Design and Performance of Dry Powdered Polymers

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1. INTRODUCTION

Rehabilitation of existing roads by stabilising with cementitious and bituminous binders has been well-documented and proven to be a successful process. An Australian developed insoluble 'Dry Powdered Polymer' (DPP) has found wide acceptance within the road industry. DPP's expand the range of pavement materials and situations for which stabilisation is suitable. DPP's were first incorporated into pavements in 1988 and has since been extensively used in National and State Highways in Australia and parts of Asia. More recently trials have been conducted in New Zealand and Finland.

The Australian Stabilisation Industry Association (AustStab) has defined a Dry Powdered Polymer as 'a dry powdered road stabilising binder consisting of an insoluble polymer thermally bound to a very fine carrier such as fly ash'. This comprehensive definition avoids confusion with water-soluble binders that are sometimes referred to as polymers.

Most road gravels have adequate strength to resist typical traffic stresses when dry but dramatically lose strength when wetted up. When wet clay fines within gravels become 'greasy', they lubricate the larger particles resulting in plastic deformation.

The aim of the DPP is to preserve the 'adequate' dry strength of water-susceptible gravels by a process of 'internal' waterproofing of fine grained particles. This involves creating a hydrophobic soil matrix between the particles which limits water ingress. The typical softening and lubricating effect of any moisture that enters the gravel is also significantly reduced.

Since DPP stabilisation does not involve a cementitious chemical reaction, gravels incorporating DPPs remain flexible and therefore are not susceptible to shrinkage, cracking or premature fatigue load failure.

The process used to establish the suitability of DPP stabilisation requires basic soil parameters to be determined, such as maximum dry density, optimum moisture content, particle distribution and Atterberg limits. Once these parameters have been established, the correct binder type can be chosen to then carry out CBR and UCS testing, and capillary rise and swell as per Australian Standard AS 1141.53 – 1996.

Laboratory results conducted over the last ten years by several state and local government authorities has consistently shown a considerable increase in soaked CBR strength when mixed with insoluble DPPs for moderate to poor quality gravels. Performance in the field during the same period has seen minimal to no change to the 'as-built' formation shape and condition, and without failure or repair expenditure attributed to DPP binders to date.

Many DPP stabilised pavements have already experienced traffic loadings approximating 1E+07 equivalent standard axles (ESAs) per lane. Their current shape and excellent condition strongly suggests that many more maintenance free years will continue, therefore ensuring highly competitive whole-of-life costs.

This paper documents much of the many kilometres of roadway constructed using insoluble DPPs and presents guidelines for their use.

2 DRY POWDERED POLYMERS

2.1 WHAT IS AN INSOLUBLE DRY POWDERED POLYMER?

Within the local road industry, only brief descriptions of polymers are provided in stabilisation literature. The Austroads Guide to Stabilisation in Roadworks (Austroads, 1998) deals briefly with polymers in Sections 8.3.1, Polymer in Dry Powder Form, and 9.8.2.3, Powdered Polymer Stabilisation. The Australian Stabilising Industry Association (AustStab) (1998) has defined the material as, *'A dry powdered road stabilising binder consisting of an insoluble polymer thermally bound to a very fine carrier such as fly ash'*. This comprehensive definition avoids confusion with water-soluble stabilisers that are sometimes referred to as polymers.

The DPP consists of an insoluble polymer thermally bound to an 'inert fine carrier', which is then added to small percentages of hydrated lime. The lime is not coated with polymer. The lime's function is only to flocculate and prepare clay particles for adhesion to the polymer rather than generate pozzolanic reactions that produce cementitious bonds.

There are three insoluble DPP products available;

- Polyroad PR100, consisting of 100% polymer-coated fine carrier spread at a rate of 1% by mass and is targeted at non-plastic gravels.
- Polyroad PR21L, consisting of a mixture of 67% polymer-coated fine carrier and 33% hydrated lime spread at a total rate of 1.5% by mass for gravels having a Plasticity Index (PI) of 12% and below.
- Polyroad PR11L, consisting of a mixture of 50% polymer-coated fine carrier and 50% hydrated lime spread at a rate of 2% by mass for gravels having a PI of 12% to 20%.

Through extensive research and development, and early field trials, 1% by mass of DPP is sufficient to coat all fine grained particles and provide the desired 'internal' waterproofing effects.

