RECYCLING OF CHIP SEALED PAVEMENTS
NEW ZEALAND EXPERIENCE IN COMBATING TOP SURFACE LAYER INSTABILITY ISSUES

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ABSTRACT

The financial tensions and demanding investment criteria being applied to road maintenance in New Zealand make it difficult to justify investment in pavement replacement based on economic analysis of user benefits. As a result, there has been:

(a) A notable increase in the average life of pavements

(b) More resurfacing treatments applied over the life cycle of the pavement

(c) Challenges in determining what the “do minimum” treat is, and

(d) Heightened awareness of the safety features

New pavement maintenance techniques, which are based on top surface layer recycling and have been developed in response to these maintenance issues, are discussed.

KEY WORDS

PAVEMENT / STABILISATION / MATERIALS / SKID RESISTANCE / MAINTENANCE.

1. Introduction

The financial tensions that are being applied to the New Zealand road maintenance budget, and associated demanding investment criteria, are making it difficult to justify investment in capital projects such as pavement rehabilitation. This is particularly the case in Transit New Zealand Regions 5 and 6 (Gisborne and Hawke's Bay) where comparatively low traffic volumes and the difficult construction environments combine to make economic justification for capital projects even more challenging. This has over time resulted in:

(a) A pavement maintenance programme which has aimed to provide timely and cost effective intervention with a "fix only when faulty" philosophy

(b) More resurfacing treatments, in particular chip seal treatments, have been applied over the life cycle of these pavements

(c) A notable increase in the expected life of pavements, and the depth of surfacing layers

(d) Challenges in determining what the "do minimum" maintenance treatment should be

Much of the New Zealand roading network comprises a thin chip seal applied as a surfacing treatment to a flexible pavement constructed from unbound granular materials. Typically a sub-base material on subgrades with CBR strengths in the range of 2 to 6 is overlayed with a basecourse and a chip seal applied as the running surface. Resurfacing with further chip seals at 4 to 16 year intervals (depending on the chip size and failure mechanism) is the principal maintenance strategy. Many chip seal resurfacings may be applied before structural deterioration of the flexible pavement justifies further investment in pavement strength.

The increased depth of chip seal layers, which has resulted from the extended life expected from our pavements, has also meant that other safety related aspects of the road network have been affected. The selection of the most appropriate technique to maintain the surface friction characteristics of the network, in particular texture and skid resistance, has been made more difficult by flushing in the deepening chip seal layers.

Our investigations have shown that the deeper chip seal layers perform more like poorly graded, bitumen rich asphalt mixes. Such materials can be unstable. We have discovered that a proportion of the shallow shear failure evident on the network was attributable to shallow shear within the surfacing layers. The underlying pavement is in many cases found to be structurally sound and adequate for the intended traffic loading. Flushing of many of these pavements was also shown to be occurring as a direct result of this top surface layer instability.

The innovative maintenance techniques we have developed in response to these findings include recycling of the chip sealed surfacing and upper basecourse layers. (World Road Association, 2001)

This paper will discuss the outcomes of Transit's research into the performance of pavements that include deep chip seal layers. It will describe the criteria we use to select those pavements in which surface layer instability is believed to be the main cause of deterioration requiring maintenance intervention. The site investigation and risk based pavement design techniques we have used to design the corrective recycling treatments will then be described. The paper will also discuss the recycling construction techniques used in the field, and the performance of recycling projects.

2. The Location of the Study Area

Transit New Zealand's Regions 5 and 6 (Gisborne and Hawke's Bay), the study area for this paper, is a highway network consisting of 800km of sealed highways and 21km of unsealed highway. Figure 1 shows the location of the study area in New Zealand.

Figure 1 – Location of Study Area in New Zealand

The topography affecting much of the highway network in the study area is hilly to mountainous. The underlying geology is predominately formed from soft rock sedimentary materials. Aggregate sources vary in quality over the network. Good quality pavement aggregate sources are rare, and not wide spread.

