Foamed Bitumen Stabilisation

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1. INTRODUCTION

As Queensland's State and National Road Network matures, Main Roads is spending less money on new construction and more on maintenance and rehabilitation.

The challenge of Main Roads' maintenance and rehabilitation task is increased by the fact that Queensland has substantial lengths of road network consisting of thin, highly plastic and low strength pavements over weak and highly expansive subgrades.

Since 1995 Border (Warwick) District has been working with Transport Technology Department (TTD) and other world leaders to trial and develop cost-effective methods of rehabilitating its aging road network.

After extensive work with lime stabilisation, and two relatively small trials using foamed bitumen stabilisation, Border District has recently completed the largest foamed bitumen stabilisation job ever carried out in the Southern Hemisphere.

This paper addresses:

- the basics of foamed bitumen stabilisation;
- situations where foamed bitumen stabilisation could be considered;
- the design process for foamed bitumen stabilisation;
- lessons learnt from the $2.5m, 17.6 km New England Highway project;
- what to look for when carrying out foamed bitumen stabilisation; and
- the future of foamed bitumen stabilisation for Queensland's Main Roads Department.

2. WHAT IS FOAMED BITUMEN STABILISATION?

Foamed bitumen (also known as foamed asphalt, foam bitumen or expanded asphalt) is a mixture of air, water and bitumen. When injected with a small quantity of cold water, the hot bitumen expands explosively to about fifteen times its original volume and forms a fine mist or foam. In this foamed state, the bitumen has a very large surface area and an extremely low viscosity.

This expanded bitumen mist is incorporated into the mixing drum where the bitumen droplets are attracted to and coat the finer particles of pavement material, thus forming a mastic that effectively binds the mixture together.

Foamed bitumen stabilised pavement can be produced either insitu (Figure 1) or by using a central plant through a pugmill-paver operation. This paper concentrates on insitu stabilisation as used on the New England highway project.

Figure 1 Insitu foamed bitumen stabilisation using Wirtgen WR2500

3. HISTORY OF FOAMED BITUMEN STABILISATION

3.1 Background

For many years, cement has been used for the modification and stabilisation of pavements.

Main Roads has recently carried out extensive research and several successful trials to investigate the role of lime in the stabilisation of highly plastic subgrades under the direction of the Queensland Main Roads Lime Stabilisation Steering Committee. Hundreds of kilometres of pavements have been stabilised using lime/flyash blends in conjunction with this research.

Some cracking problems have recently been observed in pavements stabilised using combinations of cement, lime and fly ash. This cracking is believed to be due to the sensitivity of cementitiously bound pavements to vehicle overloading where there is inadequate subgrade support.

Accelerated Load Facility (ALF) trials suggest that a twelfth power relationship applies for damage to rigidly bound pavements due to overloading, whereas for flexible pavements, a fourth power relationship is understood to apply. For example, 20% overloading corresponds to almost nine times the damage in rigidly bound pavements, compared to just over twice the damage for a granular pavement (i.e $1.2^4 = 2.1$ for flexible granular pavements compared to $1.2^{12} = 8.9$ for rigid pavements).

Quantification of the fatigue relationship for foamed bitumen stabilised pavements would be useful in predicting the design life for the pavement. At this point in time it is believed that the bitumen binder enables an increased resistance to fatigue. TTD is currently conducting research using flexure beams to obtain quantitative fatigue relationships.

In view of the fatigue properties of cementitiously stabilised pavements with low subgrade support,[1] bitumen stabilisation was explored in order to utilise the strength and flexibility properties of bitumen.

Stabilisation trials were carried out using bitumen emulsion and cement in Warwick District in 1994.

3.2 Historical perspective

CSIR Transportek's Mix Design Procedure records that "The potential of foamed bitumen for use as a soil binder was first realised in 1956 by Dr Ladi H Csanyi at the Engineering Experiment Station in Iowa State University. Since then, foamed bitumen technology has been used successfully in numerous countries with a corresponding evolution of the original bitumen foaming process as experience was gained in its use. The original process consisted of injecting steam into hot bitumen. The steam foaming system was very convenient for asphalt plants where steam was readily available, but it proved to be impractical for insitu foaming operations because of the need for special equipment such as steam boilers."[2]

"In1968 Mobil Oil Australia, which had acquired the patent rights for Csanyi's invention, modified the original process by adding cold water rather than steam into the hot bitumen. The bitumen foaming process thus became much more practical and economical for general use."[3]

The process of foamed bitumen stabilisation was developed more than forty years ago, but the lack of a standard design procedure and the failure of Mobil to exploit their patent have contributed to its limited implementation.[4] Since the expiration of Mobil's patent on the foamed bitumen process and subsequent intensive research, particularly by South Africa's CSIR Transportek, many road authorities world wide have carried out successful trials using foamed bitumen stabilisation technology.

3.3 Queensland trials

Main Roads has recently carried out a number of foamed bitumen stabilisation trials.

3.3.1 Gladfield

Main Roads carried out its first foamed bitumen trial in Queensland on 1.6km of the Cunningham Highway at Gladfield (21km east of Warwick) in May 1997.

The CBR 30% clayey gravel overlying a CBR 2% black soil was stabilised to a depth of 200mm in the inner wheel path and 250mm in the outer wheel path using 3.5% bitumen and 2.0% cement additive.

At the end of the first day of the trial, rebound deflections in the order of 0.75mm were measured on the treated pavement. Traffic was allowed on the stabilised pavement after each day's work after which the pavement did not show any signs of early distress.

Given the very high content of commercial vehicles on the Cunningham Highway (AADT = 4000 with 24% commercial vehicles) these low early deflections are a good indication of the capacity of foamed bitumen stabilised pavements to gain strength rapidly, and the potential to allow for early trafficking.

Following completion of the trial, the pavement was left without any surfacing for a period of two weeks and then lightly sealed. The pavement suffered no distress during this period.

After three months, the back-analysed modulus from deflection was 1,250MPa.[5]

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[1] Fatigue problems are eliminated from cementitiously stabilised pavements if they are designed with sufficient cover over a strong subgrade, thus minimising flexure in the pavement.

[2] CSIR Transportek, 1998.

[3] Ibid.

[4] Ibid.

[5] Moduli determined from back analysed pavement deflection data.

After two years of service, the pavement is exhibiting distress in approximately 10% of the pavement due to block cracking which coincides with the original cement treated patches and the lack of subgrade support and overloading, but is otherwise performing well. It is believed that the use of lime instead of cement as the additional additive in future foamed bitumen work will reduce this block cracking which occurs coincident with previously cement stabilised patches.

3.3.2 Gympie

After the initial success of the Gladfield job, Main Roads trialed foamed bitumen with various additives at Rainbow Beach Road, east of Gympie, in order to test the effectiveness of various mix designs in low plasticity gravels and sand pavements.