Insoluble DPPs have also been scientifically evaluated by CSIRO (Melbourne) on several occasions during the last twelve years using an electron microscope. Samples of various ages of DPP stabilised pavements have been examined and shown that the DPP has not degraded in the field.

2.2 HOW INSOLUBLE DRY POWDERED POLYMERS WORK

Most road gravels have sufficient strength to resist typical traffic stresses when dry however, they dramatically lose strength when wetted up. When wet clay and silt fines within gravels become 'greasy' they lubricate the larger aggregates resulting in permanent plastic deformation.

DPPs act to preserve the 'adequate' dry strength of water-susceptible gravels by a process of 'internal' waterproofing. This involves creating a hydrophobic soil matrix between the aggregates which reduces permeability and limits water ingress. The typical softening and lubricating effect of any moisture that enters a granular pavement is also significantly reduced ('internal' waterproofing).

Because insoluble DPP stabilisation does not involve a cementitious chemical reaction, the incorporation of DPP is not associated with a time constraint during mixing and achieving compaction.

3. GUIDELINES FOR THE ASSESSMENT AND USE OF DRY POWDERED POLYMERS

3.1 ASSESSING MATERIAL SUITABILITY

The process used to establish the suitability of DPP stabilisation requires basic soil parameters to be determined, such as maximum dry density, optimum moisture content, particle distribution and Atterberg limits. Once these parameters have been established, the correct DPP binder type can be chosen to then carry out CBR testing, and capillary rise and swell as per Australian Standard (AS 1141.53 – 1996).

3.2 PARTICLE DISTRIBUTION

An assessment of particle distribution is required to ensure sufficient fine grained particles are present within the gravel to provide satisfactory 'internal' waterproofing i.e., a dense graded matrix. From extensive laboratory results and performance in the field, it is recommended there be a minimum of 35% of material passing the 2.36mm sieve.

While base and subbase gravel specifications also limit the percentage passing 2.36mm (typically not more than 55%) DPP stabilisation has shown to be effective with high percentages passing the 2.36mm sieve.

The recommended particle size distribution for insoluble DPP stabilisation is shown in Figure 1 below.

