6 YEARS OF FOAMED BITUMEN STABILISATION IN NEW ZEALAND – A PERFORMANCE REVIEW AND COMPARISON TO OVERSEAS PRACTICE

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Abstract

Hiway Stabilizers NZ Ltd has been foamed bitumen stabilising pavements in New Zealand for the last six years. A wide variety of materials and treatment constraints have been encountered and mitigated. Valuable lessons have been learnt regarding the reliability of testing, materials sensitivity, maximising reconstituted asphalt, required curing periods, surfacing and standardising mix design and quality assurance practices. This paper will expand on recently developed guidelines and performance to date in New Zealand along with key points of difference to practice in Australia and South Africa. The paper will also focus on a number of lessons learnt regarding the process from design to construction, identifying risk elements and means of ensuring the successful application of this treatment option.

Figure 1: FBS 'train' operating in Tukino, Central Volcanic Plateau, New Zealand.

1. INTRODUCTION

The last six years has seen Hiway Stabilizers (Hiways) undertake a significant quantity of foamed bitumen stabilisation (FBS) after initially trialling the treatment process in 2004. Research, quality assurance and post construction evaluation to date suggests, at the least, a continued achievement of design expectations. Projects to date have been completed nationwide in both rural and urban settings and from desert to alpine environments. Initially the New Zealand expertise in FBS was held almost entirely by the Contracting sector. During this time extensive research has been undertaken by the Contracting fraternity on testing protocols, refining mix designs, curing/hydration times and sensitivity to different types and/or proportions of reagents to laboratory failure mode(s). A wide variety of materials and treatment constraints have also been encountered and mitigated with some interesting outcomes. As a result of this experience, valuable lessons have been learnt regarding the reliability of testing, materials sensitivity, maximising reconstituted asphalt surfacing, curing periods, surfacing preparation/design and standardising mix design and quality assurance practices in New Zealand.

With this relatively new technology (to New Zealand conditions), an effort has been made to gently 'push the envelope' and assess the optimum design and construction methodology for a variety of materials and settings. This has lead to a significant improvement in our understanding of where the process is applicable in New Zealand conditions, where mix design testing can differentiate and predict treatment performance, and what considerations can enhance the likelihood of project success.

This paper will expand on developments and experience gained through Hiways foamed bitumen research and construction to date. Lessons have been learnt regarding identification of risk elements and approaches to ensure design assumptions are realised. This paper will outline key findings that help ensure the successful application of this innovative treatment option.

2. FBS IN NEW ZEALAND / AUSTRALIA / SOUTH AFRICA

2.1 Background

When foamed bitumen was introduced to New Zealand, overseas guidelines such as the South African Asphalt Academy "*Interim Technical Guideline: The Design and Use of Foamed Bitumen Treated Materials*" TG2 (September 2002) and the Wirtgen Cold Recycling Manual (2nd Edition November 2004) formed the basis of developing best practice. Through the last few years, New Zealand stabilisation specifications, design guides and technical notes have been developed by all-party (Client, Consultant, Contractor and Supplier) working groups and have been adopted for industry utilisation, and TG2 has been significantly revised with the release of the TG2 Technical Guideline: Bitumen Stabilised Materials (Second Edition May 2009). Evaluation of the Austroads "*Review of Foamed Bitumen Stabilisation Mix Design Methods*" (December 2010) has also demonstrated some distinct differences in methodology and philosophy.

2.2 Tri-Nations Distinctions

While there are many general similarities, a summary of some distinctions between New Zealand, South Africa and Australian approaches to using FBS is as follows:

Table 1: Tri-Nations Distinctions of Foamed Bitumen Stabilisation Practice

Element	New Zealand Specification	Australian Specification	South African Specification
Design Philosophy	Equivalent granular state (phase 2) Mechanistic design	Effective Fatigue Phase - Austroads Asphalt Criteria (phase 1)	Knowledge based method – structural number Empirical design
Expansion / Half Life Requirement	Minimum of: 10 times & 6 seconds	Minimum of: 15 times & 30 seconds	Minimum of: 10 times (for 10 to 25°C) & 6 seconds
Foaming Agent	Not used[1]	Teric 311 foaming agent used for design and construction	Not used[2]
Percentage by mass of Active Filler	≤ 1.5% cement (Lime Oxide or KOBM for pretreatment)	≤ 2% Hydrated Lime (Hydrated Lime for pretreatment)	≤ 1% Cement (Lime or other active filler for pretreatment)
Tensile Test Loading Rate	1mm/minute recently proposed	3000ms test pulse with 40ms rise time	50.8mm/min

Element	New Zealand Specification	Australian Specification	South African Specification
Base aggregate	Single specification. Focus on grading and plasticity	Single specification. Focus on grading and plasticity	Two specifications BSM1 (high strength) and BSM2 (medium strength)
Characteristic Design Modulus	800MPa Soaked (phase 2)	3000 to 4000 MPa Dry & 1800-2000 Soaked	BSM1 600 MPa max BSM2 450 MPa max
Initial Modulus	Unstated. Able to be trafficked without rut/shove. Clegg Impact Value 45+ common requirement	700 MPa (3 hours curing)	As per characteristic design modulus.
Rut Resistance	Repeat Load Triaxial ≤1.0mm (ideally 0.5mm) rutting / Million ESA	Max rut depth at 2000 Cycles 5 – 7mm	Not stated. Require quality aggregate properties & minimise moisture if early loading
Characteristic Bitumen Content	2.7% to 3.5% Typically 2.7 to 3%	Typically 3.0 to 4.0%	Typically 1.7 to 2.5%