The following mix designs were trialed:

1. 1.0% and 3.0% residual bitumen from emulsion with 1.0% and 2.0% cement;
2. 3.0%, 4.0% and 5.0% foamed bitumen with 2.0% lime; and
3. a control section of granular construction.

This job received some rain during the period between construction and sealing. The foamed bitumen section held up well and was still trafficable, while the bitumen emulsion section became very slippery with some rutting occurring. Screenings had to be spread on the surface to make the emulsion stabilised section trafficable again.

Both the bitumen emulsion and the foamed bitumen sections are now performing well. Through continued long term monitoring, we will be able to ascertain whether foamed bitumen has superior fatigue properties.

3.3.3 Inglewood

A third foamed bitumen trial was carried out in June 1998 on the Cunningham Highway just east of Inglewood using 4.0% bitumen and 1.5% quicklime.

At the end of the first day's production, the job received 30mm of rain, following which the road was still trafficable. The only rework required was to remove a thin slurry film off the top of the pavement using a grader.

This job was left unsealed for six weeks, during which time it was unfortunately subjected to 142mm of rain. This rainfall would have destroyed a conventional unbound pavement; however, the foamed bitumen stabilised pavement emerged requiring only relatively minor patching. This is again a positive testimony to the strength of foamed bitumen stabilised pavement, and its reduced susceptibility to damage from wet weather, in comparison to other methods of rehabilitation.

This pavement is performing very well and has required no maintenance since being sealed.

4. CONSIDERATIONS

This section discusses the things that one should consider in deciding whether bitumen stabilisation is the appropriate solution in a particular situation.

4.1 Appropriate uses

Situations that should trigger the consideration of the use of foamed bitumen technology include the following:

- a pavement has been repeatedly patched to the extent that pavement repairs are no longer cost effective;
- a weak granular base overlies a reasonably strong subgrade (a minimum CBR of 5% is required.);
- conventional reseals or thin asphalt overlays can no longer correct flushing problems; or
- overloading is significant and can not be easily controlled.[6]

4.2 Advantages

The advantages in using foamed bitumen stabilisation include the following:

- increases the shear strength of a granular pavement;
- strength characteristics approach that of cement treated materials while remaining flexible and hence relatively fatigue resistant;
- lower moisture contents are required in comparison to bitumen emulsion stabilisation and hence wet spots are minimised;
- after construction, the pavement can tolerate heavy rainfall with only minor surface damage under traffic, and hence is less susceptible to the effects of weather than other methods of stabilisation; and

[6] Based on the short-term results of trials carried out by Warwick District, foamed bitumen stabilisation seems to have better fatigue properties than cementitious binders such as lime fly ash or cement and hence better resist overloading.

- is carried out insitu and hence is quicker than other methods of rehabilitation such as an overlay.

4.3 Disadvantages

Disadvantages of foamed bitumen stabilisation include the following:

- more expensive than lime/flyash stabilisation;
- not suitable for all pavement types (requires a full particle size distribution);
- design methodologies for foamed bitumen are relatively new, as a rapid evolution of the technology associated with foamed bitumen stabilisation has only recently occurred;
- the process requires hot bitumen (180°C) for the foaming action to be successful, and thus there is a risk of burning (common to all road construction operations involving bitumen); and
- purpose built foamed bitumen stabilising equipment is required.

5. DESIGN AND PRECONSTRUCTION

This section gives an overview of the design and pre-construction phases on the New England highway foamed bitumen job.

5.1 Subgrade issues

Before stabilising with foamed bitumen, the strength of the subgrade must be assessed. A flexible foamed bitumen stabilised pavement layer cannot be expected to bridge over a subgrade with a CBR value of less than five.

Extensive Dynamic Cone Penetrometer (DCP) tests were carried out on the New England Highway project to ensure that the subgrade had the required strength.

Subgrade failures must be repaired before insitu stabilisation occurs, while failures confined to the upper base pavement can be ignored. Extensive base failures on the New England Highway project were not treated before stabilisation took place.

5.2 Foamed bitumen testing machine

Initial testing for concept and preliminary design were based on a handful of tests carried out in a private laboratory in Melbourne. The 4.0% recommended equated to approximately $1m of bitumen for the project.

Due to the high variability of the pavement materials and the expense of individual tests in Melbourne, a Wirtgen foamed bitumen testing device costing $50,000 (Figure 2) was purchased to carry out a range of tests to fine tune the design. This testing device has been found to be a good investment in Main Roads' corporate knowledge.

Figure 2 Foamed bitumen testing device

5.3 Types of bitumen

Bitumen samples from a number of suppliers were tested in order to confirm that bitumen supplied under the State Stores Contract did not require more foaming agent than bitumen from other sources. The proposed foaming agent performed similarly in bitumen obtained from all suppliers.

5.4 Optimisation of moisture content and foaming agent

Figure 3 shows a theoretical plot of moisture content versus expansion ratio and half-life for the optimisation of moisture and foaming agent. For each combination of bitumen and foaming agent, there is an optimum combination of added water and foaming agent in order to achieve the required expansion with minimal expenditure.

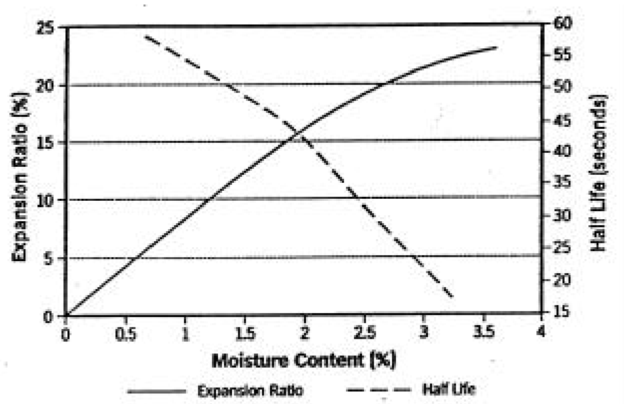

Figure 3 Moisture content vs expansion ratio and half-life

Testing was performed using injected water percentages ranging from 1.0% to 2.5% with 0.5% foaming agent. Two percent (2.0%) added moisture barely met the required expansion and half-life values, giving an expansion of 14–15 times with 28–35 seconds half-life. Two point five percent (2.5%) injected water gave consistently better results than required, achieving expansion of 18 times and half-life of around 35-40 seconds. As 2.5% is the practical maximum level of injection of water in the field, no further reduction in foaming agent was attempted.

The reduction in the design foaming agent from 0.67% to 0.50% represented a further cost saving.

