ENGINEERING CHARACTERISATION OF *IN SITU* FOAMED BITUMEN STABILISED PAVEMENTS

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SUMMARY

This report is the second of two papers that reviews the results of research undertaken into the stiffness and fatigue performance of *in situ* foamed bitumen stabilised pavement materials at various sites in the Cities of Canning and Gosnells in Western Australia. In the first paper "The development of a fatigue transfer function for *In situ* Foamed Bitumen Stabilised Pavements," the authors reported a review of laboratory fatigue testing that was undertaken over a 13 year history.

In this paper, a review of recent work by Collings and Jenkins in South Africa where failure by shear is examined in relation to failures to date at pavements constructed in City of Canning which do support Collings and Jenkins theory.

1 INTRODUCTION

The City of Canning has some experience with the *in situ* foamed bitumen stabilisation process. In January 1999, four pavement sections were rehabilitated using this process (Leek, 2001). From three of these pavements, slabs were extracted for fatigue beam testing.

Following the success of these projects, a further eight pavement sections were rehabilitated in the City using the process in December 1999. The City of Gosnells undertook the rehabilitation of two adjoining pavement sections in 1999.

Slabs from four completed pavements in City of Canning and one location from City of Gosnells were extracted and sent to the ARRB Transport Research laboratory in Melbourne for flexural fatigue testing. In addition, extensive MATTA testing was undertaken on cores cut from the pavement. The results of these investigations have been previously reported at the 20th ARRB conference in 2001. (Leek, 2001)

The aim of the research was to determine:

- An approach to predict the fatigue life of *in situ* foamed bitumen stabilised pavements
- If the flexural modulus was temperature dependent
- If the fatigue life was temperature dependent
- If the asphalt fatigue transfer function was applicable to *in situ* foamed bitumen.

Following the success of the early works, *in situ* foamed bitumen stabilisation has continued to play an important role in pavement rehabilitation in the City of Canning, where at December 2012, 33 sections totalling 166,000 m² had been rehabilitated using this method.

Over subsequent years, slabs have been extracted from completed road pavements and tested for fatigue performance to add to the data base. In 2008 after 9 years of service, two pavement sections, both of which demonstrated early transverse cracking, were sampled for repeat fatigue testing, and three sections were sampled for repeat Indirect Tensile Modulus Testing.

This repeat testing has influenced previous predictions regarding the design life of *in situ* foamed bitumen stabilised pavements, and further knowledge regarding the effect of shift factors between laboratory testing and field performance has been considered.

Fatigue life due to applied loading rate was not part of this study and, at this time, failure by shear had not been considered. A fatigue transfer function and a modulus value were considered as the primary inputs required for design purposes.

As will be discussed, only for the original projects was a laboratory characterisation to predict the properties of the material and to optimise binder content undertaken. Following this, it was decided that due to pavement variability and cost, characterisation and optimisation of binder content was not to be undertaken on future works and that design would be based on past experience.

The stabilised pavements have been monitored over the intervening years and, as will be discussed, it has become apparent that shear, rather than fatigue, may be the defining failure mode.

2 FAILURE MODES FOR *IN SITU* FOAMED BITUMEN PAVEMENTS

Prior to discussing the results of the extensive testing of samples taken from constructed pavements within the City of Canning, it is worthwhile considering the major possible failure modes. These are discussed in the following sections.

2.1 MATERIAL CHARACTERISATION

Collings and Jenkins (2011) define *in situ* foamed bitumen stabilised materials as a non- continuously bound material. Figure 2.1 shows a compacted slice of aeolian dune sand treated with 4% foamed bitumen, magnified 40 times. It shows the bitumen is dispersed throughout the matrix of the dune sand as tiny splinters. The coarser particles (maximum size is 0.425 mm) are not coated with bitumen. When such a material is compacted, the individual bitumen splinters are mechanically forced against their neighbouring particles and the bitumen splinter adheres to its neighbour, setting up an isolated bond. With the bitumen dispersed as millions of such splinters, the result is millions of localised bonds that are isolated; hence the term "non-continuously bound" material (Collings and Jenkins, 2011).