[1] Some laboratories use Teric 311 foaming agent exclusively for mix design
[2] No reference to the use of foaming agent in TG2 2009

3. UNIQUE CHARACTERISTICS OF FOAMED BITUMEN

Simplistically, the process of foaming bitumen involves the introduction of a small quantity of pressurised air and water into hot bitumen creating a low viscosity/high volume expanded ‘foam’ that preferentially coats the moist, fine (passing 75µm) fraction of aggregates.

3.1 FBS Properties

The addition of foamed bitumen to aggregate creates a material with unique properties relative to other more conventional treatment processes. Where a suitable material is foamed bitumen stabilised (FBS) with bitumen (typically 2.7% to 3.0% by weight for NZ aggregates) and a small amount of active filler (typically 1.0 to 1.5% cement by weight) a visco-elastic medium is created that is strong and rut resistant - yet flexible. A resilient modulus of 800 MPa is the long term “saturated” (phase 2) baseline target. In New Zealand wet and dry indirect tensile strength (ITS) and unconfined compressive strength (UCS) testing is undertaken to interpolate the theoretical resilient modulus. More recently, MATTA, Repeat Load Triaxial and Flexural Beam testing is undertaken on design briquettes to derive more comprehensive mix design parameters, and expand on direct modulus relationships.

3.1.1 Strength Relative to Flexibility and Failure Mode

Recent research testing and construction quality assurance has demonstrated that very high strengths can be achieved for some materials. Central North Island dacites, have provided UCS results for 3.0% bitumen and 1.0% cement of 5.0 to 6.0 MPa, significantly higher than typical UCS values of 1.0 to 2.5 MPa. This strength would place the material firmly into the ‘bound’ category for conventional cement stabilising - where the risk of shrinkage or fatigue cracking would be considerable. However, extended compressive strength testing of the FBS samples confirms that the failure mode is ductile - with continued load capacity well beyond 200% strain of the peak load. This suggests that provided the quantity of active filler is controlled to no more than 1.5%, the visco-elastic properties are maintained despite generating very high strength. Consequently FBS materials do not conveniently fit into conventional Austroads pavement design materials classifications.

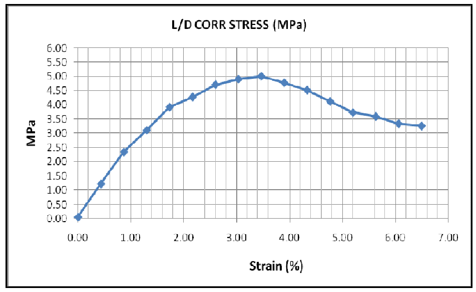

Figure 2: UCS Plot for FBS Dacite

Before UCS Testing After UCS Testing

Figure 3/3A: FBS (3.0% bitumen % 1% Cement) V Cement-only (4^{+}%) Briquettes

3.1.2 Moisture 'Insensitivity'

Another notable FBS feature is significantly reduced moisture sensitivity after treatment. This is due to the problematic fines (clay/fine silt size) being fully or partly encapsulated by bitumen - rendering them unable to change volume or become mobile upon the introduction of moisture.

Also assisting this moisture 'insensitivity' is the reduced permeability, where testing to date suggests a significant reduction from base material properties (as would be expected). Limited testing to date using laboratory permeability of samples has shown between 40% to 50% reduction in permeability. Laboratory permeability testing undertaken on 'untreated' basecourse samples and FBS treated cores from Coronet Peak Road Shotover Aggregate provided the following:

Table 2: Permeability Test Results

Sample Description	Permeability	Test Method
Untreated basecourse (compacted into mould)	2.62×10^{-7} ms^{-1}	Constant head permeability of aggregate (K H Head)
FBS basecourse (3.5% bitumen & 1.0% cement 200 mm x 100 mm test cores)	0.014 – 0.015 m/min, conv. to 1.60×10^{-7} ms^{-1}	Falling head permeability (AS/NZS 4456.16.2003)

Note that different test methods were utilised due to different test times and sample states (loose versus bound). Note also that the FBS basecourse permeability had a head of more than twice that of the untreated basecourse which is likely to have disadvantaged the comparison.

Field Permeability testing, as typically undertaken for Open Graded Porous Asphalt (OGPA), has been carried out on a number of FBS basecourse sites prior to sealing. The test utilises a 150mm diameter CBR 'collar' with a silicone sealant forcing flow through layer 'voids'. 300ml of water is placed inside the ring to saturate (or 'prime') the basecourse interface, and once the water level has dropped to the top of the surface, another 150ml of water is added and time to drain is recorded three times and the average time reported (this is the dispersion time measurement).