5.5 Desirable materials

It is claimed in CSIR Transportek's Mix Design Procedure that "foamed bitumen can be used with a variety of materials ranging from conventional high quality graded materials and recycled pavement materials to marginal materials such as those having a high plasticity index."[7]

Experience gained by Main Roads indicates that testing must be carried out to ensure that foamed bitumen does give the required results.

The success of foamed bitumen is dependent on the grading of the material being stabilised. A 'C' grading is required. Figure 4 shows the desired grading curve for a foamed bitumen mix (zone A). If the grading is fine (zone B) or coarse (zone C) the grading of the material to be stabilised can be altered by adding more coarse or fine material respectively.

Higher quality pavement materials (i.e. Type 2.1, Type 2.2 and some Type 2.3) whose grading lacks the required fines and plastic properties may not be suitable for foamed bitumen stabilisation. The low initial modulus of these materials requires the addition of sufficient fines so that the percentage of material passing the 0.075mm sieve is between 5% and 15%.

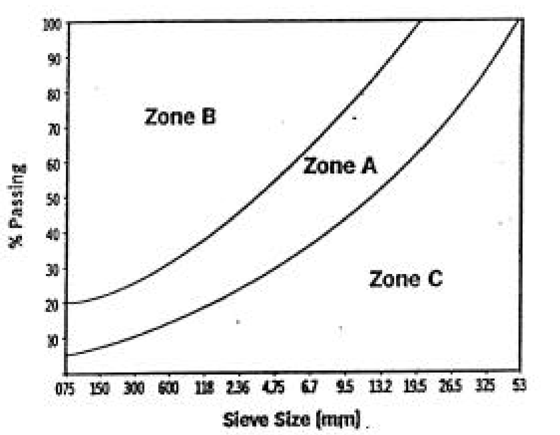

Figure 4 Foamed bitumen desired grading

[7] CSIR Transportek, 1998.

Further to the above, CSIR Transportek's Mix Design Procedure states that "a wide range of aggregates may be used with foamed bitumen, ranging from crushed stone to silty sands and even to ore tailings. Certain soil types may require lime treatment and grading adjustment to perform satisfactorily."[8]

Table 1 shows the range of binder contents required for various soil types along with any additional requirements (e.g. addition of lime). This data gives a starting point for subsequent laboratory bitumen content tests.

Table 1 Optimal binder content range[9]

Soil type	Binder (%)	Additional
Well graded clean gravel	2.0 – 2.5%	
Well graded marginally clayey/silty gravel	2.0 – 2.5%	
Poorly graded marginally clayey gravel/silty gravel	2.0 – 2.5%	
Clayey gravel	4.0 – 6.0%	Lime modification
Well graded clean sand	4.0 – 5.0%	Filler
Well graded marginally silty sand	2.5 – 4.0%	
Poorly graded marginally silty sand	3.0 – 4.5%	Low penetration of bitumen & filler
Poorly graded clean sand	2.5 - 5.0%	Filler
Silty sand	2.5 – 4.5%	
Silty clayey sand	4.0%	Possibly lime
Clayey sand	3.0 – 4.0%	Lime modification

5.6 Bitumen content

The bitumen content was designed to meet a minimum soaked resilient modulus of 1500 MPa. The results of modulus testing shown in Figure 5 indicate that the strength of the mixture peaks when 3.5% bitumen for this blend of pavement materials.

The design bitumen content was initially reduced from 4.0% to 3.0% to achieve the required strength but later increased to 3.5% in the field to allow for construction tolerances and water proofing of the pavement. This reduction of 0.5% in the design bitumen content resulted in a saving of $122,000,

[8] CSIR Transportek, 1998.

[9] Bowering & Martin, 1976.

thus recovering more than twice the cost of the foamed bitumen-testing device (Section 5.2).

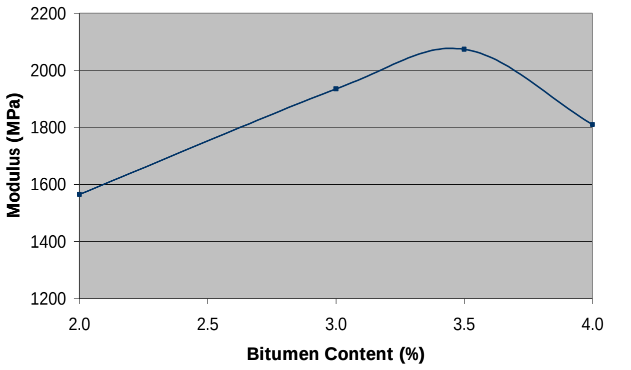

Figure 5 Strength gain with bitumen

5.7 Supplementary additive

The supplementary additive was confirmed by testing to be 2.0% hydrated lime (equivalent to 1.5% quicklime).

The strength of the foamed bitumen mixture peaked when 2.0% hydrated lime was used.

This peaking can be explained by the fact that when lime reacts with the clay particles it flocculates and increases the particle size which in turn requires more bitumen to lubricate the sample in order to achieve compaction. The samples treated with 3% lime appeared to have more voids because the lime affected the plasticity, thus giving the pavement a more open structure.

5.8 Cement treated patches

Over the years, considerable cement stabilisation had occurred on the New England Highway. Figure 6 shows a heavily cemented stabilised patch that has been pre-milled. Laboratory testing was carried out to establish what effect this existing cement treated pavement may have on the final product.

Figure 6 Pulverised cement treated patch

It was observed that the early strength of cement stabilised sections was approximately twice that of the previously untreated sections. However, as the final soaked values are only marginally higher than for untreated road materials, no change was made to the design for these sections.

The cost of removing all the cement patches in the job would have been substantial. It is believed that the residual lime present in the cement treated patches could lead to marginally higher rates of strength gain and hence early fatiguing. Future monitoring will concentrate on these cement treated areas to further investigate the effect of previously stabilised patches.

5.9 Culverts

The location and depths of culverts within the job were established and noted in the tender documentation for this project. There must be at least 300mm of cover over culverts to avoid severe damage to both the culverts and the stabiliser. The contractor was also responsible for checking the location of the culverts before proceeding with the work.

5.10 Statistics

Table 2 shows statistics for the job.

Table 2 Job statistics

Location	New England Highway (22B) (Toowoomba – Warwick Road) between 34.45-48.25km and 52.75-55.69km north of Warwick
Job No	35/22B/802
Timeframe	23 March – 28 May 1999
Construction time	37 working days
Length	17.59 km
Area	145,086 m^2
Quicklime	1,026t @ 1.5%
Bitumen	2,735t @ 3.5%
Foaming Agent	12,191 litres @ 0.5%

5.11 Cost

The following table details a breakdown of the major cost items for the job.