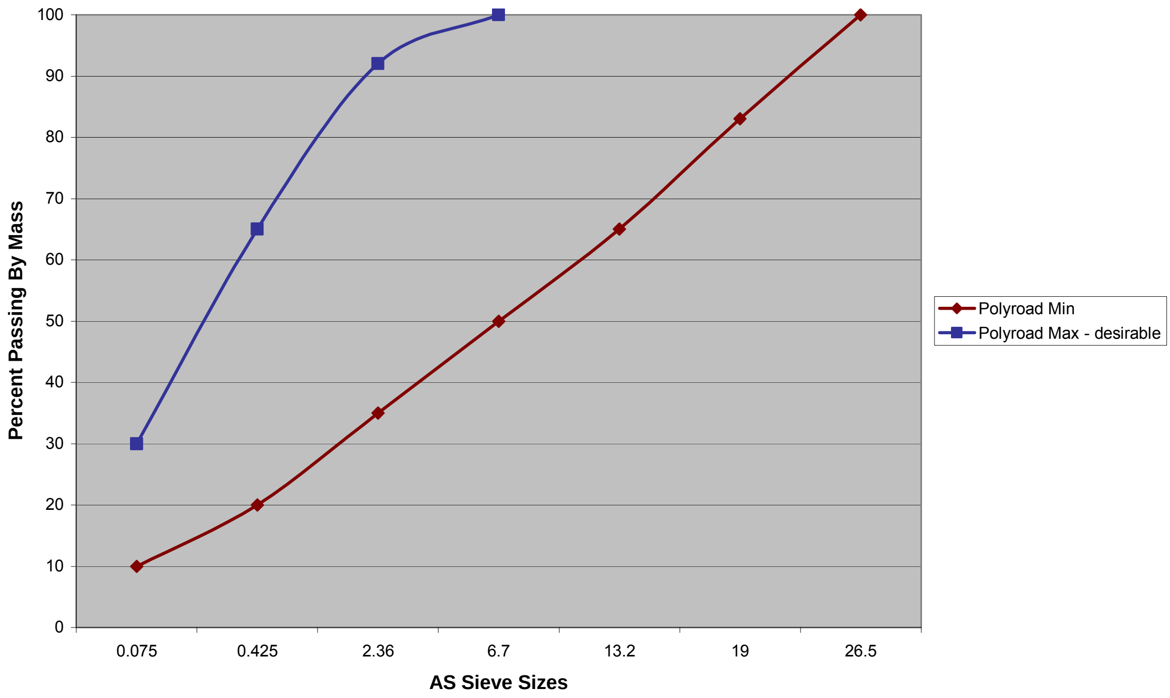

Figure 1 Recommended Particle Size Distribution for Insoluble DPP Stabilisation

3.3 PLASTICITY INDEX

Gravels need to be tested for plasticity (PI) to ensure the correct DPP binder type PR21L or PR11L is chosen i.e., extent of hydrated lime required to enable complete polymer-coating of clay plates. Alternatively PR100 is used for non-plastic gravels.

For gravels having a PI in excess of 20%, pre-treatment with hydrated lime or quicklime is required. Laboratory testing should be carried out to ensure the desired PI range after pre-treatment is achieved relative to the binder type proposed to be incorporated.

3.4 CAPILLARY RISE AND SWELL

Capillary rise and swell testing as per AS 1141.53 is highly recommended to provide visual evidence of compatibility and integrity of the DPP treated sample. It should be remembered that this test method is designed to represent free subgrade moisture. In reality, very wet subgrades typically will not support construction plant irrespective of pavement treatment proposed and therefore would require pre-treatment of the subgrade and/or sub-surface drainage works.

For gravel samples with the minimum recommended percentage of fines passing the 2.36mm sieve, up to 100% capillary rise may be observed. However, the compacted sample will not deteriorate nor will it significantly impact upon soaked CBR strength increases. At the same time of observing moderate to high capillary rise, it is common that the sample will measure 0% swell. Because the clays and silts within the gravel sample have been physically coated by the insoluble DPP, water cannot successfully penetrate to the fine grained particles to cause detrimental affects upon swell or strength.

A photograph of typical insoluble DPP results using AS 1141.53 is shown in Figure 2 below.

