

Foamed Bitumen Stabilisation in New Zealand – A Performance Review and Lessons Learnt

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ABSTRACT

Hiway Stabilizers (Hiways) has been stabilising pavements in New Zealand for over 20 years - but have been carrying out foamed bitumen stabilisation only since 2004, and since 2005 with purpose-built plant. While four years is a relatively small proportion of the (generally) 20 to 25 year nominal design life, the performance of these foam bitumen stabilised pavements has been exemplary. All quality assurance and post construction evaluation to date suggests, at the least, a continued achievement of design expectations.

The last two years has seen Hiways undertake a significant quantity of foamed bitumen stabilisation nationwide. During this time various research has been undertaken on refining mix designs, curing/hydration times, sensitivity to different types and/or proportions of reagents and laboratory failure mode(s). A wide variety of locations, materials and treatment constraints have also been encountered. As a result of this experience some valuable lessons have been learnt regarding materials requirements, surfacing preparation / design and the unique challenges regarding quality assurance testing.

With this relatively new technology (to New Zealand conditions), an effort has been made to gently 'push the envelope' and assess performance in a variety of materials and settings. This has lead to a significant improvement in understanding where the process is applicable in New Zealand conditions and what considerations can enhance the likelihood of project success. This paper will expand on Hiway Stabilizers foamed bitumen performance to date and focus on a number of lessons learnt regarding identifying risk elements and ensuring the successful application of this innovative treatment option.

Key Words

Foamed Bitumen, Pavement Investigation, Characteristics, Mix Design, Quality Assurance, Surfacing, Innovation, Performance



FBS 'train' operating in Queenstown illustrating from left to right bitumen tanker, WR2000 purpose-built hoe, water tanker and primary steel drum compaction plant.

1. INTRODUCTION

The last two years has seen Hiway Stabilizers (Hiways) undertake a significant quantity of foamed bitumen stabilisation (FBS) nationwide. During this time various research has been undertaken on refining mix designs, curing/hydration times, sensitivity to different types and/or proportions of reagents and laboratory failure mode(s). A wide variety of locations, materials and treatment constraints have also been encountered. Comprehensive quality assurance and post construction evaluation to date suggests, at the least, achievement of design expectations. However, some valuable lessons have been learnt regarding materials requirements, surfacing preparation / design and the unique challenges regarding quality assurance testing.

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 and what considerations can enhance the likelihood of project success.

This paper will expand on developments and experience gained through Hiway Stabilizers 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. UNIQUE CHARACTERISTICS

Simplistically, foamed 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 75um) fraction of aggregates¹.

2.1 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 3.0% by weight) with 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 long term resilient modulus of 800 MPa is the baseline target, then wet and dry indirect tensile strength (ITS) and unconfined compressive strength (UCS) testing is undertaken to derive the theoretical resilient modulus.

2.2 STRONG YET FLEXIBLE

Recent testing and construction quality assurance has demonstrated that some very high strengths are achieved for some materials. Taupo Dacites, for instance, have provided tested UCS results for 3.0% bitumen and 1.0% cement of 5.0 to 6.0 MPa². This strength would place the material firmly into the 'bound' category for conventional cement stabilising - where the associated risk of shrinkage or block cracking would need to be considered. However, extended compressive strength

¹ Rooding New Zealand Technical Note No. 001 Foamed Bitumen treated Materials

² Note – these pavement aggregates had previously been cement stabilised

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 characterisations.

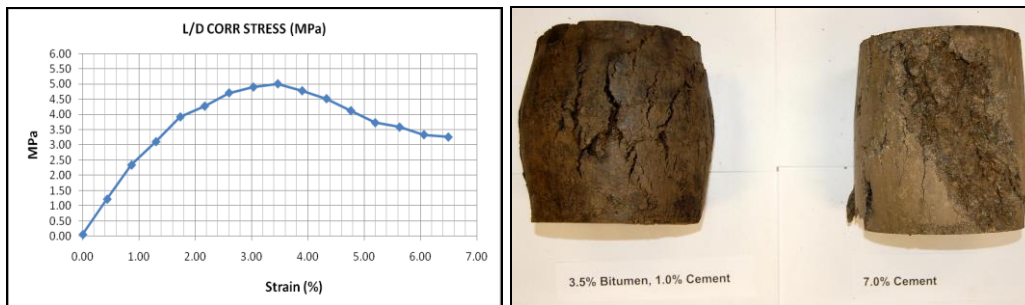


Fig 1: UCS Plot for Dacite

FBS v Cement-only UCS Briquettes

2.3 MOISTURE 'INSENSITIVITY'

Another notable FBS feature is significantly reduced moisture sensitivity after treatment. This is effected where problematic fines (clay/fine silt size) are 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 in permeability. Non-scientific testing results of more than an order of magnitude (10 times) reduction in permeability has been observed using the same methodology as that for OGPA field permeability testing. However, 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 1: Permeability Test Results

Sample Description	Permeability	Test Method
Untreated basecourse (compacted into mould)	$2.62 \times 10^{-7} \text{ ms}^{-1}$	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 $1.60 \times 10^{-7} \text{ ms}^{-1}$	Falling head permeability (AS/NZS 4456.16.2003)

Note the different test methods were 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. Further research is required to provide accurate comparative permeabilities of non-foamed versus foamed aggregate using identical means.