Table 3 Foamed Bitumen Stabilisation Costs

Stabilisation (excluding bitumen, traffic & seal)	\$963,421 (\$6.64/m^2)
Bitumen	\$853,766 (\$5.88/m^2)
Survey & Traffic	\$121,600 (\$0.83/m^2)
Design & Supervision	\$102,977 (\$0.71/m^2)
Seal & Pvt Markings	\$515,100 (\$3.55/m^2)
Total	\$2,556,864 (\$17.64/m^2)

The following table shows a comparison of prices using other methods of stabilisation (excluding seal).

Table 4 Relative Costs of Stabilisation[10]

Treatment	Cost (\$/m^2)
2-3% lime/flyash (200mm)	\$6 - \$9
Bitumen (2%) emulsion/cement (2%) (200mm)	\$12 - \$14
Ad-Base 4/cement (175mm)	\$12 - \$14
Foamed bitumen (250mm OWP, 200mm IWP)	\$13- \$15

5.12 Specification

A new specification was written for this job in the form of the MRS11.07 specification for In Situ Stabilised Pavements. Following revision to incorporate the lessons learnt on the New England Highway project it will be submitted for incorporation in the Main Roads Standard Specifications. In the interim period before its publication, interested parties can contact TTD for copies of this specification.

6. PROCESS

This section provides an overview of the processes employed in the construction phase on the New England Highway foamed bitumen project.

6.1 Award of contract

Stabilised Pavements of Australia (SPA) won the contract for the supply and incorporation of lime, transportation of bitumen, incorporation of bitumen, supply and incorporation of foaming agent, compaction, and trimming. Traffic control, sealing and line marking were carried out by Main Roads' Road and Transport Construction Services (RTCS), while design and audit testing was carried out by TTD's Pavement Rehabilitation Branch.

6.2 Partnering

A partnering meeting involving the major stakeholders was convened before the works commenced. Through this process a greater level of understanding emerged between the major stakeholders, thus facilitating the resolution of outstanding issues before the work commenced. This resulted in the creation of an environment in which experimentation could take place in an atmosphere of mutual trust.

6.3 Pre-milling

The pavement was initially pre-milled using a CMI RS500 Reclaimer/Stabiliser to a depth of 50mm less than the design depth to eliminate the effect of the existing cement-stabilised patches (see Section 8.5 for a discussion of the pre-milling process).

6.4 Shape correction

The pre-milling process allows the pavement to be shape corrected with a grader and thus enable the stabilisation to be carried out to the correct depth. After pre-milling, the shape-corrected material is lightly rolled. Figure 7 shows the type cross section used.

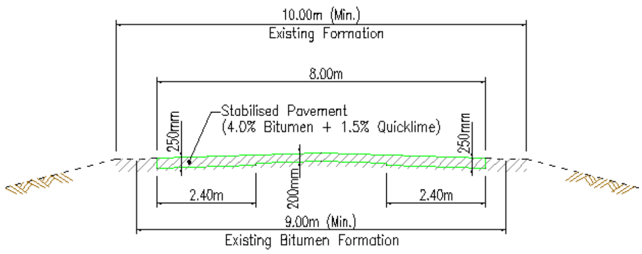

Figure 7 Typical cross section

6.5 Spread and slake lime

One and a half percent (1.5%) quicklime was spread on the road using a purpose built spreader and subsequently slaked using two passes of a water tanker. Sufficient water was used so that no more steam was released when extra water was added.

[10] These figures are distorted to an extent due to increased density and roughness testing on the foamed bitumen job. It was found necessary to take a separate proctor MDD for every density test.

Figure 8 shows the steam plume from slaking of the lime in the background. Compaction of the previous run, having had lime and bitumen incorporated, is occurring in the foreground.

Figure 8 Slaking of quicklime and final compaction after stabilisation

Figure 9 shows the fine powdered quicklime slaked into a paste on the road ready for the incorporation of foamed bitumen.

Figure 9 Slaked quicklime

6.6 Mix lime and bitumen

The lime and bitumen is then mixed to the specified depths of 200mm and 250mm using the 30 tonne 601 horse power Wirtgen WR2500 Reclaimer/Stabiliser.

The hot bitumen is pumped out of the attached bitumen push tanker and is injected into the mixing box of the Wirtgen WR2500. Water is sprayed into the bitumen at 2.5% by mass of the hot bitumen, which causes the treated bitumen to foam to fifteen times its initial volume. The bitumen is then mixed into the pavement material by the WR2500 (Figure 10) while the bitumen is in its expanded state.

Figure 10 Wirtgen WR2500

Figure 11 shows diagrammatically the process of incorporation of the bitumen into the pavement material in the mixing chamber of the Wirtgen WR2500.

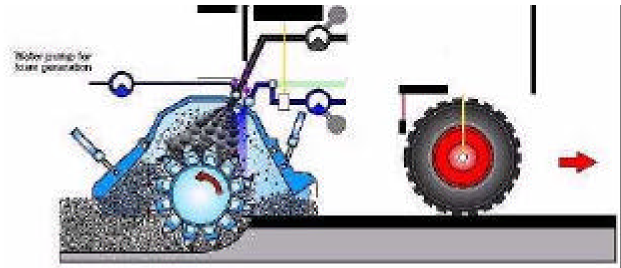

Figure 11 Incorporation of foamed bitumen

Figure 12 shows the foamed bitumen-monitoring device on the side of the stabiliser used to ensure that the required foaming of the bitumen is being achieved.

Figure 12 Foaming monitoring device

Figure 13 shows the foamed bitumen stabilised pavement material as it comes out of the machine. The material is slightly warm from the hot bitumen. It is initially hard to see an appreciable colour change in the material because the bitumen coats only the fine particles. By comparison, if a similar percentage of bitumen were mixed into aggregate to manufacture asphalt, the mixture would turn black because the large particles are also being coated.

Figure 13 Freshly stabilised pavement material

After stabilisation, there is a large mound between the tyre tracks of the stabiliser because the wheels of the machine provide a significant amount of compaction under the weight of the machine. It is important that this mound is not leveled with a grader before compaction; otherwise, the compaction of the pavement material will be unevenly distributed across the road.

Figure 14 Freshly stabilised pavement

6.7 Trim and compact to 100% STD

Following stabilisation, the pavement is compacted to 100% Standard Compaction using a self propelled pad foot roller, a self propelled smooth drum vibrating roller, and a rubber tyred roller as per normal road construction practice.

It is imperative that the vibrating pad foot rollers follow closely behind the bitumen stabilisation operation in order to optimise compaction (Figure 15).

Figure 15 Padfoot roller following behind stabiliser

After compaction, the pavement was wet with the water tanker to facilitate curing, and left to the traffic. A trim is sometimes required the next day to correct rutting caused by traffic loading before the pavement had cured.