The network is affected by a variable climate, with weather extremes ranging over hot dry summers, cold winters and cyclonic rainfall events.

3. Identification of Network Maintenance Needs

Transit uses a Ten Year Forward Work Programme and Annual Planning Process to identify and report the maintenance and development needs of the highway network. These needs are planned at a treatment length level. That means the network is segmented into similarly performing sections of pavement that represent the actual lengths to which treatments will be applied.

Forward work predictions are forecast over a twenty-year planning period following the application of various treatment intelligence models and ultimately field inspection of the network. The data taken into the field by our experienced practitioners assessing the forward work needs includes historic records and exception reports that will help them determine the probable cause of distress, including those relating to flushing. Exception reports are then used in conjunction with predictions from pavement deterioration analysis to resolve the optimal life cycle treatment strategies.

4. The Case for Recycling

Our investigation of pavement maintenance needs for treatment lengths requiring maintenance often showed shortened reseal cycles, and increasing routine maintenance costs. These defects were also often associated with the treatment of surfacing (flushing or bleeding) or near surface maintenance problems such as shallow shear or cracking.

Many of the pavements were usually older (more than 40 years), had deeper existing surfacing layer depth typically between 40 and 100mm, and the surfacing materials had high effective bitumen content (>20% by mass). The inconsistently graded, bitumen rich seal mixes in the top surface layers were made up of multiple layers of binder and chip. The resulting aggregate grading and high binder content made these layers significantly less stable than a conventional asphaltic concrete material.

In pavements exhibiting signs of shallow shear, we would have previously attributed the failure to the basecourse layer. However as illustrated in Figure 2, in many cases it appears that the failure remained within the surfacing layer.

Figure 2 – Evidence of Shallow Shear in Top Surface found on the Highway

5. Objectives for Recycling

Having determined that a loss of top surface layer stability is the predominant failure mechanism to be addressed by pavement recycling, the treatment objectives can then be established:

(a) The treatment is a maintenance treatment designed to address top surface layer instability

(b) The objective is not to enhance other attributes of the pavement (such as pavement life), unless analysis confirms that it is economic to do so.

(c) The treatment design recognises that correction of the layer instability must be achieved. Masking of the problem by applying treatments that may restore texture but will not result in correction of the high binder-stone ratio, are not seen as solutions unless economic analysis suggests that a reduced expected life is an appropriate strategy.

(d) The treatment design life is that which arises from a life cycle economic analysis.

6. Project Justification

Transit uses Benefit-Cost analysis to justify roading investment strategies in New Zealand. The benefits to the road user are weighed against the capital investment required. Recycling is designed to correct a maintenance deficiency. The investment in this case is tested against a Net Present Value analysis considering only the agency cost streams. The intent of such an analysis is to reduce the accrued cost of ownership over the life cycle of the asset when considering the different strategies that could be applied to maintain service level. This approach is illustrated in Figure 3.