This is a quick and effective way of evaluating insitu permeability of compacted and finished basecourse prior to surfacing. Testing of FBS GAP40 basecourse showed an order of magnitude (i.e. around 10x) reduction in permeability when compared to the same untreated base aggregate, or treated with 2% cement.

Untreated 40mm 'topsize' basecourse (typically 10^{-4} m/s permeability) provided a dispersion time of 5 to 12 seconds, where a dispersion time for the FBS treated aggregate was from 65 to 300+ seconds. [note: the same basecourse treated with cement only provided similar or slightly less permeable results to the untreated].

Further research is required to provide accurate comparative permeabilities of non-foamed versus foamed aggregate using identical means. Much of the surfacing / seal design process is focussed on waterproofing the underlying basecourse. However, advantages of FBS basecourse are: a) superior resistance of fines to the effects of moisture, and b) very strong bonds can be achieved for a well prepared FBS surface.

4. MIX CONSIDERATIONS

4.1 Basic Requirements

Provided the basic materials requirements are achieved, then FBS provides a very low risk of unsatisfactory performance once treated. These requirements are:

- A well graded aggregate with 5% to 20% passing the 75-micron test sieve.
- A plasticity index (PI) target of less than 10 (must be less than 15).
- Moisture condition to be no higher than optimum for untreated aggregate.

Where these properties are not provided by the basic materials, deficiencies can be remedied by the addition of inert fines (or specifically sized material) to remedy grading, the addition of reagents to control plasticity, and pre-treatment to correct moisture content.

Based on our experience, Hiways recommend pre-treatment to mitigate plasticity prior to FBS – as benefits also include full visual evaluation of materials, opportunity for moisture correction, services location, level correction and removal of bulked materials (where working to constrained finished levels).

It is mandatory for some territorial authorities in New Zealand to pre-pulverise, and is common practice in parts of Australia (Queensland, Victoria). In addition to ensuring the grading is appropriate for optimising FBS properties, the impact on grading after pulverising several times needs to be considered, and should be evaluated with trial sections and representative materials for mix design testing.

4.2 Proportion of Asphalt in FBS Mixes

When treating pavements with a reasonable thickness of existing asphalt or chip-seal that will not be removed prior to pulverising, the implication on the overall FBS grading and performance must be evaluated. Multiple seal coats and/or asphalt surfacing can comprise up to 50% of the treatment depth without compromising performance and properties, and can even enhance the overall FBS properties.

Design and construction testing undertaken on the SH16 Coatesville-Riverhead Highway to Old North Road project incorporated seal coats and OGPA comprising typically 30 to 40% (and up to 50%) of the 180mm treatment depth. This confirmed that adequate FBS properties were comfortably achieved despite no pre-pulverisation phase and adopting a single pulverisation methodology to granulate surfacing and mix foamed bitumen / cement.

Figure 4: SH16 FBS – note cement spread on existing OGPA surfacing

Mix design average: ITS (dry) 320 kPa, ITS (wet) 295 kPa, phase 2 resilient modulus = 900 MPa.
QA construction average ITS (dry) 250 kPa, ITS (wet) 235 kPa, phase 2 resilient modulus = 1150 MPa.

This confirms that provided overall grading requirements are still met, a reasonable thickness of existing surfacing can be incorporated.

4.3 Increasing Bitumen Content In FBS Mixes

Hiways has undertaken FBS mix designs with a wide variety of bitumen contents to confirm optimum application. Increasing the bitumen content to a maximum of 5% by weight in 0.5% increments, to evaluate performance and the feasibility of producing cold mix ‘asphalt’, results only in increased cost and reduced strength and stability. The significantly increased cost due to binder quantity, and lesser performance, reinforces how the FBS process is suited to bitumen percentages ranging from 2.5 to 3.5% by dry weight for New Zealand aggregates, where a dependable second phase modulus of 800MPa is required.

Lower binder contents have also been evaluated, and strength/durability issues have been observed where the bitumen content drops to less than 2.5% (in particular the soaked to dry ITS strength ratio suffers). While these mixes (<2.5% bitumen) often don’t meet New Zealand Transport Agency (NZTA) design requirements, these materials still provide superior performance to that of conventional treatments. The ability of current testing methodologies to confirm modulus and performance in a laboratory setting of very lightly bound mixes may understate interpolating their dependable field performance.