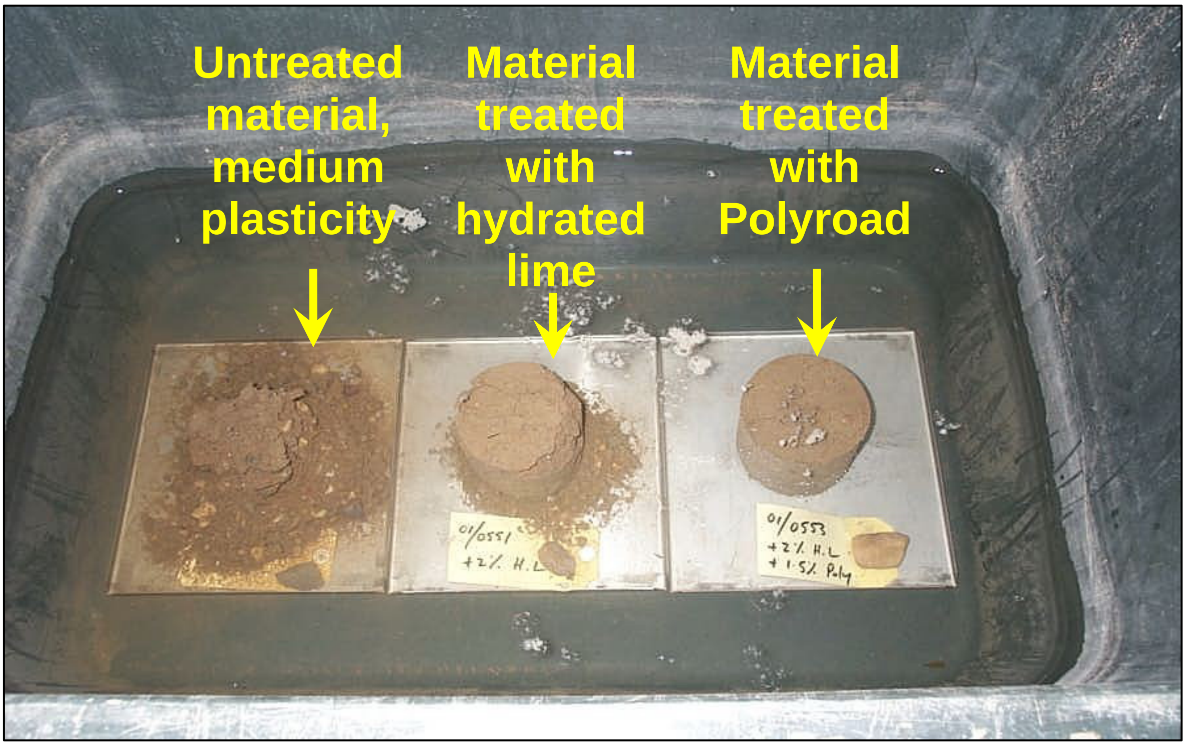

Figure 2 Capillary Rise & Swell Test AS 1141.53

3.5 CBR TESTING

CBR testing is strongly recommended particularly when comparing the raw parent gravel against the DPP treated sample. Moderate to poor quality gravels record the greatest strength increases. Table 1 is indicative of the range of CBR strength increases that occurs after DPP stabilisation.

Table 1 Example of soaked CBR % strength increases after DPP stabilisation

Project Location	4 Day Soaked CBR % of Existing Pavement Material	4 Day Soaked CBR % after DPP Stabilisation
Pacific Highway at Cooperabung, NSW		
Lot B2	40	80
Lot B3	20	60
Lot BP5	30	120
Lot BP8	60	120
Oxley Highway 5km west of Port Macquarie, NSW		
Lot B1	25	50 (9 day soak)
Lot B2	25	45 (10 day soak)
New England Highway 31km south of Tamworth, NSW		
Sample P5	50	150
Sample P6	100	120
Kulgera Pit, Northern Territory		
Sample 420	68	140
RTA South West Region NSW, State and National Highways projects that incorporate Prior Stream gravels[1] – typical range of past results	5 to 40 (10 day soak)	45 to 80 (10 day soak)
Note: All Lots/Samples in NSW tests consist of a blend of quarry and ridge gravels. [1] Prior Stream gravels are clayey/silty sands.		

3.6 UCS TESTING

Unconfined compressive strength (UCS) testing can also be carried out with DPP stabilised material. In accordance with Austroads classifications, 'modified' pavement materials generally have strengths between 0.7 < UCS < 1.5 MPa.

Pavement materials stabilised with Polyroad DPPs most commonly range from 0.5 < UCS < 1.2MPa for moderate to poor quality pavement materials. Higher quality pavement materials may achieve UCS strengths of 1.5 MPa.

4 DESIGN CONSIDERATIONS

4.1 INDUSTRY GUIDELINES

Guidelines for insoluble DPP stabilisation have been published in;

- AUSTROADS APRG Technical Note 14
- AustStab Technical Note No. 3
- RTA Towards Best Practice, Modification of base course materials using Polyroad, Reference: 2003/02

The benefits that insoluble DPPs provide by way protection of fine grained granular particles and reduced permanent plastic deformation of pavement materials is not directly modelled in current pavement design procedures. Whereas the mechanistic design model in the Austroads guide assumes the subgrade will fail due to subgrade rutting, increasing vehicle loads and tyre pressures increase the potential of granular pavements to rut before the subgrade. In the absence of a suitable estimate of pavement life in this scenario, the design of DPP stabilisation is based on accumulating field evidence over the last 10 years involving State and National Highways, and Local Government Roads.

Within the current pavement design guidelines, all efforts are directed towards minimising surface rutting by limiting the vertical compression strain at the top of the subgrade i.e.: increased rut resistance and protection of the subgrade is only achieved by significantly increasing the stiffness of a stabilised layer or a significant increase in depth of unbound granular overlay.

Specifically, the pavement design method does not factor in the benefits of reduced plastic deformation of a layer or the benefits of 'internal waterproofing' produced by an insoluble DPP binder.

As a result, pavement designers must currently rely on the accumulated field evidence to assess the effectiveness of DPP stabilisation. Vehicle usage data has been effective in indicating the extent of traffic loadings that DPP stabilised pavements have supported over the years (refer Figures 2 and 3).