Figure 16 shows the surface of the compacted pavement after twelve hours of traffic. Without a seal, the surface becomes very tight, and markedly darkens. Experience has shown that this surface is almost immune to the effects of weather.

Figure 16 Foamed bitumen stabilised pavement after trafficking

The pavement becomes almost impossible to trim after twelve hours. A final cut was given to the pavement just prior to roughness testing.

6.8 Seal

Figure 17 Sealed pavement at Nobby intersection

The pavement was lightly sealed using Class 170 bitumen with 7% cutter at 0.9L/m^2 and 10mm aggregate with a spread rate of 1m^3 per 145m^2.

This seal treatment has worked well except where fresh seal stripped at some intersections due to tyre stresses. Alternative treatment should be considered at intersections (refer Section 8.17).

6.9 Production

At the peak of production, the contractor was achieving a production rate of 1,200 lane metres per day (four 25,000-litre bitumen tankers). It was found, however, that a superior finish could be achieved if more time was taken; hence, the production rate was reduced to 900 lane metres for the remainder of the contract.

7. RESULTS

A variety of tests were carried out on the foamed bitumen stabilisation project to monitor the success of the processes during, and subsequent to, construction. This section addresses the monitoring procedures used, and the results obtained.

7.1 Depth

Depth of stabilisation was monitored, both on the Wirtgen WR2500 machine by viewing the depth gauge, and by digging test holes at the interface of the stabilised and the existing pavement before compaction took place.

7.2 Bitumen content

The percentage of bitumen being incorporated is shown on a digital readout on the Wirtgen WR2500, based on the bitumen pump speed.

Dockets from the bitumen tankers were checked regularly to ensure that the required bitumen was being incorporated. TTD also carried out residual bitumen content tests in the laboratory.

7.3 Lime content

The lime-spread rate was checked by tray tests. A canvas mat (or tin tray) of known mass and area is placed under the centre of the path of the spreader truck. The nett weight (after deducting tare weight of mat or tray) of the spread lime is measured using hanging "fish" scales for the canvas mat or a platform balance for the tray. The tolerance on the spread rate was set at ± 5%. Most of the spread rates were within this tolerance. This tolerance is under review as it is quite tight when spreading small quantities such as 1.5%.

7.4 Slaking

The degree of slaking is important. Too much or too little water can minimise the effect of the lime.

Too little water will cause the lime to be left in chunks and not mix or react properly. Too much water will drown the lime and cause unreacted lime to be trapped in small balls. Excess water will also cause wet spots and failures when the pavement is compacted.

The quicklime was slaked to the point that no more steam was produced when more water was applied to the lime with a water bottle.

7.5 Mixing

The adequacy of the mixing is checked visually. No specks of lime should be visible after mixing. The lime and the bitumen must be uniformly mixed throughout the pavement. Adequate mixing was not a problem after both the pre-milling and mixing passes.

7.6 Start of runs

As with any construction joint, there tends to be a hump at the end of each run where the stabiliser drum was lowered at the start of each run. This can be minimised by careful grader work in these locations.

7.7 Roughness

The roughness achieved was generally within the range of 50-60 counts per kilometre. This roughness was influenced by the requirement that the stabilised pavement be tied into the shoulders. Roughness could be improved significantly in future jobs by pre-milling the shoulders and reshaping the full formation before stabilisation (see Section 8.5).

7.8 Moisture content

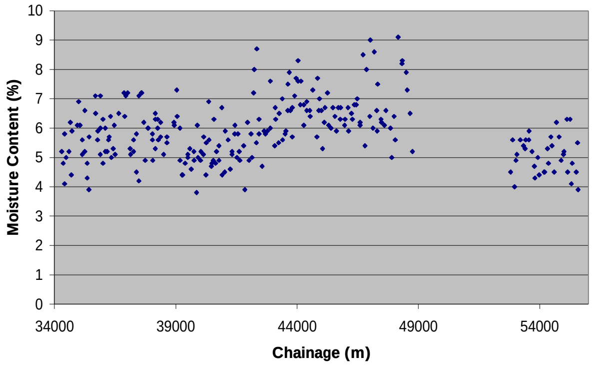

Figure 18 Moisture content at time of construction

Although the variation in moisture content (4–8%) shown in Figure 18 could be improved with extra field control, they are reasonable considering the initial variation in insitu moisture prior to stabilisation.

7.9 Relative dry density

The Warwick RTCS Soil Laboratory carried out density testing.

The compaction results shown in Figure 19 reveal that very high compactions were being achieved on the road in comparison to the reference proctors being done in the laboratory.

It is likely that the high compaction results could be because some degree of setting often occurs in the material before it is compacted in the laboratory, and therefore the field densities are comparatively higher than the laboratory densities. This indicates that the true MDD is not obtained by Standard Compaction.

The high variability in these density results was reduced after Chainage 41,800m when reference proctors were taken for every density test due to the high variability in the insitu pavement material.

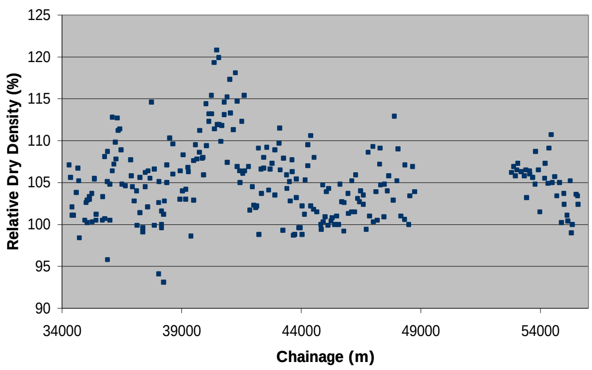

Figure 19 Relative dry density at time of construction

7.10 Air voids versus density

Figure 20 shows that there is a linear relationship between the measured field density and the percentage of air voids.

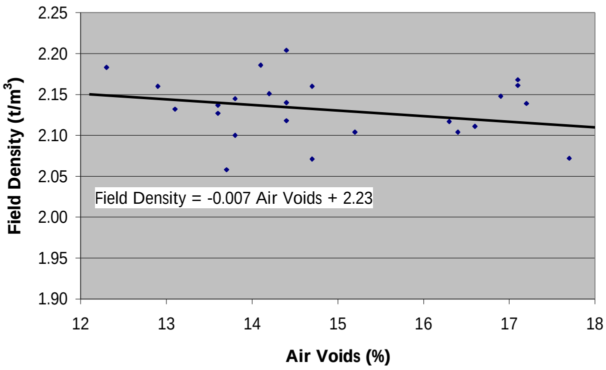

Figure 20 Air voids vs field density

This information is useful as more work is being carried out as part of the research work by TTD in order to control the compaction by targeting the voids content rather then density. For example, it is likely that Main Roads will, in the future, require maximum air voids of 12-14% rather specifying a measure of density.