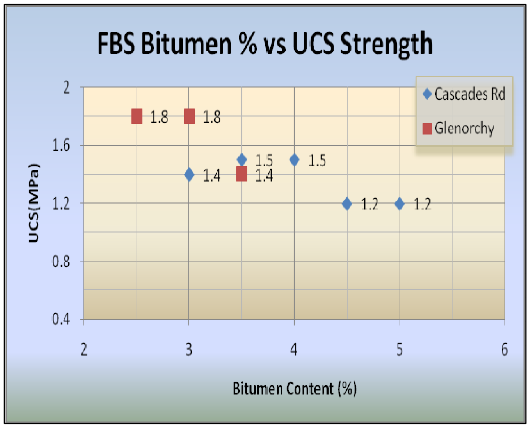

Figure 5: Bitumen % Vs UCS Strength

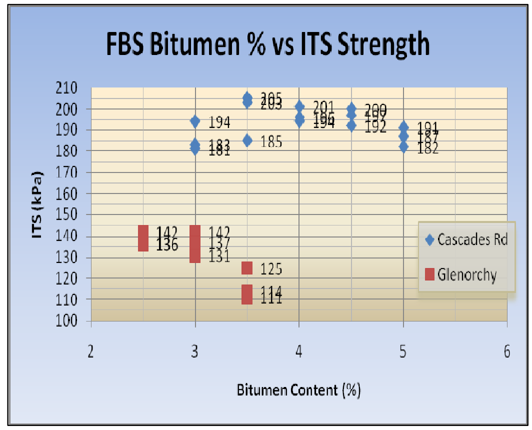

Figure 6: Bitumen % Vs ITS Strength

4.4 Type and Quantity of Active Filler in FBS Mixes

New Zealand aggregates, especially those in the North Island, have moderate levels of plasticity and respond well to a small quantity of active filler. This is typically cement, although lime (Lime-oxide fines) may be used for pre-treatment of high plasticity aggregates. The standard practice of adopting 1.0% to 1.5% cement also provides good early strength for trafficking (where narrow NZ carriageways require early trafficking to allow FBS to progress). The cement also improves moisture susceptibility. It is extremely rare to use only bitumen in FBS mixes in New Zealand.

The use of a cementitious filler introduces time restrictions for working of the FBS material. A finite time is available from pulverising of the FBS material to finishing primary compaction and the newly released NZTA B/05 “Insitu Stabilisation of Basecourse Aggregates” Specification limits the time from introduction of cement to completing primary compaction to a maximum of 2.0 hours. Ideal conditions however would see primary compaction progressively completed behind the FBS ‘train’, where it is likely that this component of work is completed in 20 – 30 minutes and trimming completed on the same day. It is common for FBS materials to set up quickly to a high strength therefore if any ‘hard cutting/long grading’ of the pavement is required it can be very difficult to trim unless undertaken on the day of FBS.

In New Zealand to date FBS aggregate is not generally stockpiled for later use as is undertaken overseas - but rather is treated insitu. In some instances FBS excess has been stockpiled and reused - but in these situations, to achieve full capacity, the cement must be reapplied as the benefit will have been largely negated due to hydration and then rendering of the cemented bonds during handling or pulverising. There have been instances of grading and construction difficulties when FBS mixes with even small quantities of active filler have been stockpiled for later use.

4.5 Construction Considerations Due to Active Filler in FBS Mixes

The use of cementitious fillers in FBS introduces additional construction considerations to primary compaction timing. Secondary compaction, finishing and preseal works should ensure that minor level corrections are only carried out by trimming or ‘cutting’ of the surface. On no account should thin laminates result or thin aggregate levelling layers be attempted on following days due to the inability to successfully merge into the ‘hard finished surface’ of the FBS basecourse. Any correction of ‘low’ finished surface levels needs to be undertaken via re-pulverising or asphalt levelling course as part of the surfacing operation.

Trimming and preparing an FBS pavement (to a high standard) is a specialised task. Often Hiways undertakes a full service contract, however on occasions main contractors often attempt to undertake the trimming and surface preparation themselves. These contractors are often used to constructing conventional granular pavements and problems can arise where the finished geometrics of the FBS pavement are not established on the day.

5. QUALITY ASSURANCE ISSUES

The author has already discussed the ability of FBS to accommodate significant differences in materials grading, plasticity and geology. This is beneficial as many New Zealand pavements are piecemeal with significant differences through inherent material variability and historic widenings, overlays or maintenance using different materials. It is not uncommon to have basalts and greywackes (with Specific Gravities of approximately 3.0 t/m^3 and 2.7 t/m^3 respectively) in subsections, layered or even blended. Neither is it uncommon to have asphalt or heavily stabilised inlays that have been camouflaged by resurfacing. While the FBR process can accommodate this with adequate mix design processes and construction methodology - various difficulties are raised for robust quality assurance procedures. The primary problem is determining the maximum density compaction target, and robust compaction procedures are critical.

5.1 Nuclear Densometer Testing

Nuclear Densometer (NDM) testing is commonly undertaken at the preseal stage and compared to densities achieved via plateau and compacted bulk sample densities. In the first instance the NDM’s ‘read’ the low density bitumen as moisture in addition to existing water. For this reason samples are required to be taken from the FBS layer and laboratory moisture content tests undertaken to provide accurate moisture and density results. If the materials are consistent, the NDM can be calibrated.

Unfortunately in New Zealand, the treated materials are often ***not*** consistent and where material variation occurs, it is extremely difficult to establish a clear density target. Taking additional bulk samples (or doing additional plateau density testing) where changes are observed in the FBS ‘mat’ improves benchmarking of the contract section - but it is not always feasible to cover all materials/blends. Similarly, variations in insitu moisture content prior to FBS will also result in quality assurance (QA) reporting inaccuracies where only a limited number of laboratory moisture content corrections are practical. Weaker substrates also limit achievable densities.