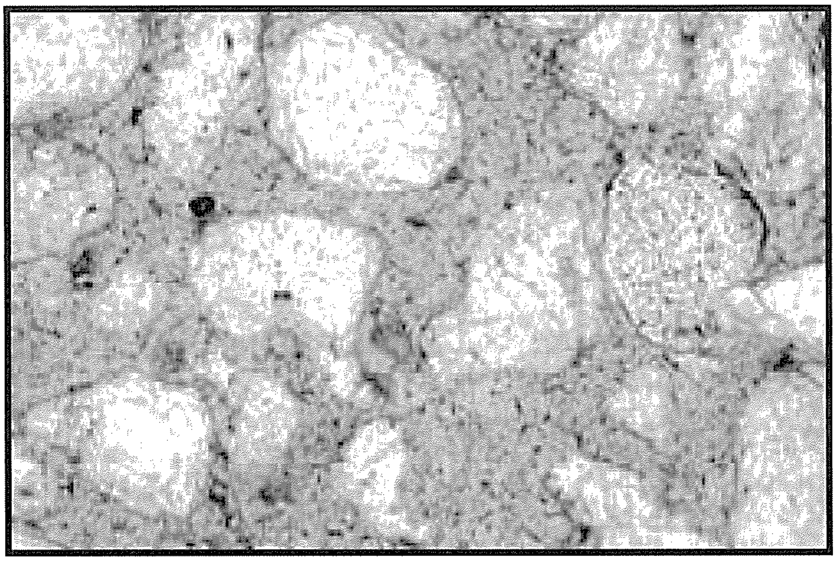

Figure 2.1: Slice of foamed bitumen stabilised material (Source: Collings and Jenkins, 2011).

In Australia, the assumed failure mode for *in situ* foam bitumen stabilised pavements has been that the material would fail by fatigue, and hence the Australian practice has been to design the thickness based on the fatigue transfer function for asphalt.

One of the reasons for making this assumption is the higher binder contents adopted in Australia compared to South Africa, and the very high resilient modulus values obtained by testing of field cores. However there is another probable method of failure and that is shear failure.

2.2 SHEAR FAILURE

In their paper, Collings and Jenkins (2011) discuss the failure modes of *in situ* foamed bitumen stabilised pavements. It is argued that unlike asphalt, these pavements do not have a continuum of bitumen and are seldom homogeneous, especially when recycled material is stabilised. Thus the classical theory of crack propagation does not apply.

Fracture mechanics has proven to be a very useful tool for modelling materials that suffer fatigue cracking under repeated loading conditions. The principles of fracture mechanics have been successfully applied in pavement engineering to the design of asphalt overlays where reflective cracking requires analysis. Paris' Law is used to describe crack growth in a material. (Collings & Jenkins 2011)

∂_c/∂_n =AK^n ....Paris' Law (1)

where, ∂_c/∂_n = increase in crack length per load cycle
K = stress intensity factor at the tip of the crack, due to bending or shear
A,n = material constants

The stress intensity factor is dependent on the ratio of crack length to beam thickness.

Unlike asphalt, *in situ* foamed bitumen is not homogeneous, nor is the bitumen coating all particles, and so, the bitumen film is discontinuous. The bitumen is instead distributed as discrete droplets centred around fines in the mix as shown conceptually in Figure 2.2. (Collins and Jenkins, 2011).

Collings and Jenkins argue:

"If shear deformation between individual particles ruptures a "spot weld" of bitumen, there is no continuity of bound material that will allow a crack to develop, so c/d becomes meaningless. There is neither opportunity for a crack "head" nor stress intensity at the tip to develop. A broken spot weld will result in particles re-orientating (micro-shearing), resulting in permanent deformation, as with granular material"