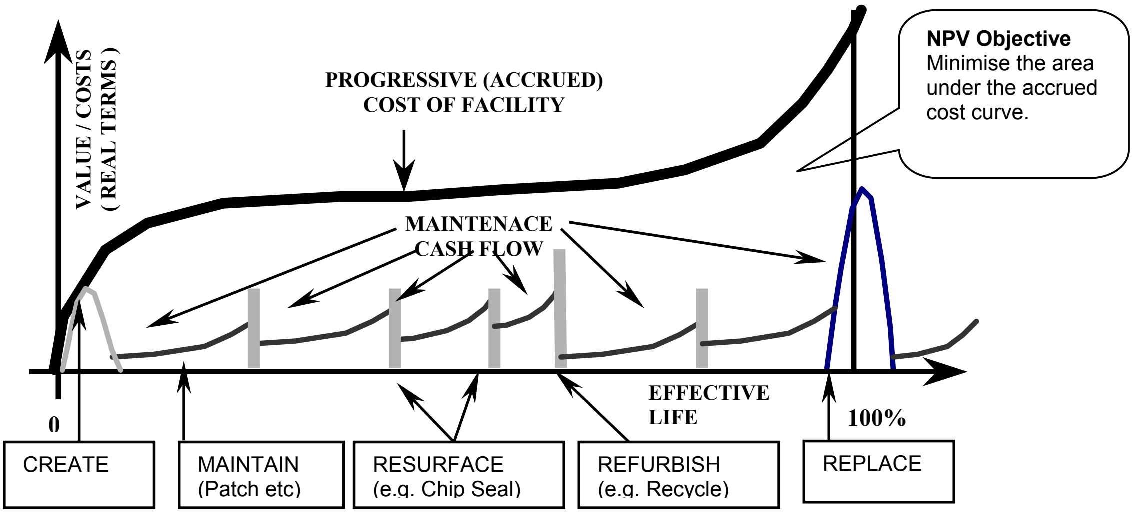

Figure 3 – The Pavement Maintenance Value/Cost Curves

In current economic analysis, eligible recycling projects are justified using a discount factor of 10%. The preferred option must show a positive Net Present Value.

7. Selection Criteria for Recycling Sites

The criteria we use to identify whether a treatment length can be classified as being a candidate for recycling are the binder-stone ratio present in the existing surfacing layers, the depth of the surfacing, and the presence of maintenance needs within the surfacing layers such as shallow shear failure or cracking. The selection process we use is illustrated in Figure 4.