¹ Roading New Zealand Technical Note No. 001 Foamed Bitumen treated Materials

² Note – these pavement aggregates had previously been cement stabilised

3. MIX DESIGN CONSIDERATIONS

3.1 BASIC REQUIREMENTS

Provided the basic materials requirements are achieved, then FBS provides a very good treatment option. These requirements are:

- A reasonably well graded aggregate with 5% to 20% passing the 75-micron test sieve.
- A plasticity index (PI) of less than 15.
- Moisture condition is not significantly wet of optimum.

Where these properties are not present in 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 pretreatment to correct moisture content.

3.2 PROPORTION OF ASPHALT IN FBS MIXES

Where stabilising insitu pavements with a reasonable thickness of existing asphalt or chip-seal that will not be removed prior to hoeing, the implication on the overall FBS grading / performance must be considered. Hiways have found that multiple seal coats or asphalt can comprise 50% of the treated depth without compromising performance and properties, and can even enhance the overall FBS properties. Design and construction testing on SH16 Coatesville-Riverhead to Old North Road where up to 60% of the stabilised layer comprised seal coats and open graded porous asphalt confirmed that adequate FBS properties were comfortably achieved. This suggests that provided overall grading requirements are still met, a reasonable thickness of existing surfacing can be incorporated.

3.3 INCREASING BITUMEN CONTENT IN FBS MIXES

To confirm assumptions, Hiways has undertaken FBS mix designs with a wide variety of bitumen contents to confirm performance. Increasing the bitumen content to increments of 4%, 5% or 6% by weight, to evaluate the feasibility of producing cold mix 'asphalt', results only in 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. Lower binder contents have also been evaluated, and strength / durability issues have been observed where the bitumen content drops to 2.5% or less (in particular the ratio of soaked to dry ITS strength begins to suffer). Hiways has found that the optimum bitumen content is generally 3.0%.

Figure 2
FBS Bitumen % versus ITS Strength

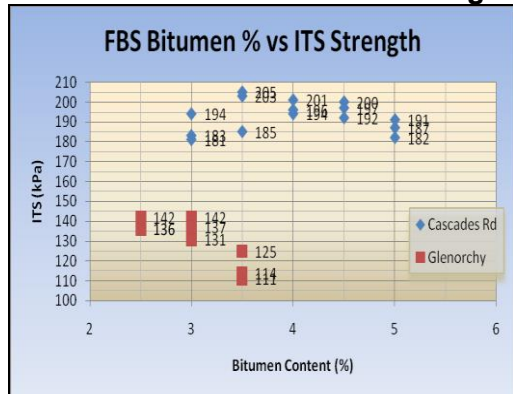
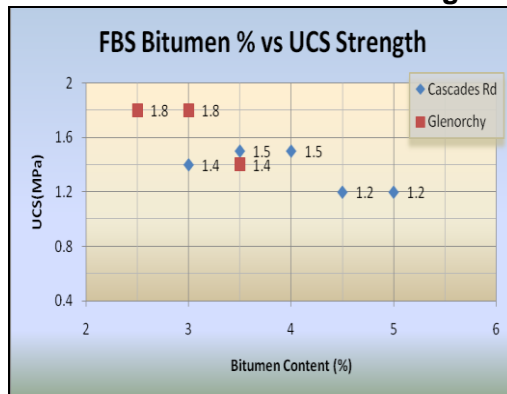


Figure 3
FBS Bitumen % vs UCS Strength



New Zealand aggregates respond well to a small quantity of active filler (generally cement). The standard practice of adopting 1.0% to 1.5% cement provides early strength for trafficking. It also improves moisture susceptibility and adds 'insurance' regarding the control of plastic fines. However – this introduces time restrictions for working of the FBS material. A finite time is available from hoeing of the FBS material to finishing primary compaction and the newly released TNZ B/05 Specification limits this time to a maximum of 2.0 hours. 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 instances to achieve full capacity the cement must be reapplied as the benefit will have been largely negated.

While TNZ B/05 calls for primary compaction to be completed within two hours, ideally the compaction *and* trimming will be completed on the day of FBS as it can set up quickly to a high strength and if any 'hard cutting' is required the following day for geometry it can be very difficult to trim. Similarly, finishing and preseal works should ensure that no laminates are generated or thin make-up levelling is attempted as it will not be able to successfully merge into the 'hard finished surface' of the FBS basecourse. Any correction of low finished surface levels needs to be corrected via re-hoeing or via surfacing.