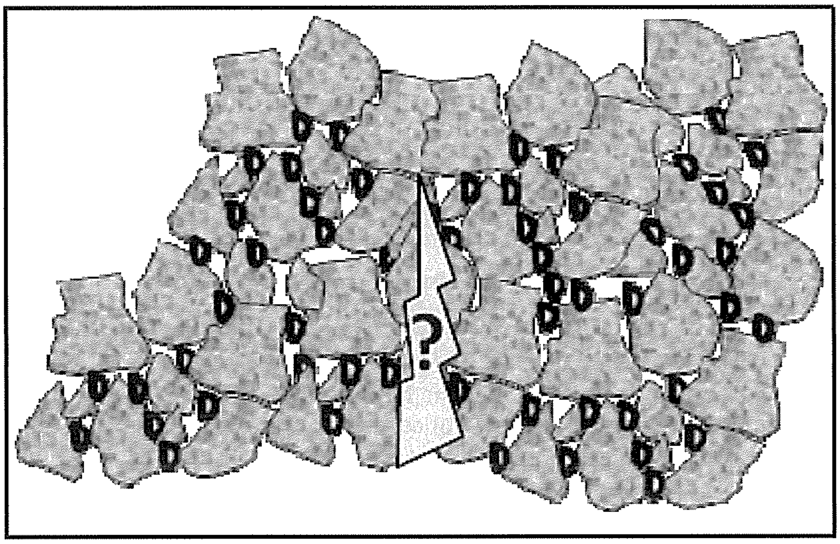

Figure 2.2: Non continuously bound material. (Source: Collings and Jenkins, 2011)

Again quoting Collings and Jenkins (2011):

"The relatively low effective stiffness of (Bitumen Stabilised Materials) BSM's need to be taken into consideration (often less than 50% of HMA stiffness, depending on temperature and loading time). The horizontal strains experienced by a BSM are commonly in the order of 10 to 70 με and very seldom exceed 90 με. By comparison, strain-at-break (εb) tests from monotonic flexural beam tests on BSMs yielded results of 1000 to 3000 με and four-point beam fatigue results can yield between one and several million load repetitions at 200 με ˇconstant strain loading. The non-continuously bound nature of BSMs, coupled with their relatively low effective stiffness regime, does therefore not create conditions conducive to fatigue failure".

This quote shows the difference in performance between the South African experience and that in Western Australia, where higher bitumen contents and lower active binder contents result in resilient modulus values of *in situ* foamed bitumen materials are considerably greater than 75 blow Marshall asphalts and the design strain is usually greater than 75 με.

2.3 FATIGUE FAILURE

Whilst fatigue failure of *in situ* foamed bitumen stabilised pavements is discounted by Collings and Jenkins (2011) who state:

"The ability to manufacture beam specimens from a material used to construct pavement layers and subject them to various tests to measure the strain-at-break and fatigue characteristics does not imply that such properties are the dominant ones that determine the material's behaviour within a pavement layer."

The Australian direction is persisting at present with fatigue, and there is some indication from laboratory testing to support this, although no fatigue failure of *in situ* foam bitumen pavements has yet been observed in Western Australia. The experience by Collings and Jenkins in the field of foamed bitumen stabilisation should not be ignored and the above statement needs to be considered in the analysis of past data.

In analysing test data undertaken on beams extracted from Western Australian roads, Alderson (2001) found that the beams seemed to exhibit one of two types of trend, and were called Type 1 and Type 2.

Type 1 behaviour involves the disruption of the cementitious bonds during the first stage of the tests and then the properties of the bituminous materials dominate the behaviour in the second stage of the test. For results with Type 1 behaviour, the fatigue life is similar to that of asphalt as the onset of cracking occurs early in the test data. That is, there is considerable fatigue life after the onset of cracking. A typical Type 1 data set is shown in Figure 2.3.

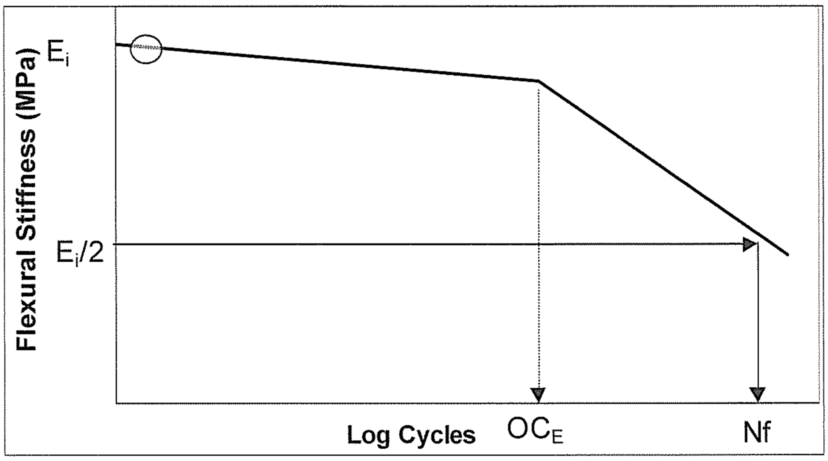

Figure 2.3: Type 1 data (Source: Alderson, 2001),

The second less common data trend is defined as a Type 2 result, characterised by the lack of a well-defined discontinuity. It is postulated that the Type 2 behaviour involves no disruption (or delayed disruption) of the cementitious bonds while the bituminous binder permits the material to withstand relatively high strains. For results with Type 2 behaviour, the fatigue life is greater than that of cement treated crushed rock due to the ability to withstand higher strain levels. (Alderson 2001). A typical Type 1 data set is shown in Figure 2.4.

