the manufacturing costs of emulsion and the cost of transporting the high percentage of water in the emulsion are avoided. Road materials are either treated insitu or in a stationary mixing plant. For rehabilitation work, in place treatment is usually more cost effective.

Foamed bitumen was introduced into Australia in the 1960's. Taxiway flanks at Sydney airport were stabilised insitu with 4% of foamed bitumen in 1972 to prevent erosion caused by jet blast from the outermost engines of the newly-arrived Jumbo jets. Use of foam lapsed for the next 20 years but it is now used by many State Road and Local Government Authorities in both urban and rural applications. Councils such as Fairfield (NSW) have been using foamed bitumen for some five years. Major highway works include the New England Highway at Warwick QLD where a 17km length is being stabilised. Stabilisation thicknesses are typically 200 to 250mm.

## POLYMER STABILISATION

The new Austroads Stabilisation Guide deals only briefly with polymers (Sections 8.3.1 and 9.8.2.3) so the material and the stabilisation process are described here in some detail.

The stabilising powder consists of a polymer thermally bound to an inert fine carrier, typically fly ash, which is then mixed with hydrated lime. The lime is not coated with polymer. Its function is to flocculate and prepare clay particles for adhesion to the polymer. As can be seen under an electron microscope and demonstrated by attempting to stir the powder into water, the fly ash is effectively encapsulated by the polymer. Therefore it is misleading to compare the product with stabilising agents that contain fly ash/lime mixtures. The latter act differently and involve pozzolanic reactions that produce cementitious bonds.

Two products are available, Polyroad PR21L and PR11L. The first consists of a mixture of 67% polymer-coated fly ash and 33% hydrated lime The second differs only in that it contains 50% hydrated lime and is used for higher plasticity gravels. The dosage rates for the products are 1.5% and 2% respectively of the dry mass of treated soil. Thus in either case 1% of polymer-coated fly ash is used. For gravels, based on the capillary tests described below, 1% is ample to produce the desired waterproofing effects. Because this dosage rate is low relative to many other stabilisation additives it is important to dose accurately and mix thoroughly.

### *How Polymer 'works'*

Many road gravels have adequate strength to resist traffic stresses when they are dry but dramatically lose this strength with the increases in moisture contents that often occur in service. When wet, the clay fines within the gravel become 'greasy' and mlubricate the larger stones. This allows them to slide relative to each other to produce rutting under wheel loadings. Strength loss is often very pronounced for gravels that have smooth, rounded coarse stones and highly plastic fines.

Polymers act to preserve the 'adequate' dry strength of water-susceptible gravels by a process of 'external' and 'internal' waterproofing. This involves creating a hydrophobic soil matrix between the stones, which reduces permeability and so limits water ingress ('external' waterproofing). Also, because the polymer is so strongly attracted to clay particles, it competes successfully with water to coat them. Thus the softening and lubricating effect of any moisture that does enter the pavement is much reduced ('internal' waterproofing).

A simple laboratory test is used to quickly indicate, for any gravel proposed for treatment, whether the polymer produces the intended external waterproofing effect. Compacted 100mm high cylindrical samples of both untreated and treated gravel are allowed to dry back for a few days then placed in a tray containing 30mm of water. After 24 hours the capillary moisture is typically seen to rise to near the top of the untreated sample and the sample begins to disintegrate below the 30mm waterline. By contrast, the polymer-treated sample typically suffers only a moderate capillary rise of around 25mm and the sample remains intact below the waterline. The effectiveness of the waterproofing treatment is further demonstrated by squirting drops of water onto the dry top of each sample. The water immediately soaks into the untreated sample but forms beads on the treated sample.

The Polymer's 'internal' waterproofing effect is best confirmed by triaxial testing of the kind done for the Taree Aerodrome project (Polymix Industries, 1998) referred to below. In that case, as expected, the untreated plastic gravel had high shear strength when tested dry of optimum but the strength dropped dramatically when tested 2% wet of optimum. Compared to the untreated material, the polymer-stabilised sample retained relatively high shear strength even when tested 3% wet of optimum.