5.2 Time to Compaction for Bulk QA Samples

Contract quality assurance testing requires bulk samples to be taken from the freshly pulverised FBS ‘layer’. These samples are compacted into briquettes in the same manner as design to confirm that treated pavement properties comply with pavement and mix design requirements. This has commonly been undertaken via bulk sampling then transportation back to the testing agency laboratory. Due to the incorporation of cement, the time permitted between pulverising and compaction by the independent testing agency had been restricted by Hiways to no more than one hour (to completion of briquette manufacture). Recent research and quality assurance testing, however, has shown a significant reduction in strength can occur between samples compacted within (say) 20 minutes - and those compacted within two hours.

Any disparity between test data and as-built properties is a concern, as the FBS properties can be mis-represented, resulting in non-conforming QA data and potential contractual problems.

A reduction in sample strength is likely to be the result of two elements related to the cement.

- Cement is hydrating in the bulk sample between sampling and testing. The greater the delay until compaction - the greater the proportion of active cement that is negated.
- The cement bonds are forming during transportation in the sample bag / container and then being ruptured. The cement will immediately start binding particles in the bulk sample - and the greater the delay between pulverising and compaction, the greater the quantity of cemented bonds that will be formed then ruptured upon compaction of laboratory samples.

The combination of these elements has produced non-compliant FBS QA briquette results for some remote work sites, requiring extensive insitu testing to confirm the adequacy of the insitu FBS basecourse.

The remedy to this problem is to undertake field compaction for all or part of the project bulk samples. It has also been particularly helpful to undertake field and laboratory compaction for the same bulk sample for remote sites - however this has cost implications.

Table 3: Comparison of Field Compaction versus Delayed Laboratory Compaction

Location	Compaction Type	Dry ITS Range (kPa)	TSR	UCS (MPa)	Average Dry Density (t/m^3)	Resilient Modulus Phase 1	Resilient Modulus Phase 2
Project A	Laboratory	327 - 348	0.90	4.2	2.350	3033	975
Project A	Field	421 - 697	1.00	4.1	2.310	4238	1541
Project B	Laboratory	240 - 277	0.84	2.7	2.193	2364	969
Project B	Field	346 - 391	0.93	3.0	2.271	3217	1360

Project A Field Compaction within 20 minutes
Laboratory Compaction within 75 minutes

Project B Field Compaction within 20 minutes
Laboratory Compaction within 90 minutes

This confirms a significant difference is achieved for tested properties / inferred modulus where a delay to compaction occurs.

6. SURFACING ISSUES

There have been a number of surfacing issues realised and addressed in NZ that are unique to FBS basecourse. The FBS process results in a finished surface that does not present the conventional “stone mosaic” finish as referenced in NZTA B/2 (conventional granular construction specification). The finished surface at sealing stage is very hard, but can be relatively smooth and ‘fatty’ - providing a low texture. While it is essential to maintain a slightly moist surface and undertake robust brooming prior to surfacing, it is also important to adjust the first coat or membrane seal residual binder application rate.

6.1 FBS Seal Design Adjustment Factor

As distinct from surfacing for other basecourse materials, literature and experience confirms that for the first coat seal, a reduction of between 10% to 20% residual binder is required to mitigate the risk of flushing of sprayed seal surfacing and/or binder rise into overlying thin asphalt surfacing.

Surfacing for some contracts undertaken soon after FBS was introduced to New Zealand resulted in flushing issues for seal coats and/or problems with binder rich membrane seals ‘flooding’ thin asphalt surfacing to the extent that instability developed in high stress areas. Seal design and surfacing needs to accommodate the unique properties of FBS basecourse.

Figure 7: Membrane seal ‘bleeding’ through thin asphalt surfacing. Note line of ‘blooms’

Figure 8: Common FBS Surface Finish

Figure 9: This picture shows rutting/shoving and an unstable asphalt surfacing in a high stress braking area. An investigation was undertaken to confirm causes.

Figure 10: Trenching by the Client confirmed relief was entirely in membrane / asphalt surfacing with a level FBR surface

The standard seal design algorithm should be carried out and a residual binder application rate determined as usual taking traffic, texture, temperature etc into account. Following this the first coat rate should be reduced by 10 to 20% (commonly by 15%). The reason for this is the very low absorption of the FBS basecourse, due to the finer grading and lower permeability matrix as outlined earlier.

It is important to consider the effect of diluents for seal coats that are going to be overlaid, and the industry is still working towards the best approach for the interface beneath thin asphalt surfacing for FBS basecourse. Cutback binders require time to allow diluents to dissipate prior to asphalt surfacing. Traditionally a single or two-coat membrane seal may be used beneath thin asphalt surfacing to maximise waterproofing of the aggregate. However, with the lower permeability and (more importantly) the lower moisture sensitivity of the FBS basecourse, achieving a waterproof interface is not as critical. It is more important to consider the bond strength for high stress areas and ensure that excess binder does not compromise the overlying asphalt layer.

In New Zealand, industry has developed Technical Note 002 “First Coat Sealing on a Stabilised Basecourse” which details best practice recommendations.

6.2 Surfacing Case Study

FBS basecourse where small proportions of active fillers are utilised (i.e. 1.0 to 1.5% Cement) can be trafficked almost immediately, and provided shear stresses are not high, an unsealed surface can accommodate traffic for a period of time prior to surfacing. It is common practice to put traffic back onto “green” FBS basecourse within hours while the other side of the carriageway is treated. FBS basecourse is much better able to accommodate inclement weather and trafficking prior to surfacing without failure than an unbound or active filler (i.e. cement) treated basecourse.