4.2 RECOMMENDED MIX DESIGN

The flowchart in Figure 3 summarises the elements previously described in Section 3 regarding assessment and suitability of DPPs.

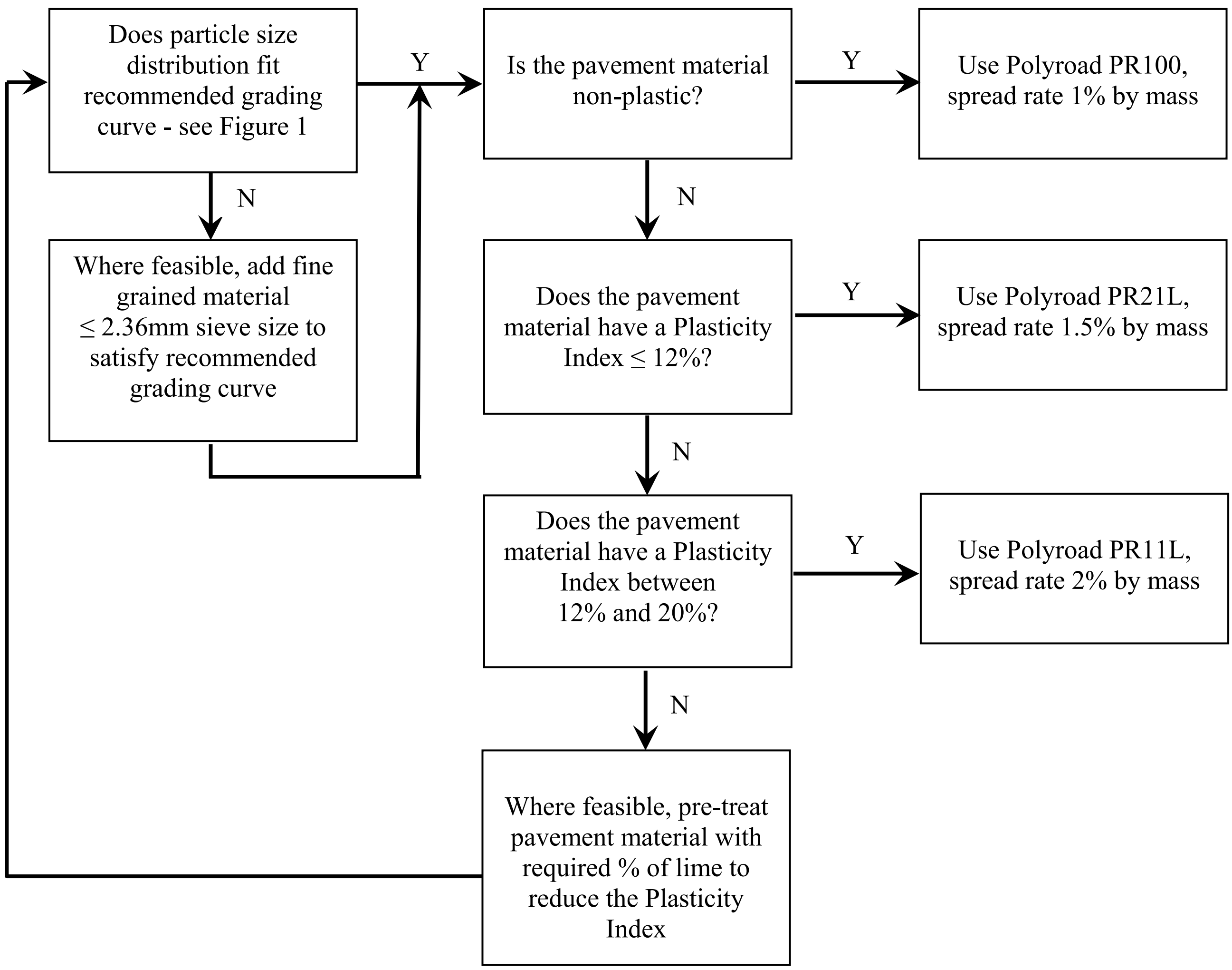

Figure 3 Mix Design Selection Flowchart

4.3 RECOMMENDED PAVEMENT THICKNESSES

Based on considerable field experience to date, the following recommended pavement thicknesses have been found to adequately provide support and service life for varying traffic, subgrade and pavement material conditions. The recommendations are based upon adequate geotechnical investigation, competent construction and subgrades capable of supporting construction equipment when managed effectively.