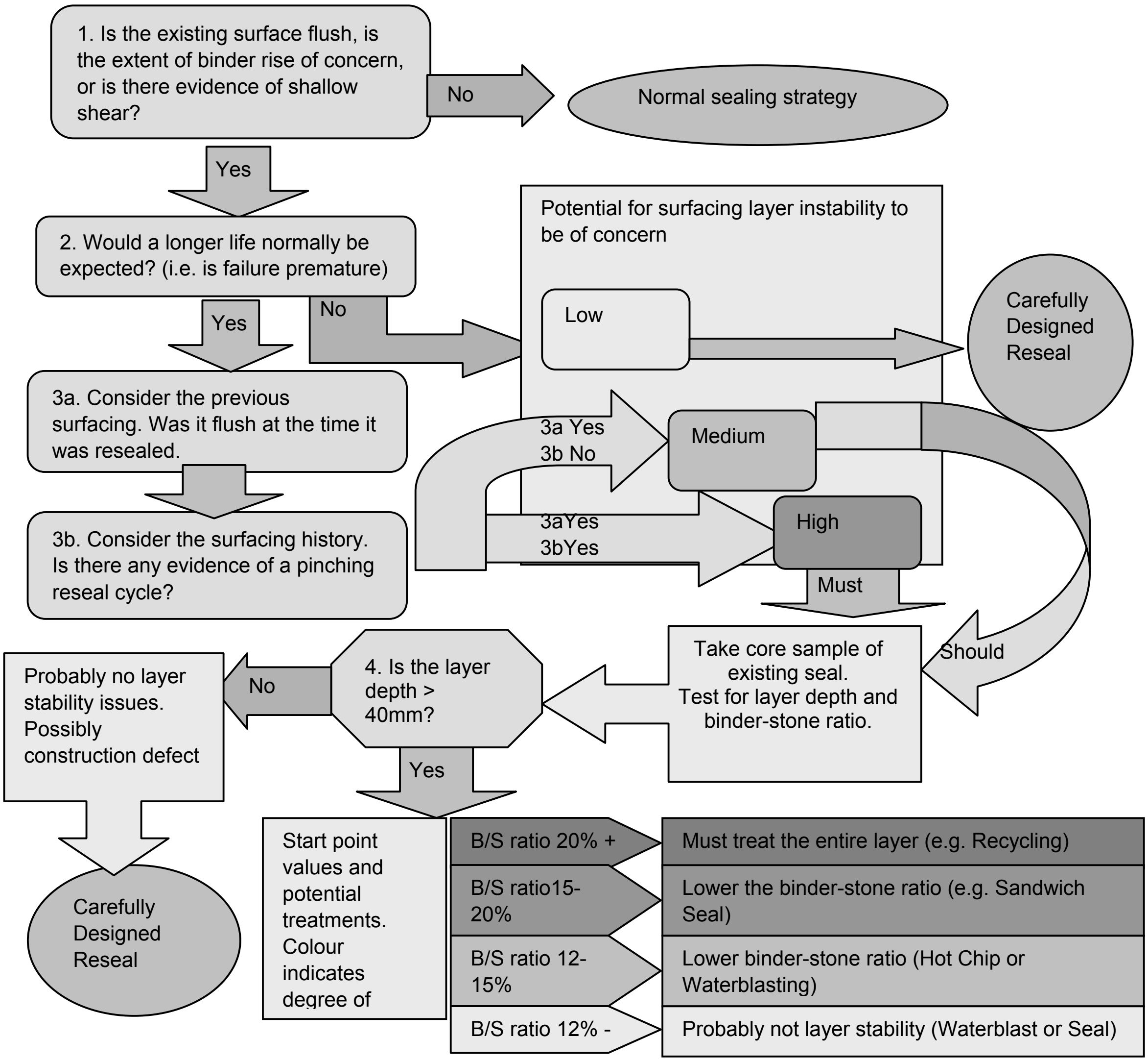

Figure 4 – Treatment Selection Analysis Decision Flow Chart

8. Detailed Investigation And Design Of Recycling Sites

Once sites have been identified as being suitable for recycling, detailed investigation and design work is required to verify the appropriateness of the proposed treatment.

Flowchart 1 below outlines the investigation and design process that is followed for each recycling site.

Flowchart 1 - Investigation/Design Process for Pavement Recycling

Steps	Description of Investigation and Design Process	Key Inputs
Step 1	Inspect the existing pavement condition and quantify the extent of flushing, bleeding and shallow pavement distress. Look for any sign of deeper pavement distress that may indicate the need for deeper rehabilitation.	Identify length and location of site, traffic data and likely pavement structure from inventory records to assist preliminary FWD analysis.
Step 2	Undertake FWD inspection of each traffic lane and complete preliminary elastic analysis of the assumed pavement structure	Use recorded pavement deflections from FWD, known traffic data and assumed/known? Pavement structure
Step 3	Study the preliminary treatment recommendations for the site from the FWD analysis. Locate areas of different pavement strength, particularly low strength area. Programme test pit excavations at selective locations	Look for indicators of low pavement strength including low or variable layer moduli, high deflections (>1.5mm), overlay depths and low structural number
Step 4	Complete test pit investigations, and pavement material identification. Sample for laboratory tests e.g. bitumen content, cement reactivity	Identify seal depth and structure, pavement depth and structure, material types, subgrade material and strength
Step 5	Re-run the structural analysis of the pavement using the FWD Prepare final FWD rehabilitation recommendation report.	Test pit information giving pavement structure and material types, and FWD data from previous inspections
Step 6	Review the FWD rehabilitation recommendations (in particular overlay depths) and determine: Is the site still suitable for recycling? If so, what treatment is required?	Look for indicators of low pavement strength including low or variable layer moduli, high deflections (>1.5mm), overlay depths and low structural number
Step 7	Summarize recommended pavement treatments for the selected site, and discuss the recommendations and risks with client. Prepare treatment schedule for Tender Documents	Economic analysis of options is required at this stage.

9. What Design Assumption Are Made?

Recycling is intended to be a “maintenance” process, to extend the life of an existing pavement. A number of assumptions are made and risks considered during the design process in order to ensure that this concept is followed. These are:

(a) The recycled pavement life is expected to be between 10 and 15 years, based on existing and predicted traffic loading, and the back analysis of the existing pavement using the Falling Weight Deflectometer (FWD). If this back analysis shows that the existing pavement is basically “sound”, then the recycling of the top surface layers will extend the life of the pavement.