Polymer-stabilisation of a section of the Taree runway is one of the earliest Australian examples of this type of rehabilitation treatment. The top 150mm of conglomerate gravel basecourse was polymer-stabilised insitu in September 1988 and resealed. It continues to perform well after ten years so provides the best evidence to date of the permanence of the stabilisation effect. The good performance contrasts with the previous runway behaviour. Before treatment localised rutting under the Fokker Friendship aircraft (dual wheel loads of 8 tonnes) had necessitated frequent patching. The rutting was found to be confined to the basecourse gravel, which lost strength dramatically after rain due to water ingress through an aged, permeable seal. This is an example of where mechanistic rutting design based on subgrade deformation would not predict actual pavement behaviour. The Taree experience is particularly relevant to Local Government roadwork. This is because basecourse gravels that are marginal with respect to plasticity, grading and soundness must often be used. They, rather than the subgrade, can be the primary source of pavement failure.

Polymer stabilisation has now been used by NSW, Victorian, Queensland and Tasmanian State Road Authorities and also by Local Government Authorities including Yass, Singleton, Wagga, Gosford and Urana Councils. Stabilisation depths of 150 to 200mm are most common but depths up to 350mm have been used. Overseas locations include Port Moresby, the UK and, most recently, Brunei.

## STRUCTURAL DESIGN OF PAVEMENTS

The Austroads Design Guide introduced a rational approach to pavement design based on engineering properties of the materials and structural design principles. This is acknowledged as an important advance in design methodology. However, as explained below, not all stabilisation methods are adequately catered for.

The designer uses CIRCLY, (Wardle, 1999) a layered elastic computer program, to calculate elastic strains in the pavements. Selected critical strains are then empirically related to observed pavement performance. The vertical compressive strain at subgrade level is related to the repetitions to cause rutting failure, and the tensile strain at the underside of bound layers is related to repetitions to cause cracking. This is called a ‘mechanistic’, ‘rational’ or ‘analytical’ design method. However, it is still largely an empirical method because there is no adequate theory to relate tensile strains to crack formation nor to relate vertical strain at subgrade level to the rate at which surface rutting develops. The last step in the design process remains purely empirical. In other words, calibration against actual pavement performance is necessary.

The Austroads empirical formula that relates subgrade strain to rutting life in ESAs is

$$N = (0.008511/\text{subgrade strain})^{7.14}.$$

It was developed from observations of the performance of unbound pavements. In the absence of comparable performance observations for stabilised pavements, the same ‘unbound’ formula is used for predicting the life of stabilised pavements. This was never likely to be fully satisfactory, essentially because the formula could only respond to any increase in stiffness caused by the process of stabilisation. An increased stiffness reduces the subgrade strain and so the formula predicts increased rutting life.

The Austroads rutting design method concentrates on protecting the subgrade from overstressing. The type of failure being guarded against is rutting of the road surface arising primarily from subgrade deformation. Deformation within the basecourse itself is not directly addressed. Yet it is known that when marginal pavement materials are used, much of the surface rutting can be due to basecourse deformation. Stabilised basecourses increase rutting life not only because they protect the subgrade. Improvement is also due to the lower plastic deformations of the stabilised basecourse itself. This is sometimes overlooked now that the move from ‘empirical’ to ‘mechanistic’ design methods has put such emphasis on the elastic stiffness (modulus) of pavement materials. High modulus is now often incorrectly accepted as the only measure of a 'good’ material even though it deals mainly with load–spreading ability.

Pavement life can also be increased in other ways. It is improved if the stabilisation treatment does not lead to shrinkage and load-induced cracking of the basecourse. This is because access of surface water through cracks to the subgrade does not occur and also because there are no basecourse cracks to reflect into the overlying, fatigue-prone asphalt or sprayed seals.

Also, in some cases the waterproofing produced by the stabiliser can be more relevant to pavement performance than increased stiffness. For example, where road distress is not primarily due to traffic but involves environmental cracking of the surface caused by movements in a reactive clay subgrade, stiffening of the basecourse may not be important. Here it is important for the stabilised basecourse to function as an impermeable, non-cracking protection to the subgrade to improve its volume stability. Especially in areas of poor drainage, the treated basecourse should be a barrier rather than a path to water reaching the subgrade from periodically flooded shoulders.

Thus there are ways in which stabilising methods produce improvements in pavement performance that cannot be explained or quantified in terms of elastic modulus and the Austroads mechanistic design method.

## POLYMER-STABILISED DESIGN

As discussed above, polymers act to preserve the considerable dry strength of plastic gravels by a process of internal and external waterproofing. The treated basecourse has reduced plastic deformability and also functions as a flexible, low permeability protective barrier to the subgrade. The resulting improvements to road performance are not acknowledged by mechanistic design procedures.