Low to moderate traffic $\leq 5 \times 10^6$:	150mm to 200mm, 200mm to 250mm in floodways/highly expansive subgrades
Moderate to high traffic 5×10^6 to 9×10^7:	200mm to 300mm, 250mm to 300mm in floodways/highly expansive subgrades

It is recommended that the design of DPP stabilised pavements be discussed with the manufacturer to ensure all elements have been considered and evaluated thoroughly.

Additionally, information provided in the following section regarding performance of DPPs in the field contains several examples of varying traffic regimes, existing pavement profiles and indicative subgrade strengths. The field examples are indicative of the successful performance for insoluble DPP rehabilitation projects carried out to date.

5 PERFORMANCE OF INSOLUBLE DRY POWDERED POLYMER STABILISATION

5.1 OVERVIEW

The earliest documented example of insoluble DPP stabilisation took place in 1988 in a section of Taree airfield runway, NSW (Polymix Industries, 1998). Since 1998, insoluble DPP stabilisation has been used by New South Wales, Victorian, Queensland and Tasmanian State Road Authorities, numerous Local Government Authorities in NSW and Victoria, overseas in Brunei, New Zealand, Finland and Papua New Guinea.

Stabilisation depths of 200mm are most common but depths of 150mm and 325mm have been carried out. The majority of DPP stabilisation has occurred on National and State Highways within NSW carrying 20 year design traffic loadings between 10^6 and high 10^7/low 10^8 design equivalent standard axles (DESAs).

In accordance with Austroads Guide to the Structural Design of Road Pavements, Figure 8.4 (Austroads, 2004), many of the pavements stabilised from the mid-nineties should have theoretically failed by now (low subgrade and pavement CBR strengths and considerably less pavement thickness than required). Their ongoing ability to perform without pavement misshape or maintenance repair to date, is predominantly a result of no plastic deformation occurring within the pavement because of the ‘internal’ waterproofing of fine grained particles that insoluble DPPs provide.

5.2 PERFORMANCE IN THE FIELD

To understand and appreciate the performance of insoluble DPPs, the following table summarises some of the National and State Highways in NSW which have incorporated insoluble DPP stabilisation. Indicative twenty year design life, available pavement depths, actual stabilised depths and theoretical pavement thicknesses required are outlined in Table 2 below.

In Table 2, the typical depth of existing granular pavement and resultant DPP stabilised depth are considerably less than theoretically required to provide a twenty year design life. As shown in the above table, some of the DPP stabilised pavements have in fact incorporated part of the subgrade (material blend tested prior to construction approval).

The subgrade CBR strengths listed above are indicative of known test results through extensive geotechnical investigation over the last ten years. It should also be noted that many of the existing pavement materials prior to stabilisation do not have high elastic modulus values (vertical MPa). Whereas Austroads Table 6.3 (Austroads, 2004) suggests a subbase gravel over granular material may have a presumptive modulus of 250MPa, many of the sites have base materials (Prior Stream gravels) of approximately 150MPa. When wetted up, Prior Stream gravels perform extremely poorly due to its high percentage of fine grained particles.

Table 2 Overview of design parameters and available pavement thicknesses

Description	Indicative 20 Year Design Life (ESAs)	Approximate Thickness of Granular Pavement Required (Austroads 2004 Fig 8.4)	Depth of Existing Pavement in the Field	Actual Depth of DPP Stabilised Pavement
Newell Highway - National (Tocumwal to Marsden)	High 10^7 To Low 10^8	600mm on CBR 5% 450mm on CBR 8%	150mm to 350mm	150mm to 300mm, commonly 200mm
Sturt Highway - National (Wagga to Wentworth)	Mid to High 10^7	575mm on CBR 5% 425mm on CBR 8%	130mm to 200mm	150mm to 325mm, commonly 200mm
Riverina Highway - State (Corowa to Deniliquin)	Mid to High 10^6	475mm on CBR 5% 375mm on CBR 8%	150mm to 200mm	200mm
Main Road 57 – State (Junee to West Wyalong)	High 10^6 to Low 10^7	500mm on CBR 5% 400mm on CBR 8%	150mm to 200mm	200mm
Note: Pavement materials in the field includes base and sub base (mostly one material source only), and is directly upon the subgrade. CBR values in column 3 based on 10 day soaked.				