4. 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 materials variability and historic widenings, overlays or maintenance using different materials. It is not uncommon to have basalts and greywackes adjoining, 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 process and construction methodology - various difficulties are raised for robust quality assurance procedures.

4.1 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 along with water. For this reason samples are required to be taken from the FBS layer and laboratory moisture contents undertaken to provide accurate moisture content / dry densities / total voids. If the materials are consistent the NDM can be calibrated.

Unfortunately, the treated materials are often **not** consistent and where materials variations occur it is extremely difficult to establish a clear density target. Taking additional bulk samples (or doing additional plateau 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 materials moisture content prior to FBS will also result in quality assurance (QA) reporting inaccuracies where only a limited number of laboratory moisture corrections are practical.

4.2 TIME TO COMPACTION FOR BULK QA SAMPLES

Contract quality assurance testing requires bulk samples to be taken from the freshly hoed FBS 'mat' and compacted in the same manner 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 hoeing and compaction by the independent testing agency had been restricted by Hiways to no more than two hours. 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-representative 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 then being ruptured. The cement will immediately start binding particles in the bulk sample - and the greater the delay between hoeing and compaction, the greater the quantity of cemented bonds that will be formed then ruptured upon compaction.

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 2
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	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.

5. SURFACING ISSUES

There have been a number of surfacing issues realised and addressed over the last several years. The FBS process results in a finished surface that does not present the conventional “stone mosaic” finish as referenced in TNZ B/2. The finished surface at sealing stage is very hard, but can be relatively smooth and ‘fatty’ - providing a low texture. It is essential to maintain a slightly moist surface and undertake robust brooming.

5.1 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 15% residual binder is required to mitigate the risk of flushing or binder rise.

The surfacing of FBS basecourse for some early contracts presented flushing issues for seal coats. In addition to this, several sites presented problems related to binder rich membrane seals ‘flooding’ thin asphalt surfacing to the extent that instability developed in high stress areas. Seal design and surfacing needs to represent the unique nature of FBS basecourse.



Common FBS surface finish



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



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



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

The 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 that 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. Cutback binders require time to allow diluents to dissipate prior to asphalt surfacing. Traditionally a 2-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.

5.2 EMULSION VERSUS HOT BITUMEN

The FBS basecourse generally responds very well to straight run hot bitumen - as the bitumen 'flecks' at the surface of the FBS layer are 'reactivated' providing a positive bond. However, the industry is moving towards emulsion seals for a high proportion of surfacing. While emulsion seal coats have been successfully applied, the period of time where the seal coat is susceptible to stripping is greater than that for hot bitumen and the pavement location, loading and traffic control planning need to be carefully considered.

FBS can be undertaken throughout the year, and the only restriction is often the ability to be able to ensure an adequate weather 'window' to permit surfacing to be undertaken. Hiways have found that the use of hot bitumen is 'lower risk' for the early and latter part (or even outside) of the roading 'construction season'.

5.3 SURFACING CASE STUDY

The FBS basecourse can be trafficked almost immediately, and provided shear stresses are not high an unsealed surface can accommodate traffic for some time prior to surfacing. The FBS basecourse can accommodate inclement weather and trafficking prior to surfacing without failure.

Hiways were the FBS subcontractors for a contract on SH1, Taupo that was surfaced in mid-June. The chip stripped from the emulsion seal coat and the seal coat was 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 in approximately 4 months time. Despite the use of intermittent wheeltrack seal coats and asphalt maintenance repairs employed during winter, much of the FBS basecourse surface in the wheeltracks was exposed to traffic for extended periods.



June '07 Primary wheel track repairs



October '07 major surfacing failure

The first period of sustained hot 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 graded away and the FBS surface evaluated, and found to be in adequate condition for resurfacing with no structural repair required.



Removal of all seal



Exposed FBS basecourse prior to reseat

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 stresses through the winter period without failure.

6 STRIVING FOR INNOVATION - LAKESIDE DRIVE CASE STUDY

6.1 BACKGROUND

Hiways attempted an innovative FBS approach to an urban pavement rehabilitation at Lakeside Drive, Orewa, where thin asphalt surfacing over 100 to 200 mm of aggregate had comprehensively failed. A number of test pits showed a dependable cover to subgrade of 120 mm surfacing/aggregate overlying a non-cohesive sand subgrade of good strength. A number of test pits were undertaken in areas showing the greatest distress. The dependable aggregate depth was not adequate for achieving a 25-year design life by any treatment means and an overlay was not feasible due to the presence of kerb and channel and numerous residential driveways.