(b) The objective of the recycling process has been to produce a modified or lightly bound top surface layer. The Austroads Stabilisation Guide (Austroads, 1998) defines a modified material as having an Unconfined Compressive Strength (UCS) of <1MPa, and a lightly bound material as having UCS of between 1MPa and 4MPa.

(c) The Modified Pavement layer produced by recycling is assumed to behave either like a premium unbound granular pavement, or a lightly bound material. The Austroads Pavement Design Guide (Austroads, 1992) assumes then that the recycled pavement could be represented by layer moduli of up to 2000Mpa.

(d) The depth of the existing pavement needs to be deeper than the recycled layer. This should prevent subgrade being drawn up into the recycled pavement. Make up metal can be applied if required.

(e) The pavement recycling work would be preceded by the maintenance of drainage and other surface features.

(f) Cement is used as the stabilising agent during the recycling process.

10. Recycling Construction Process

Recycling involves the following construction activities:

(a) Milling the existing surfacing layers to depths of between 200 – 250mm. The milling process should achieve a material breakdown to a maximum stone size <50mm

(b) Applying appropriate water control for compaction

(c) Limited shaping by grading, followed by immediate compaction

(d) Resurfacing with chip seal within 24 - 48 hours

Figure 5 below shows a typical recycling operation in process.

Figure 5 – Recycling Operation (Cement Application, Milling and Primary Compaction)

11. Monitoring During and After Construction

The monitoring of the recycling process during construction has included sampling of milled material (including cement) and the preparation of samples for Unconfined Compression (UCS) and Repeated Load Triaxial (RLT) testing.

The UCS results have been collected and collated to provide us with an indication of the consistency of the recycling/milling process. One of the main objectives of the recycling process has been to produce no more than a lightly bound top surface layer. The Austroads Stabilisation Guide defines a lightly bound material as having an Unconfined Compressive Strength (UCS) of between 1MPa and 4MPa (after 7 days). If cracking was to occur in the recycled pavement the use of lightly bound material should encourage the development of controlled micro-cracking rather than block cracking as a result of tensile fatigue. The UCS test can be repeated on each site relatively easily and consistently.

The RLT testing has been used to test our design assumption that the recycled material behaves like a lightly bound layer with a design modulus between 1500 and 2000 MPa.

Our site monitoring has also included an annual review of High Speed Data from Annual Surveys, and in specific cases annual surveys of selected sites post construction using the Falling Weight Deflectometer. The latter, like the RLT test programme, has been used to monitor how well the recycling sites have been performing, and how closely these are behaving compared to the original design assumptions.

12. Unconfined Compression Test Data

Figure 6 presents the Unconfined Compression Test data obtained from separate recycling contracts in the Gisborne and Hawke's Bay regions, in the years between 1999 and 2003.