7.11 Deflection

Figure 21 shows the deflections measured three months after the work was completed on the northern end of the job. The deflections are in the region of 0.15–0.45mm indicating that there has been a structural improvement to the pavement/subgrade system when compared to the significantly high deflections prior to stabilisation (approximately 1mm).

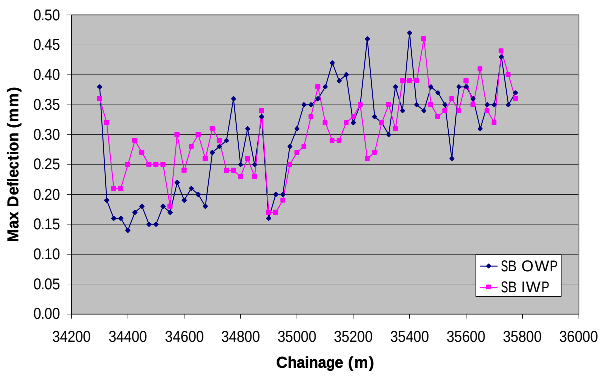

Figure 21 Maximum deflection

The foamed bitumen pavement was originally designed for 20-year life, assuming a conservative design modulus value of 800MPa. It was anticipated that a 75mm asphalt overlay would also be required on most sections of the stabilised pavement to meet the 20-year design life.

Deflection and back analysis after stabilisation now indicate that an asphalt overlay will not be required during the 20-year design life for structural purposes.

Surface correction with conventional asphalt or SMA may be necessary during this period if funding permits, due to anticipated environmental induced distortions.

7.12 Curvature & deflection ratio

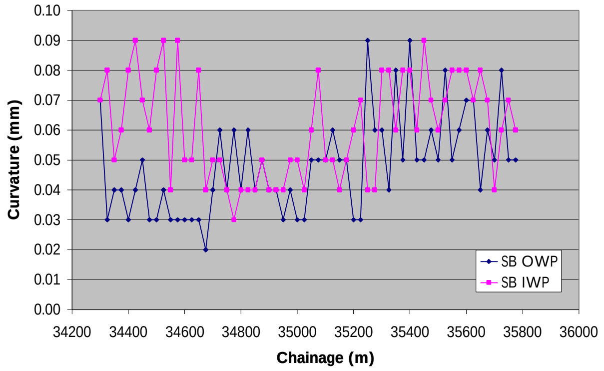

Figure 22 Curvature

The range of curvature values shown in Figure 22 indicates that a sound modified pavement rather than a stiff pavement has been achieved. This is also verified by the deflection ratio values shown in Figure 23 which are in the range of 0.60–0.85mm.

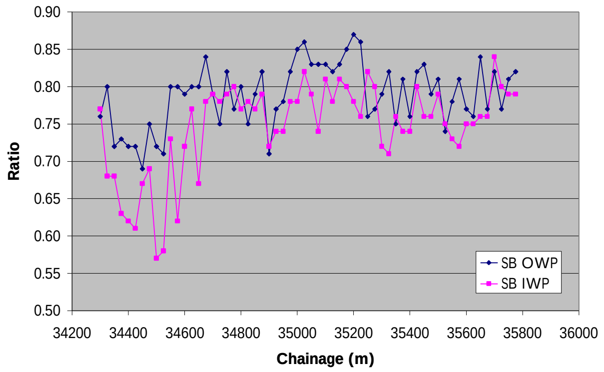

Figure 23 Deflection ratio results

7.13 Strength

Transport Technology Division drilled cores to check wet modulus strength of the final product.

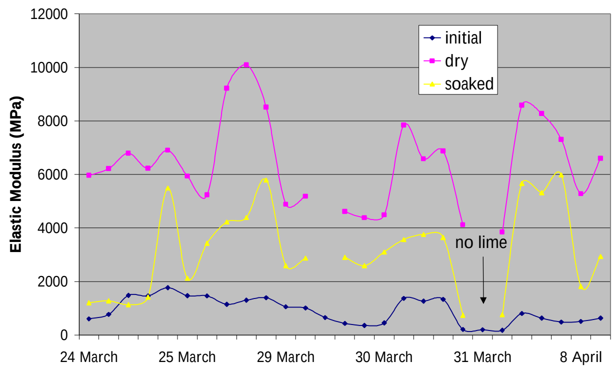

Figure 24 Resilient modulus at time of construction

The insitu modulus results shown in Figure 24 reveal that:

- there is a definite increase in the soaked resilient modulus when 3.5% bitumen is used rather than 3.0% on 26 March;
- the strength is significantly decreased without the addition of lime (lime was not incorporated in one run on 31 March); and
- the actual moduli results show a high degree of variability but are generally well above the design soaked modulus of 1500 MPa.

8. Discussion

This section addresses the issues that have arisen on this project. It is hoped that the lessons learned on the New England Highway project documented here will be utilised in the future to increase the excellence of, and confidence in foamed bitumen stabilisation.

8.1 Type cross section

Stabilisation was carried out to a width of eight metres (i.e. traffic lanes plus 0.5 metre of each shoulder) rather than full width in an effort to optimise the cost to the benefit gained (see Figure 7).

A significant difficulty associated with the use of this cross section is that the unevenness of the remaining shoulder is reflected into the traffic lanes with a consequent influence on road roughness. There was also little scope to change the longitudinal grade with this design.

Once one side is rehabilitated, the crown level is set and, depending on the levels of the opposite shoulder, a 3% crossfall for the second side may not be obtainable.

A possible solution for future stabilisation projects to balance the economic and roughness issues, is to pre-mill almost the full width at the shallowest stabilisation depth less 50mm (i.e. 150mm on this job), grade to shape, and then nominally roll.

The pre-milled, non-stabilised shoulder may require the addition of moisture during the pre-milling stage in order to achieve the optimum moisture content at compaction. Hence, the pre-milling machine used should have the ability to vary the supply of water across the machine width.

8.2 Shoulders

Shoulder preparation consisted of the removal of any signage/deliniation, the degrassing of unsealed shoulders, and the installation of temporary delineation. If the shoulders were pre-milled (total with of pre-milling of 9.4 metres) the guide posts would also have to be removed and later reinstated.

8.3 "Make up" gravel

"Make up" gravel is only required where there is severe shoulder drop off, or where the road is severely out of shape and is required to be re-constructed to a designated grade line and cross section.

Foamed bitumen stabilisation causes “bulking” (i.e. an increase in the volume of the pavement materials) and hence a slight raising of the existing surface levels, following the addition of the stabilising agents. Because of this expansion, makeup gravel is not usually required.

8.4 Traffic lights

Portable traffic lights were trialed initially but not used throughout the job because:

- the distance between signals required for this type of work was too far; and
- the delay between signal changes was too short to allow a vehicle to travel safely through the job.