6.2 FBS DESIGN TREATMENT

Due to the logged non-cohesive sand properties of the subgrade it was decided to evaluate the feasibility of purposefully incorporating a good quantity of the sand subgrade into the treatment depth creating a blend of aggregate / sand, with the worst case according to pit logs being a 50:50 blend. A pavement design and FBS mix design were undertaken on 50% aggregate / 50% sand subgrade blended sample obtained from retained test pit materials. This blended mix provided excellent FBS properties with 3.0% bitumen and 1.0% cement and this treatment was proposed. The proactive main Contractor and Client approved the proposed treatment and work proceeded.

6.3 FBS TREATMENT - WHAT WENT WRONG

Unfortunately the deflection testing and 9 x test pits for the 3,200m² area did not reveal that a significant portion of the site subgrade comprised an organic silty clay/clayey silt.



This picture illustrates the high level of subgrade variability. Soils range from the pale brown non cohesive silty fine sand with very minor organics to dark brown organic silty clay / black highly organic silty clay.

Test pit samples that the FBS mix design testing was undertaken on comprised the pale brown silty fine sand.

Two elements that raise 'alarm bells' for any aggregate stabilisation project are where cohesive soils or organic materials may be incorporated into the treatment depth. Here both of these 'undesirable elements' were present but not identified through parts of the site and by the time FBS was suspended, a significant portion of the site had been treated.

It was not considered practical to repair those compromised areas only - as a 'patchwork quilt' of good and bad areas as per the design expectation did not permit localised repair without compromising the remainder. The entire FBS basecourse was undercut and an imported FBS aggregate was utilised for filling - with a robust pavement achieved at completion that achieved the Clients requirements despite the unforeseen ground conditions.

6.4 LESSONS LEARNT

If the true extent of subgrade composition and variation had been understood, Hiways would have recommended an undercut as the only means of achieving structural capacity for a 25-year design life. For normal FBS treatment it is important to confirm that the treatment depth is not greater than the dependable aggregate depth, so differences in subgrade composition provided the strength was as tested / back analysed would not be critical. However, for the treatment of this site, the intentional incorporation of subgrade was undertaken on the basis that the subgrade had no cohesive or organic content.

The lessons learnt here were threefold:

- 1) Ensure the testing agency understands what the testing is being undertaken for and what elements are critical to treatment feasibility. The designer should personally evaluate sampled materials and not rely on the inferred accuracy of pit logs.
- 2) In sites where subgrade (or pavement composition) conditions may be variable undertake an increased number of tests - and utilise larger excavations such as test trenches to permit evaluation of a larger expanse of materials and
- 3) Discuss the site with anybody who may have experience with this area or relevant historical information.

The independent testing laboratory mix design confirmed the successful blending of aggregate and non cohesive subgrade, so this approach can work if materials are consistent (and are not cohesive and/or organic). However, if the subgrade is to be intentionally incorporated into the stabilised layer there needs to be a very compelling case for comprehensive materials evaluation and confirmation of reactivity for any potential variations.

7 PERFORMANCE OF FBR SITES

As outlined in the introduction, the performance of FBS sites across New Zealand to date has been exceptional. While only a hand-full of post-construction years have passed, testing to ascertain remaining life shows that design assumptions are met or surpassed. A small difference in pavement structure 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.

Current industry standard FBS pavement design methodology as specified in the TNZ Supplement to Austroads³ (with 800 MPa resilient modulus, no sublayering, anisotropic, and Poissons ratio = 0.3) is recognised to be slightly conservative. This is appropriate as the technology is still relatively new to New Zealand, with insufficient time for long term performance history to be validated.

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 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.



FBS in urban setting with an existing central concrete strip that was retained.

³ NZ Supplement to the 2007 Austroads Pavement Design Guide

8 CONCLUSION

Section 7 suggests that there is scope for re-evaluation of FBS modelling and development of representative failure mode with associated performance criteria for mechanistic modelling.

It is anticipated that current research in New Zealand and overseas will facilitate a dependable means to correlate mix design and mechanistic modelling and provide a design methodology that represents the unique properties of FBS.

The FBS pavement rehabilitation process when combined with thorough investigation, pavement design and mix design provides a very robust treatment option. New Zealand pavement structure and materials – particularly those in urban settings are extremely heterogeneous, and on occasion presents a number of challenges with respect to providing a low risk structural repair that does not involve full materials replacement.

Hiway Stabilizers have undertaken dozens of FBS contracts per year for the last three years, and the outcome has been very successful in terms of construction processes and as-built performance. It has been a struggle to find sites where problems have occurred, for inclusion in this paper, despite various locations where the 'envelope has been pushed'. There has been no project where a return to site has been required to remedy structural inadequacies. This confirms that provided basic design elements are achieved, as outlined earlier in this paper, the FBS process can accommodate a wide variety of materials and environments.