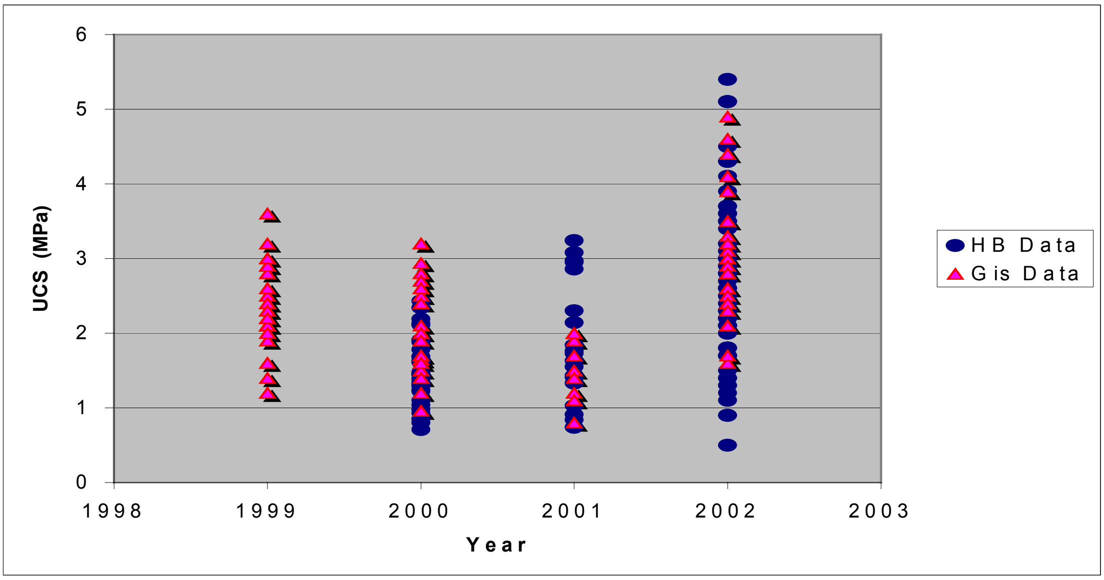

Figure 6 - Comparison of Unconfined Compression Test Data from Recycling Contracts in Gisborne and Hawke's Bay between 1999 and 2002

Our design assumption for recycled pavement layers has been to achieve either a modified or lightly bound material with the additional of the cement additive. In the first three years (1999 to 2001) the majority of the UCS test results are between 1MPa and 3MPa. This material would be characterized as lightly bound by Austroads. Notably in 2001, the UCS results for the Gisborne region were all between 1MPa and 2MPa. In this year some premature failures occurred in the Gisborne sites. These failures tended to be rutting failures.

The test results from 2002 and 2003 show a wider spread of results, with the maximum UCS exceeding 5MPa. The cement content has not changed from 3% over the four years. We note however that the effectness of the milling process has been improved with the introduction of larger milling plant in the Hawke's Bay sites in particular in these latter years.

13. Repeated Load Triaxial Testing

Figure 7 presents a sample of the data from the Repeated Load Triaxial tests that have been carried out on selected samples over the years between 2000 and 2002. The samples have been retrieved from the project sites after the materials have been milled, and before the cement additive has been added. In the laboratory, the cement has been added, and the samples have been compacted to densities and at water contents that are representative of actual compaction achievements in the field in each case.

The Repeated Load Triaxial tests have all be carried out under the following conditions:

- Sample height – 295mm, Sample diameter – 150mm
- Deviator Stress – 425 kPa, Confining Stress – 125 kPa
- Cycles – 100,000, Test condition: Sample back pressure saturated, consolidated and drained