Hiways were the FBS subcontractors for a contract on State Highway 1, Taupo (Central North Island) that was surfaced in mid-June 2007 (early winter for New Zealand). The sealing chip stripped from the emulsion seal coat and the seal coat was then lost from much of the wheel tracks on the night after surfacing. Inclement weather and cold conditions did not permit immediate remediation. A variety of temporary measures were adopted to ‘hold’ the site until a robust surfacing repair could be undertaken 4 months after initial construction. Much of the FBS basecourse surface in the wheel-tracks was exposed to traffic for extended periods, particularly through the last few weeks before remediation.

Figure 11: June ’07 Primary wheel track repairs

Figure 12: October ’07 major surfacing failure

The first period of sustained warmer weather in October resulted in a major seal failure. The entire surfacing through the section mobilised and a very rough surface quickly developed exposing large tracts of the FBS basecourse which appeared to have maintained shape and surface finish. After consultation, the entire surfacing through the site was "scraped off" with a grader. The FBS surface was evaluated and found to be in adequate condition for resurfacing with no structural repair required.

Figure 13: Removal of all seal

Figure 14: Exposed FBS basecourse prior to reseal

A new 2-coat seal was undertaken successfully with hot straight run bitumen. It is a testament to the unique properties of the FBS basecourse that it survived the environment and extreme traffic stresses (intense logging and dairy truck loading with 25 year design traffic 19.6 x 10^6 ESA) through the winter period without failure.

7. MODELLING FBS BASECOURSE IN NEW ZEALAND

7.1 Performance Criteria for FBS Basecourse

Guidance towards the recommended approach to modelling FBS materials is provided by the New Zealand Transport Agency (NZTA) in the NZTA Supplement to Austroads (2007). The FBS basecourse is not modelled with a performance criteria as is asphalt, bound materials or subgrades, but rather is modelled with unique parameters. The phase one elastic modulus is not generally used for design (although NZTA note the possibility of using Austroads hot mix asphalt performance criterion for this phase) but rather the phase two (steady state) elastic modulus or "equivalent granular state" is instead utilised for modelling as follows:

- Elastic Modulus E = 800 MPa
- Poissons Ratio = 0.3
- Anisotropic Layer – no sublayering

Also noted is "*Care should be taken to ensure that cracking is not a primary mode of failure by limiting the application of cementitious additives*".

The assumption of no sub-layering could be considered unconservative, and some designers elect to divide the FBS layer into two sub-layers with a 400MPa base sublayer. This is subject to limiting the modular ratio of the FBS layer to no more than 5 x modulus of the underlying layer. On this basis, an underlying granular subbase layer with an elastic modulus of at least 175MPa is required to permit the FBS layer to be modelled with no sub-layering.

8. EXSITU FOAMED BITUMEN

Hiways recently purchased a Wirtgen KMA200 FBS pug mill to provide a mechanism for production of premium FBS aggregates in both storage (ex-situ stockpiled) and production (ex-situ treated then placing within 2 hours) mixes. This plant also provided a means of producing a wide variety of “fit for purpose” mixes incorporating and maximising the use of waste streams generated through various recycling and rehabilitation operations throughout Auckland City.

Some mixes with exceptionally good elastic moduli using various proportions of recycled aggregates, crushed concrete, RAP, glass, steel slag and fly ash have been developed. The challenge is in developing storage grade mixes that can generate adequate early life stiffness to be trafficked without requiring long periods of curing.

Several ex-situ FBS trial pavements using mix designs that strive to maximise waste streams have been constructed through the last 12 months on roads to industrial sites to provide vigorous loading. These have been extensively tested and monitored to categorise sensitivity to water, curing / strength gain relationships, constructability when comparing grader versus paver laid, single lift versus double lift, storage grade versus production grade and performance when unsealed under extensive heavy vehicle loading.

Cured elastic modulus properties of more than 3,000 MPa have been derived using foamed bitumen and 100% recycled constituents including mixes with as much as 30% crushed glass. This is in line with Australian FBS target design modulus

Figure 15: Ex-situ FBS basecourse production trials

9. PERFORMANCE OF FBS SITES

9.1 Specific Projects

As outlined in the introduction, the performance of FBS sites across New Zealand suggests that the design process is conservative (i.e. does not overstate performance), and this is appropriate for the interim period where FBS performance criterion are developed and validated. While only five or six FBS post-construction years have passed for New Zealand, testing to derive remaining life shows that design assumptions have been met or surpassed. A small difference in pavement structure (common in old pavement profiles) can have a profound impact on performance. If a pavement is maintaining shape and stiffness for several years with no signs of distress, then structural 'robustness' has been demonstrated and the pavement is unlikely to suddenly develop problems in subsequent years.

On occasion a pavement profile has been encountered in treatment sites that have significantly less cover to subgrade than that assumed for design. These are generally undercut, but on occasion Hiways have been asked to continue treatment - but monitor the area.