8.5 Pre-milling

The original specification for this job specified pre-ripping of the surface using a grader in order to ensure that the lime being slaked on the road did not run off the road. During the course of the contract, the pre-ripping was replaced with pre-milling pass using a CMI RS500 machine before the lime and bitumen were incorporated.

It is common for a road requiring rehabilitation to be non-uniformly out of shape. An uneven surface profile can lead to pockets of unstabilised material and/or non-uniform stabilising agent incorporation and/or non uniform compacted depths.

Pre-milling to final depth less 50mm was adopted on the New England Highway project for the following reasons:

- pre-milling allowed for shape correction of the pavement before the stabilising agents were incorporated;
- foamed bitumen stabilisation can subsequently be carried out to a uniform depth below the final surface profile;
- the insitu moisture content could be adjusted as required prior to foamed bitumen stabilisation:
- the pre-milling can identify patched or extensively repaired areas that have been previously treated with cement or AC/pre-mix materials: and
- an initial mixing of the different thickness pavement materials takes place, thus giving a uniform pavement construction.

Pre-ripping is not recommended because the ripping produces large chunks of material (i.e. seal, previous patches) which tend to not get broken up in the stabilisation process. These large lumps of unstabilised material subsequently end up in the pavement as well as on the surface, leading to a deleterious effect on surface trimming and seal preparation. Pre-ripping does not facilitate a uniform mixing of the existing pavement materials or uniform moisture distribution.

The moisture content at the pre-milling stage does not need to be at or near optimum, because the bitumen foaming process adds some moisture to the pavement. The foamed bitumen also lubricates the pavement gravel making it easier to compact.

8.6 Depth of stabilisation

The design depth can usually be achieved with a tolerance of $\pm$ 15mm. However, the following practicalities should be considered:

- It is usually difficult to compact a layer depth greater than 250mm uniformly with readily available compaction equipment. With a 300mm layer it is possible to get a "gradient of compaction" from the top to bottom if large, (i.e. greater than 18 tonne static weight) padfoot rollers are used. Care must be taken to prevent the surface forming pad indentations, because they are not ideal for the bitumen seal and future performance.
- If the lower pavement layer consists of a coarse gravel, it is possible that the high speed foamed

bitumen reclaimer/stabiliser drum will pick out some of the larger stones at the bottom. The effect would be an increased depth needing to be stabilised hence diluting the stabilised mixture with respect to the design additive requirements.

To be read accurately, the depth gauge on the stabiliser must be viewed from the driver's eye level.

8.7 Oversize stone

Old pavements often contain oversize stone (i.e. 50-75mm). The occurrence of these large stones, usually in the sub-base, has three main influences:

- wear and tear on the stabiliser rotor is significantly increased;
- the quality of the finish is decreased; and
- depth control is more difficult due to "pulling out" of the oversize rocks.

Pre-milling should be to a depth of final thickness less 50mm so that no deep pockets of material are not left unstabilised or differentially compacted.

8.8 Moisture

"Wet spots" can eventuate during the stabilisation process if the moisture content after pre-milling is too close to OMC.

The ideal moisture content for effective coating of the soil particles in the mixing drum is 65-85% of the modified AASHTO OMC for the insitu material being stabilised.[11]

The optimum moisture for compaction is approximately 10–20% higher than the ideal moisture for coating and mixing and has been defined by Sakr and Manke (1985) as 8.92 + 1.48 OMC + 0.4x(Percentage Fines) – 0.39x(Bitumen Content).

Minimal problems with pavement moisture were experienced on the New England Highway project. Wet spots were baked out in a couple of days.

Figure 25 shows a wet spot that developed over a culvert where the water was not able to percolate through the pavement in the same way as on the rest of the job. This was quickly rectified by adding extra cement.

Figure 25 "Wet spot" over culvert

8.9 Foaming agent

Silicones in Australian bitumen reduce its ability to foam. South African bitumen does not exhibit these properties and hence no foaming agent is required. Close to one hundred thousand dollars of foaming agent would have been saved on the New England Highway project if silicone-free bitumen could have been found in Australia.

Bitumen in Australia is produced in "lube oil" refineries where the addition of 0.5% silicon doubles the throughput of bitumen. Shell Australia is currently investigating the practicalities of eliminating silicon from the process.

Pavement Rehabilitation Branch is working on producing a known list of foaming agents and their compatibility and concentration rates for Queensland bitumen.

Some success has been experienced in the addition of diesel instead of the more expensive foaming agent. Tests have shown that the expansion ratio increases from eight to twelve times but will not reach the required fifteen times expansion.

High flashpoint cutters such as kerosene have also been trialed without any success.

Class 320 bitumen will generally not foam, regardless of how much foaming agent or diesel is added.

Some success in foaming has been achieved when using straight bitumen feedstock with the maximum viscosity permissible for Class 170 bitumen. Use of the cutback bitumen has somewhat reduced the need for foaming agent. An expansion of ten times was achieved but foaming agent was still required to reach fifteen times expansion.

[11] Lee,1998.

8.10 Lime

8.10.1 Role of Lime

Lime is believed to play the following roles in the foamed bitumen matrix:

1. It acts on the clay particles in the pavement causing an ionic exchange that results in flocculation and agglomeration of the clay fines.
2. It reacts with the bitumen binder to increase its viscosity thereby increasing the stiffness of the foamed bitumen material.
3. The lime particles act to 'seed' the bitumen foam in a similar way that farmers use nitric oxide to seed clouds to induce rain. That is, the small lime particles act as nuclei that initiate precipitation of the foam mist around the fine particles.

The degree of each of these effects is dependent on the timing of the incorporation of the lime and bitumen. If the lime is added too soon, it will modify the host material and possibly agglomerate the fines.

If the lime is added at the same time as the bitumen, the lime will act more on the bitumen and hence give the binder of the matrix a greater strength.

Laboratory testing has shown that a greater strength is achieved when the lime and bitumen are incorporated simultaneously.

8.10.2 Quicklime versus hydrated lime

Quicklime, rather than hydrated lime, was used because quicklime is:

- more economical per tonne;
- is a denser material; and
- has as higher Calcium Oxide (CaO) content.

These qualities of quicklime make it a more efficient and economical solution.

8.10.3 Safety

Gloves and a mask should be used when sampling and weighing lime.

8.10.4 Dust and steam

Dust is generated during the spreading of the quick lime, though much less than if hydrated lime was spread on the road. The steam given off during the slaking process is believed to be harmless; however, traffic was stopped during slaking because of poor visibility.

8.11 Rework

Ideally, the pavement should not be reworked with the stabiliser.