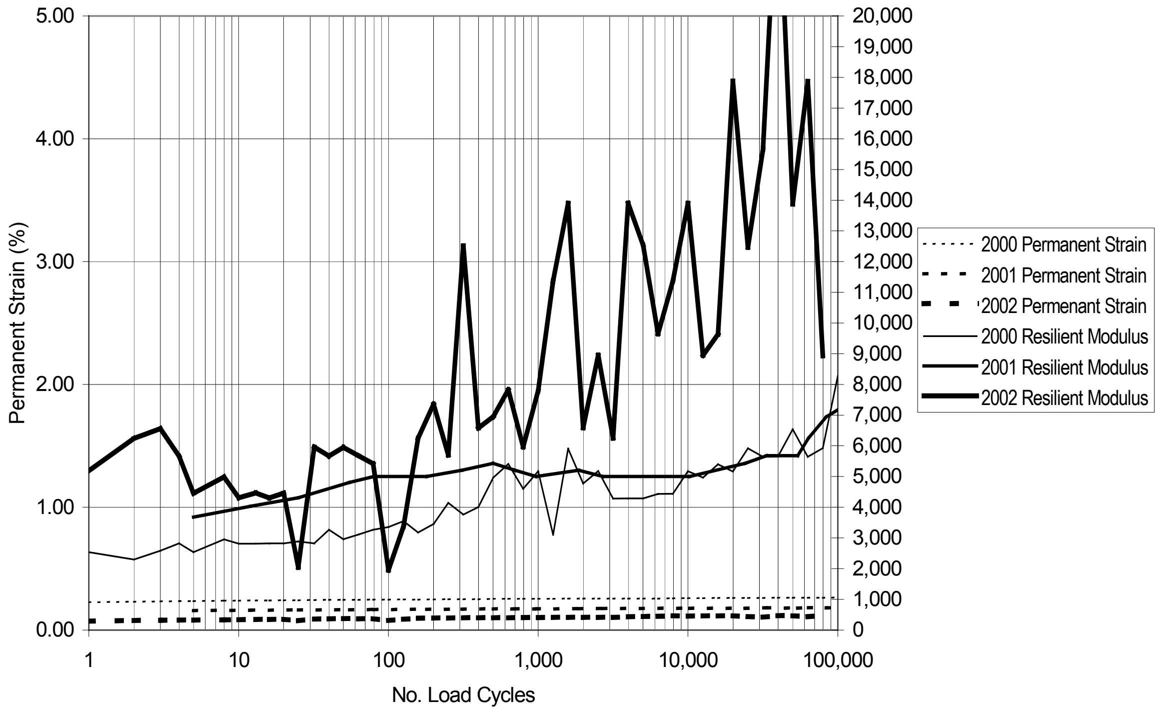

Figure 7 – Sample of Repeated Load Triaxial Test Data

14. Comparing the Performance of the Control Sites with Austroads Design Guide

We have always considered that the performance of the recycled pavement layer could be expected to be different to a conventional cement bound material, because the recycled layer includes both cement and bitumen binder, albeit somewhat variable bitumen material. To test where these recycled pavements might fit when compared to the cement bound material characterised by Austroads, we have reviewed the performance of two sites named Kareeara and Awaho, constructed in 1997.

This review has included:

(a) Using the as-built formation of the two pavements, we have back analysed using the computer program CIRCLYW the strains that could be expected within the various layers within the pavement

(b) We have then compared these strains with those predicted by Austroads for the design traffic at each site.

Austroads (Austroads, 1992) and others (Greg White and Carthigesu Gnanendran, 2002) report that the fatigue behaviors of cemented materials can be described by the relationship that takes the form shown in Equation 1 below:

$$N = \left(\frac{K}{\varepsilon} \right)^{a}$$

Equation 1 – Fatigue Relationship for Cement Bound Materials from Austroads

In this relationship N is the number of strain (ε) repetitions to failure, and K and *a* are area constants.

Figure 8 presents the Austroads fatigue relationships (Transit NZ, 1997) for cement bound materials with layer Moduli of 2000MPa and 5000MPa derived using Equation 1. The results from the back analysis of the existing pavements at Awaho and Kareeara are also shown on Figure 7. The back analysis has allowed the existing cement bound recycled layers to have layer moduli of either 2000MPa or 5000MPa, which is consistent with FWD and RLT test data.