While road authorities have been encouraged to establish correct control sections to compare Polyroad DPPs against other treatments, little has been established until recently. However, the following examples are in close proximity to other base and subbase stabilisation treatments and full depth pavement construction in accordance with Austroads pavement design guidelines (Austroads, 1992).

It should be noted that for considerable lengths at a time along many of the State and National Highway examples provided there is consistency in pavement materials, subgrade conditions, traffic regimes and environment. Only the insoluble DPP stabilised pavements have performed without pavement distress, misshape or maintenance expenditure since constructed.

The highways listed in Table 2 above are located within Southern NSW. Examples of specific site details and recent photographic records for several locations listed in Table 2 are provided.

Figure 4 Newell Highway (National) 35Km north of West Wyalong photographed Jul 2005
Site Details:

- AADT = 3500 vehicles per day
- Percentage heavy vehicles = 45%
- Indicative 20 year design life ESAs = high 10^7 to low 10^8
- Estimated back-calculated ESAs to date = $1X10^7$ per lane (RTA Vehicle Usage Survey, 2001)
- Constructed Jun 1996
- Stabilised 200mm deep with PR21L (1.5% spread rate)
- Expansive black soil subgrade
- Conventional cutback bitumen seals
- Retained formation shape
- No wheelpath rutting
- No shoulder deformation

Figure 5 Newell Highway (National) 42Km north of Jerilderie photographed Jul 2005
Site Details:

- AADT = 3300 vehicles per day
- Percentage heavy vehicles = 50%

- Indicative 20 year design life ESAs = high 10^7 to low 10^8
- Estimated back-calculated ESAs to date = $1X10^7$ per lane (RTA Vehicle Usage Survey, 2001)
- Constructed May 1996
- Stabilised 200mm deep with PR21L (1.5% spread rate)
- Conventional cutback bitumen seals
- Retained formation shape
- No wheelpath rutting
- No shoulder deformation

Figure 6 Sturt Highway (National) 60Km west of Wagga Wagga photographed Jul 2005
Site Details:

- AADT = 2700 vehicles per day
- Percentage heavy vehicles = 35%
- Indicative 20 year design life ESAs = mid to high 10^7
- Constructed Feb 1996
- Stabilised 200mm deep with PR21L (1.5% spread rate)
- Conventional cutback bitumen seals
- Floodway included in stabilisation
- Retained formation shape
- Less than 2mm wheelpath rutting
- No shoulder deformation

Figure 7 Riverina Highway (State) 22Km west of Finley photographed Jul 2005
Site Details:

- AADT = 1500 vehicles per day
- Percentage commercial vehicles = 25%
- Indicative 20 year design life ESAs = mid to high 10^6
- Constructed Sep 2000
- Stabilised 200mm deep with PR11L (2% spread rate)
- Adjacent to Mulwala Irrigation Canal – largest canal within Murray Irrigation Area
- High water table and constant head of capillary rise
- Conventional cutback bitumen seals
- Retained formation shape
- Less than 2mm wheelpath rutting
- No shoulder deformation

Figure 8 Riverina Highway adjacent to Mulwala Irrigation Canal

The irrigation canal in Figure 9 below (referenced in Figured 8 above adjacent to highway) has provided a constant head for capillary rise problems for pavements along this length of highway.

Figure 9 Mulwala Irrigation Canal

5.3 ACTUAL PERFORMANCE VERSUS THEORETICAL PAVEMENT LIFE

The following table provides an indicative comparison of performance to date versus theoretical pavement life based on the traffic regime, pavement profile and design subgrade qualities of some of the above examples.

Table 3 is indicative of what has been measured in the field to date. The inclusion of an optimistic subgrade value of CBR 15% is merely for comparison purposes. Under normal seasonal conditions many of the locations listed in Tables 2 and 3 do not regularly achieve moderate to high subgrade strengths.

The ongoing ability of DPP to perform without pavement misshape or maintenance to date is predominantly a result of no plastic deformation occurring within the stabilised pavement because of the ‘internal’ waterproofing of fine grained particles. As has been historically recognised within the road industry, pavements that have managed to remain ‘dry’ have delivered a service well in excess of their estimated design life.