If it is subsequently found that insufficient bitumen has been incorporated into the mix, it is not an option to add the deficient bitumen in a further pass. Further addition of bitumen may cause bleeding as the fine particles have already been coated in the previous pass, and there would be insufficient fines remaining.

If bitumen alone is subsequently added there would be insufficient fines, as the lime has already modified the clay fines. Free lime and clay fines would no longer be available.

If rework were required, the design would have to be revisited, possibly adding fines, to account for the effects of the previous stabilisation (i.e. the modification of the material and altered grading would have to be taken into consideration).

8.12 Foamed bitumen stabiliser

8.12.1 Blockages

The only bitumen pipe work that is not heated on the Wirtgen WR2500 is the flexible hose connecting the tanker and the foamed bitumen machine. If the bitumen is not flowing due to a stoppage in the work, bitumen in this hose can cool and consequent blockages or restrictions may occur.

It is essential that at least 200 litres of bitumen is left in the tanker so that "contaminants" in the bottom of the tanker are not sucked through into the foamed bitumen machine to clog its filter.

Where the flexible hose connecting the tanker and foamed bitumen machine joins to the tanker, the connection point should have a "straight out" connection at the back of the tanker and not go through a 90 degree bend arrangement.

8.12.2 Pressure

Everything on the WR2500 foamed bitumen reclaimer/stabilising machine is essentially pressure dependent.

The bitumen pump on the Wirtgen WR2500 used on the New England Highway project is a mechanical paddle type pump without a pressure gauge downstream of the filter. Because of the pressure dependency of the machine there is no way of knowing when it is incorporating the wrong bitumen content or no bitumen at all, into the pavement. The on-board computer on the WR2500 controls the pump rotation, although control of the pump speed does not guarantee flow of the bitumen if the filter is blocked.

It is therefore critically important that a pressure gauge be installed on the downstream side of the machine's filter. This pressure gauge will give some warning if the filter is blocked and hence the bitumen is not flowing as required.

8.12.3 Checking

Another way of monitoring the amount of bitumen incorporated into the pavement is to progressively dip the bitumen tanker every 50 metres and check the incorporation rate. Dipping is only practical when the tanker is less than half full. If the tanker is more than half full there is a danger that hot bitumen will splash onto the person performing the dip test. If the dip test is done on an incline, the measurements need to be corrected for the grade.

Dipping of the tanker at the beginning and end of each run only gives the total bitumen used and is obviously not a fail-safe check that bitumen is being applied uniformly. If restrictions do occur there is no way of isolating the problem within the run.

The following additional precautions can be taken to ensure that the bitumen is foaming and being incorporated into the gravel as required:

1. There should be an inspection of the test jet at the end of the foaming chamber so that the required expansion of the bitumen can be measured and half-life qualities of the bitumen are being achieved (see Figure 12).
2. The bitumen jets must be self-cleaning and bitumen lines must be heated. The WR2500 can lift the mixing box so that the operator can individually operate each nozzle to squirt bitumen to indicate that it is working.
3. After bitumen has been incorporated, the gravel in the rill behind the stabiliser feels warm and "spongy" or "foamy" and the bitumen can be sxmelt in the gravel.
4. When a sample of bitumen-stabilised material is picked up behind the machine it will leave black specks on one’s palm when squeezed.

8.13 Compaction testing

A Proctor Test is required for every field density taken due to material variability. The position of sampling for proctors (longitudinal and transverse) should be marked and then field density carried out at that position following compaction.

Proctors should be sampled from behind the stabiliser and compacted within two hours.

A sample must not be kept overnight before compaction, as the Maximum Dry Density (MDD) obtained is lower and hence relative density is higher; this will lead to inaccuracies in the target density required for compaction. This high level of testing may require the use of a field laboratory. Ideally, the proctors should be compacted in the field laboratory at the same time as the road is being compacted.

Field densities must be carried out by the sand replacement method (Q110C) as it was found that there was too much material variability to be able to calibrate the nuclear density gauge.

With a more consistent material, nuclear metre testing would be sufficient and fewer correlating Proctor tests would be required.

Research is currently being undertaken as part of a research thesis to establish a superior method of simulating what occurs in compaction in the field. Methods being trialed include gyratory compaction, standard, modified and 75 blows. Percentage air voids may also prove to be a useful measure of compaction.

8.14 Working hours

Work needs to start early so that at least four hours elapse from time of incorporation of the foamed bitumen until traffic is allowed back on the road.

Available daylight (i.e. summer or winter) and traffic control staffing will inevitably influence the production rates obtainable.

8.15 Effects of rain after stabilisation and prior to seal

It has been found that the foamed bitumen stabilised pavement is extremely resilient to traffic during and/or after rain as the surface seems to "slurry up" and seal off, thus creating a very low porosity/impermeable pavement.

During rain the surface can also become quite slick and slippery; thus, precautions are required with adequate traffic management considerations needing to be implemented (e.g. reduced speed, slippery road signs etc).

The durability characteristics of the foamed bitumen pavement surface under adverse weather conditions can be particularly helpful, especially when cold weather prevents the application of a seal and the pavement must be left open for a significant period.

8.16 Roughness bonus/penalties

Because the shoulders were not reworked and regraded, it would not have been equitable to invoke penalties for roughness because the remaining shoulder shape influences the road shape and roughness.

Pre-milling of the shoulders would have allowed control over the road's cross-sectional and longitudinal shape; and hence the application of roughness penalties/bonuses could then be applied.

8.17 Bitumen sealing

Two hundred metres of unsealed pavement should be left between the area being worked on and the new seal so that traffic does not damage the fresh seal.

It has been noted that the completed foamed bitumen stabilised pavement is impervious and hence there is little, or no, penetration of the initial seal and this allows a reduction in the application rate of the seal.

There were some problems with seal adhesion on the road under turning traffic. This will be combated in some locations by providing a thin asphalt overlay.

Minimal degradation of the pavement occurs even when it is exposed to adverse weather conditions. There is no embedment of aggregate and no flushing in the outer wheel path as would normally be expected.

A slurry seal is commonly used on foamed bitumen stabilised pavements in South Africa.

It is suggested that the contract documents specify that the contractor is responsible for maintenance of the road for two days after all results are presented, or until the road is sealed.

9. CONCLUSION

The use of foamed bitumen is growing in popularity and general acceptance both in Queensland and throughout the world as a result of recent research and extensive trials.

Rehabilitation using foamed bitumen has proved to be successful because of its ease and speed of construction, its compatibility with a wide range of aggregate types and its relative immunity to the effects of weather. There are now well developed procedures for the design of foamed bitumen stabilisation which should be followed..

Foamed bitumen has the potential to be used throughout Queensland another useful tool for the rehabilitation of heavily trafficked thin high plasticity pavements.

10. ACKNOWLEDGMENTS

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