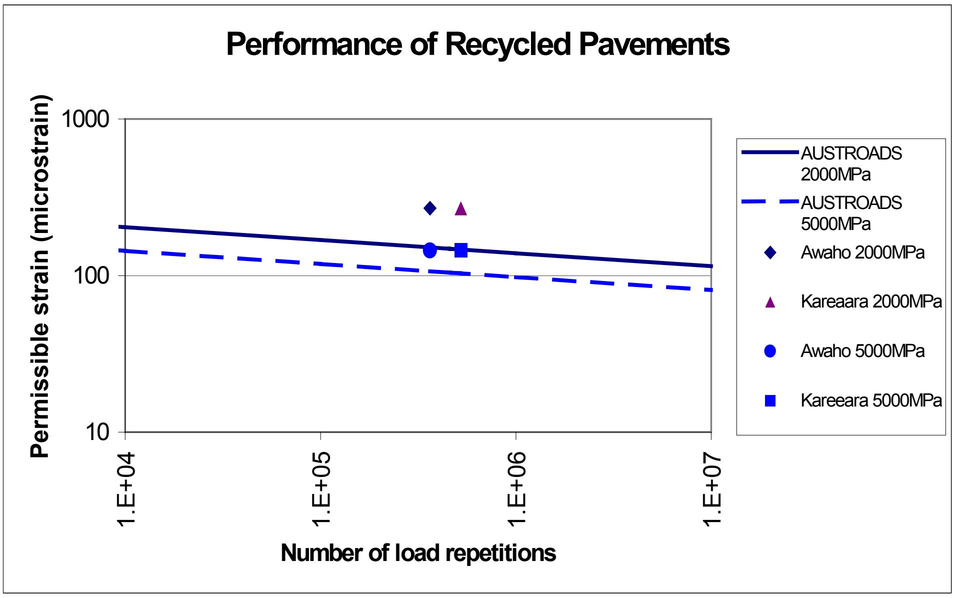

Figure 8 - Comparison between Actual Performance and Predicted Performance according to Austroads fatigue relationships for Bound Pavement Layers, for the Kareeara and Awaho Culvert Sites.

Both the Kareeara and Awaho sites are sustaining higher strain levels at the base of the recycled layer, than would be predicted by either of the Austroads (Austroads, 1992) fatigue curves. Put another way, if the as-built pavements were designed using the Austroads criteria, both of these pavements should have “failed” by tensile fatigue before now.

Our ongoing review of high-speed survey data has not identified any significant increase in cracking at either of these sites. Therefore we have concluded that up to this point, the recycled pavement layers at both these sites are still functioning as cement bound layers (W Gray 1998).

15. Conclusions Drawn from Construction Monitoring

Our post construction monitoring of the control sites at Awaho and Kareeara, and our review of the test data from the UCS and RLT Test programmes has thus far lead us to several conclusions.

When recycling involves the milling together of existing seal layers (>40mm thick with bitumen contents >20%), existing near surface basecourse layers, and if required nominal make up metal, with cement (3% by weight) the resulting pavement layer (assuming that construction is carried out effectively) will act as a lightly cement bound layer with a pavement layer moduli averaging 2000MPa. This lightly cement bound material can be expected to sustain higher levels of tensile strain than would be predicted by published Austroads fatigue relationships (Transit, 1997).

At some stage during the life of the recycled pavement, there will be a transition from lightly cement bound to unbound behavior. Provided that this transition is managed by proactive maintenance of seal surfaces (to maintain waterproofing) this transition to “unbound” behavior should not spell the end of the recycled pavement life. Whilst we do not yet know how long this new pavement structure will last, this will obviously depend on the soundness of the pavement materials below the recycled layer, the subgrade conditions, and the traffic loading.

Over the last two years, the data from the UCS and RLT testing has highlighted an increase in stiffness in the recycled layers. This has coincided with a reduction in the reported depth of existing seal layers. This means that more basecourse materials are included in the recycled layer. In order to mitigate the risk of premature cracking failure in the more recent recycling work, Transit has increased the compacted depth of the recycled layers from 200mm to 250mm.

16. Where Next For Recycling?

Recycling of unstable top surface seal layers has and continues to provide Transit with a cost effective maintenance treatment option in regions such as Hawke's Bay and Gisborne. Transit will continue to monitor the performance of existing and future recycled pavements, to ensure that the guidelines provided in this paper for the identification, design and construction of recycled pavements continue to allow the practitioner to evaluate and implement future pavement recycling strategies.

17. Acknowledgements

The support for the preparation of this paper by Transit New Zealand's Regional Manager for Hawke's Bay and Gisborne is gratefully acknowledged.

This paper summarises a larger report that has been produced on this topic. Anyone interested in the larger report should contact the authors.

18. Disclaimer

The contents of this paper are necessarily generalised. Readers are urged to obtain independent advice upon their own circumstances and must rely solely on their own judgement and such independent advice. The paper is only made available on the basis that neither the author(s), Transit New Zealand nor Opus International Consultants will have any liability of any kind whatsoever for any loss or damage caused in whole or in part by any omissions or by any reliance on its contents.

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