On one site in particular the Client instructed Hiways to proceed with FBS rather than undercut where the existing aggregate depth was only 250 mm for two areas. This depth was 100 mm less than the 350 mm design thickness of aggregate nominally required to achieve the 25-year design life. It is interesting to note that more than two years later, this section of pavement is performing as well as the adjoining robust aggregate depth sections. Back analyses suggest that this profile should have failed via excessive subgrade strain within 6 months, confirming that the actual performance of the pavement system is superior to what modelling would suggest.

Figure 16: FBS in urban setting with an existing central concrete strip that was retained

Recent site evaluation has shown no visible modes of distress for the FBS basecourse. Site investigation via Falling Weight Deflectometer (FWD) testing has demonstrated the following:

- Design (10%ile) FBS Basecourse Resilient Modulus 800 MPa
- Average FBS Basecourse Resilient Modulus 3,020 MPa
- 10%ile FBS Basecourse Resilient Modulus 1,300 MPa

9.2 Characterisation and Use of Stabilised Materials in New Zealand

The characterisation of FBS pavements to provide dependable performance criteria for mechanistic design modelling is seen as a requirement. It is not appropriate to adopt asphalt performance criteria or modified granular parameters as the FBS layers are unique. To assist in developing a set of performance criteria a research project has been underway for 18 months where modified pavements at various stages of their design life have been evaluated via FWD, coring and condition rating assessments.

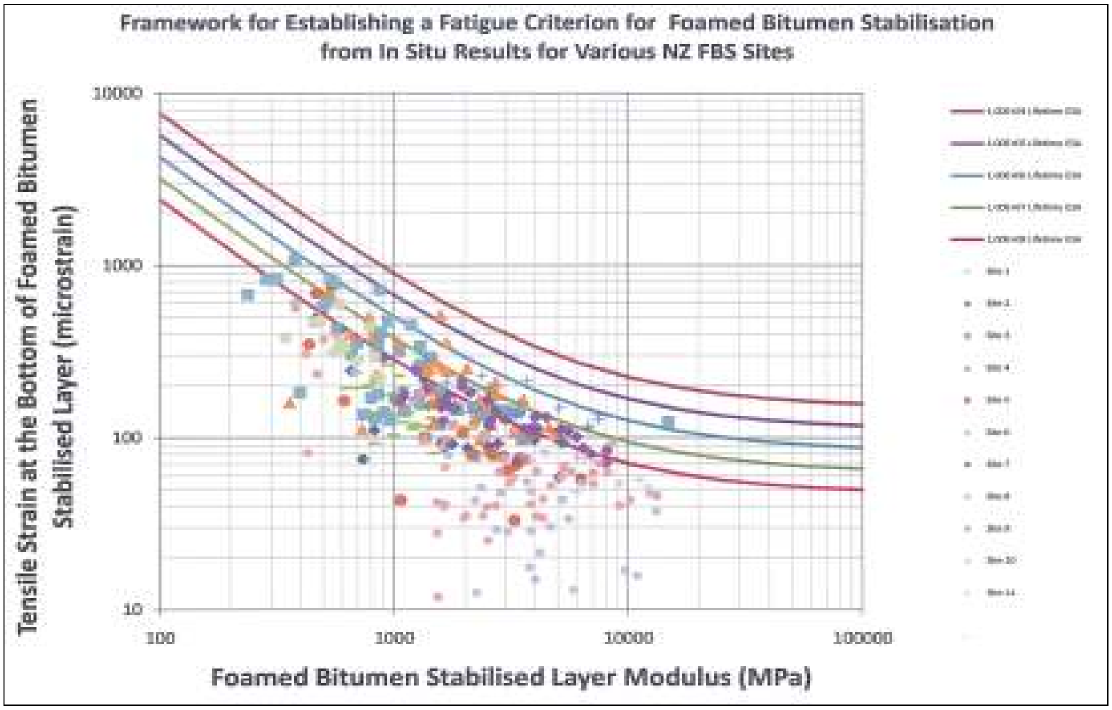

Figure 17: FWD Derived Basecourse Modulus vs Strain for New Zealand FBS sites.

This figure demonstrates the wide variety of interpolated modulus and tensile strain at base of the FBS basecourse for 11 sites throughout the North Island. While there are several localised points of marginal load capability and remaining life, none of the evaluated pavement sections could be classified as failing. A subsequent phase of this research is to carry out testing of the large quantity of 150mm diameter core samples from the test sites to validate tested second phase modulus against design expectations and post construction stiffness.

9.3 Full Scale Test Track Accelerated Loading FBS Experiment

Recently in New Zealand, a full-scale accelerated loading experiment was carried out (Gonzalez, 2009) of foamed bitumen pavements at the Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF). In this experiment, the same materials that were comprehensively tested in the laboratory (aggregates, bitumen, cement) were used to construct six different pavement sections, each with different contents of foamed bitumen and cement. Three were constructed using foamed bitumen contents of 1.2%, 1.4% and 2.8% respectively, plus a common active filler content of 1.0% cement. Two more pavements were constructed using cement only (1.0%), and foamed bitumen only (2.2%). In addition, one control section with the untreated unbound material was tested.