Polymer treatments also produce moderate increases in modulus, and modest reductions in subgrade strains and surface deflections. However, these are insufficient to explain, in mechanistic design terms, the degree of improved road performance and extended life that is typically observed in the field.

Decisions to use polymers are based on the accumulating field evidence of their effectiveness, coupled with the tests described earlier to confirm, for each candidate gravel, that polymer produces the intended waterproofing effects.

## FOAMED BITUMEN DESIGN

Design-wise, foam falls between polymer and cementitious additives. Like polymer it waterproofs the matrix and improves the plastic deformation characteristics of gravels (factors not given specific credit by the mechanistic design methods). Unlike polymer it imparts significant stiffness that can range from small to moderate (500 to 1600 MPa). This increased stiffness results in CIRCLY predictions of increased rutting life. The foam introduces fatigue concerns to an untested degree, at least at the stiffer, asphalt-like end of the range. To date, unlike cementitious additives, foam does not appear to have caused problems of reflection cracking of surfacings. However, the length of field experience is still far too short to be conclusive and to provide the necessary data to guide designers as to how the material should be characterised. In this regard, the Australian Stabilisation Industry Association, AustStab, in association with a number of Councils is monitoring the long-term performance of a number of roads stabilised with foam bitumen.

Currently an asphalt fatigue criterion is usually applied, at least for the stiffer, higher bitumen content mixes. When this is done, the design, as for cementitious stabilisation, is governed by fatigue cracking rather than by subgrade rutting. That is, the requirement to protect the subgrade is met by relatively small depths of treatment. Greater depths are needed to protect the stabilised layer itself against cracking once the fatigue criterion is invoked. Some designers consider that foamed materials with moduli as high as 1000 MPa can be designed as improved, or ‘modified’ unbound materials, and not be subject to a fatigue criterion. The contrary view is that stiffness of this magnitude could only result from such strong gluing of stones together that fatigue failure must be relevant. Although the repeated load triaxial test only imperfectly reproduces relevant stress states, it would seem to be suitable to provide useful indications as to whether the material will behave in a stress-dependent fashion.

## CIRCLY VERSION 4

Because of the uncertainties regarding modulus values, applicability of failure criteria and stess-dependency, there is currently wide scope for judgement in designing stabilised pavements. The new CIRCLY, Version 4 (Wardle and Rodway, 1998), assists the designer in making these judgements. The program simultaneously computes the traffic-induced damage to all pavement materials (asphalt surfacing, each stabilised layer and subgrade). The program then determines the required pavement thickness by adjusting the thickness of any pavement layer nominated by the designer.

The designer can specify and easily change all design inputs, including material properties (moduli and stress-dependency). Each material’s fatigue criterion can be switched on or off. The program’s computational speed coupled with the ease with which all problem inputs can be changed allows the designer to quickly assess the sensitivity of the design to each input and to each design assumption. The assumptions are, of course, only finally justified by the extent to which the resulting design reflects actual pavement behaviour. In other words, continuing calibration of the design methods against field performance is necessary.

## CONCLUSIONS

Many roads have now been successfully recycled using cementitious products. The fatigue life of cemented layers is, however, sensitive to thickness. Therefore in situations where full design pavement thicknesses cannot be constructed, the maintenance problems associated with fatigue cracking mean that alternative, more flexible stabilisation alternatives such as foamed bitumen and polymers should be considered.

Polymers are especially suited for treating poorer quality gravels that lose considerable strength if they wet up in service. They have particular application to regions of high water table and where periodic flooding of shoulders occurs.

Foamed bitumen, too, reduces water susceptibility, but is better suited to well-graded crushed rock of low plasticity and to recycled asphalt and concrete. Like asphalt, product quality can be adversely affected by clay fines.

The Austroads mechanistic pavement design method focuses on pavement stiffness to estimate rutting life. Consequently it is not well suited to value some stabilisation additives, including polymer and foam, that improve pavements in ways other than by increasing material stiffness. Specifically the benefits of reduced plastic deformability of the stabilised material itself, and also the benefits of any waterproofing produced by the stabilising additive are not factored into the design method. Consequently designers must currently largely rely on the accumulating field evidence to assess the effectiveness of these treatments. Given the essentially empirical nature of pavement design, continuing efforts to document the performance of pavements that contain new stabilising additives are required.

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