Table 3 Sample of actual performance versus theoretical pavement life.

National Highway Location	Pavement Profile - Best Case	Const Date	Age in Yrs	Approx ESAs to Date	ESA Life Expectancy based on pavement profile & design **subgrade CBR of 8%** (Austroads 2004 Fig 8.4)	ESA Life Expectancy based on pavement profile & design **subgrade CBR of 15%** (Austroads 2004 Fig 8.4)	Approx Theoretical Date of Failure
Newell Highway 35km north of West Wyalong	200mm DPP over 100mm remaining gravel	Jun '96	9.5	4×10^7	8×10^5	1×10^8	Late 1996 for Subgrade CBR 8%, or Early 2000 for Subgrade CBR 15%
Newell Highway 42km north of Jerilderie	200mm DPP over 50mm remaining gravel	May '96	9.5	2.8×10^7	1×10^5	1×10^7	Mid/late 1996 for Subgrade CBR 8%, or Late 1999 for Subgrade CBR 15%
Sturt Highway 60km west of Wagga Wagga	200mm DPP over 50mm remaining gravel	Feb '96	10	1×10^7	1×10^5	1×10^7	Mid 1996 for Subgrade CBR 8%, or Mid 2005 for Subgrade CBR 15%
Note: Existing pavement in the field includes base and sub base (mostly one material source only), and is directly upon the subgrade. CBR based on 10 day soaked.							

4. ENVIRONMENTAL INFLUENCES

LOCAL EXPERIENCE

The following two examples explain further the attributes of insoluble DPP stabilisation in difficult environmental situations.

Figure 10 Sturt Highway approximately 70km west of Wagga Wagga

Figure 10 shows typical environmental cracking resulting from expansive subgrade and variable moisture regimes. When gravels are stabilised with DPPs, moisture movement is significantly inhibited therefore maintaining equilibrium for significant periods at a time. As a result, environmental cracking is significantly inhibited after DPP stabilisation. The subgrade material at this location is equivalent to the subgrades underlying the pavements in Table 3 which have been stabilised with DPP.

Figure 11 Sturt Highway approximately 100km west of Narrandera

For the same principle as explained above, DPP stabilisation controls moisture regimes such as severe dry-back during drought periods. While cracking due to drought may be observed within the surrounding terrain and up the embankment formation, once the cracking intercepts the edge of DPP stabilisation, cracking then only travels longitudinally and does not propagate across the stabilised pavement.

It should be noted that the pavement thickness of the road formation shown in Figure 11 conforms to the current mechanistic design model in the Austroads guide. However, several locations of DPP stabilised pavements occur within kilometres either side of Figures 10 and 11 which do not conform to Austroads pavement thickness guidelines. Observations to date of the DPP stabilised pavements indicate there is no pavement distress as a result of drought conditions.

6. CONCLUSION

Many kilometres of DPP stabilisation have been competently carried out to date and without failure or reactive maintenance repair. DPP stabilisation is especially suited for treating moderate to poor quality gravels that lose considerable strength when wetted up. They also have particular application to regions of high water tables, periodic flooding of pavements and even during prolonged drought periods.

The mechanistic pavement design method is not well suited to DPP stabilisation which improves granular material behaviour in ways other than increasing material stiffness. The field performance of DPP stabilised pavements has shown to increase pavement rut resistance (less moisture sensitive) for granular materials that historically were highly sensitive to moisture. The subgrade is also further protected because there is minimal to no deformation of the stabilised pavement itself. It is important for a stabilised pavement to function as an ‘impermeable’ protection of the subgrade to improve its volume stability.

Because DPP stabilisation does not involve chemical reactions, the stabilised pavement does not suffer shrinkage cracking or premature load-induced cracking. DPP stabilised pavements have reduced deformability and functions as a low permeability protective barrier to the subgrade.

The author has had many years experience in managing road networks, in particular, managing large rehabilitation programs and annual maintenance programs. He can confirm the absence of reactive maintenance expenditure for insoluble DPP stabilised pavements since its introduction to the road industry which in turn has provided a highly competitive and cost-effective long term solution for pavement rehabilitation.

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