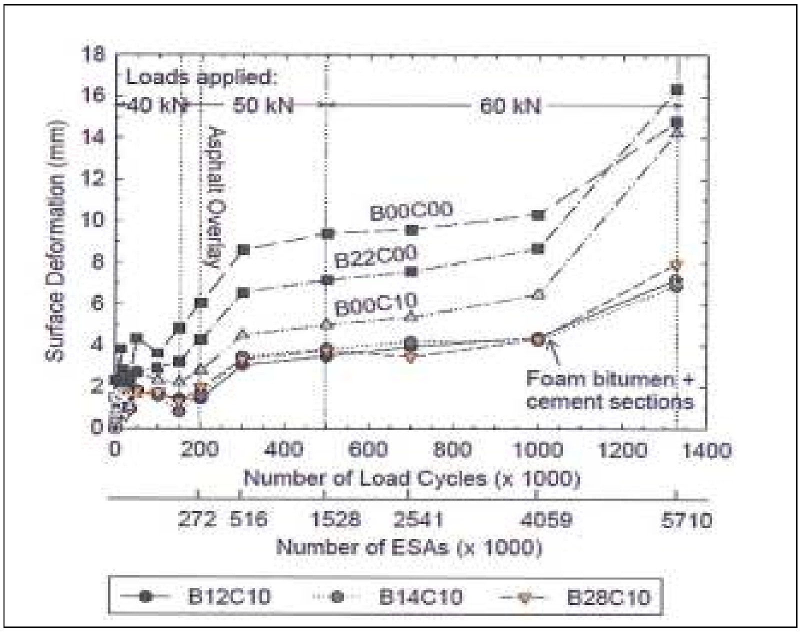

Figure 18: Rut Development Versus No. of Load Cycles for NZ CAPTIF Experiment

Figure 18 demonstrates how the conventional 'design' 8-tonne heavy duty axle (40 kN) loading was not sufficient to introduce significant rut development and this loading was increased to 60kN and water introduced to the pavement via saw-cutting and sprinklers to instigate distress. There was remarkably little difference in rut development for the three foamed bitumen and cement sections which demonstrated a rut progression in the order of 6mm / 1 million load cycles.

These results demonstrated that the addition of 1.0% cement provided superior rut resistance and fatigue capability for all three foamed bitumen and cement mixes, relative to the performance for mixes with foamed bitumen or cement only. The recommendation was that the addition of cement provides early life strength and improved stiffness / rutting resistance for the FBS basecourse. Furthermore FBS mixes utilising cement are more "constructible" while undertaking rehabilitations of 'live' carriageways with the ability to accommodate early trafficking.

Figure 19: CAPTIF Testing for the Gonzalez FBS Accelerated Loading Experiment

10 CONCLUSION

The FBS pavement rehabilitation process when combined with thorough investigation as well as pavement and mix design provides a very robust treatment option that is suited to lower quality and/or aged, contaminated aggregates of which the roading network has a profusion of with predominantly unbound granular pavements and sprayed seal surfacing. New Zealand's pavement structure and materials (particularly those in urban settings) are extremely heterogeneous, and on occasion present a number of challenges with respect to providing a low risk structural repair that does not involve full material or aggregate replacement.

The design process for FBS mixes in New Zealand is currently based upon tensile and compressive strength properties which is questionable for a pavement layer that is lightly bound due to a preferential distribution of foamed bitumen "spot welds". Pavement design philosophy also adopts an unbound aggregate second phase 'steady state' condition which is also contrary to observed behaviour. Limiting active filler to no more than 1.5% cement appears to ensure any failure mode is ductile rather than brittle where a bound fatigue criterion would be required.

Testing and performance to date suggests that the current means of modelling FBS pavements in New Zealand, while not attempting to correctly represent mechanistic properties, does not overstate the fatigue capacity of pavement layers. This is combined with a modular ratio of as much as 5, rather than two as Austroads would require for unbound aggregates. However, there is scope for re-evaluation of FBS modelling and development of a representative failure mode with associated performance criteria for mechanistic modelling.

There are many variations, some subtle and some significant, in the approach to specification, mix design and modelling for FBS pavements in Australia, South Africa and New Zealand. The primary distinction of failure mode and modelling philosophy varies from granular state mechanistic design (with no performance criteria) in New Zealand to effective fatigue state mechanistic design (with asphalt performance criteria) in Australia. The South Africa approach has recently changed to an empirical pavement number structural design approach with materials classification. This may appear to be more conservative when comparing but TG2 2009 notes that this approach has been validated using observed performance data. Ongoing research currently underway will no doubt continue to define the most appropriate approach for each country.

It is anticipated that current research in New Zealand and overseas will facilitate a means to correlate mix design, modelling and dependable performance and provide the designer a methodology that accurately represents the unique properties of FBS basecourse. The approach to FBS design is surprisingly different at this point in time. In New Zealand a variety of research projects have been recently completed or are currently underway, working towards development of a dependable performance criterion for FBS mixes. This will be vastly preferable to the current approach of adopting the "second phase" modified granular properties designed to achieve a nominal 800MPa non-sublayered resilient modulus for all FBS mixes. In the meantime we need to be prepared to closely monitor and evaluate overseas developments and philosophies.

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