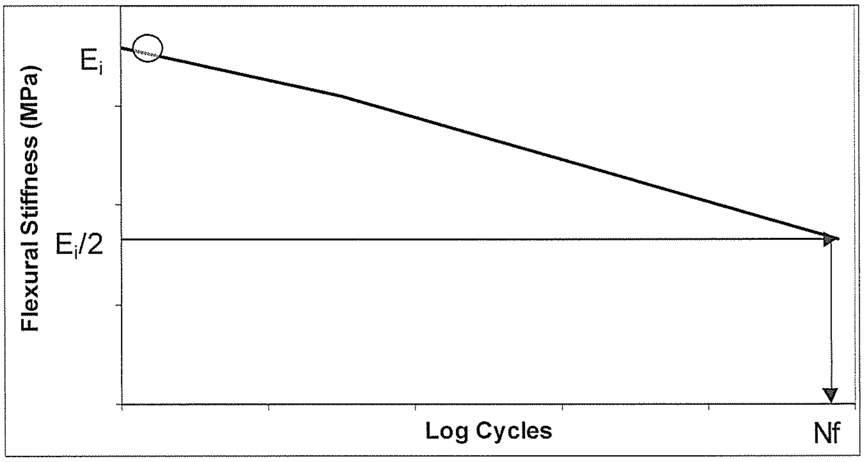

Figure 2.4: Type 2 data (Source: Alderson, 2001).

Alderson 2001 reports that:

"on average, the Type 1 results had a higher initial flexural stiffness (7,100 MPa) compared to Type 2 results (an average of 5,500 MPa). However, Type 2 results had a greater fatigue life (overall average of 3,500,00) compared to Type 1 (overall average of 300,000). The overall mean test strain level for each type was the same indicating that test strain level did not influence the overall fatigue life."

"The strain dependency for beams exhibiting Type 1 and Type 2 trends have been plotted for individual beams as shown in Figure 2.5 and Figure 2.6. A trendline has been included on each plot. The extrapolated points are for those beams where the test was terminated prior to the modulus reaching half of the initial value. Two extrapolated points were not included in the analysis for the trendline of the Type 1 data because they appeared to be outliers, but were included in the Type 2 trendline."

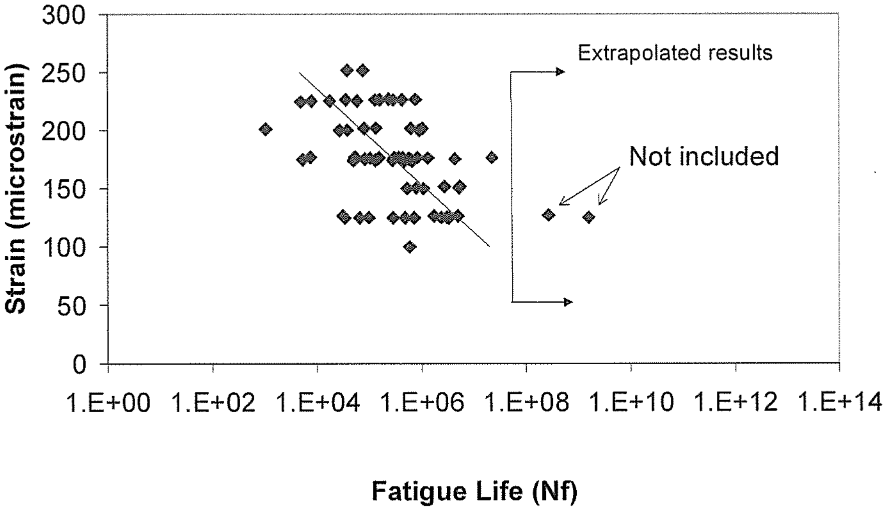

Figure 2.5: Stain dependency for Type 1 data sets (Source: Alderson, 2001).

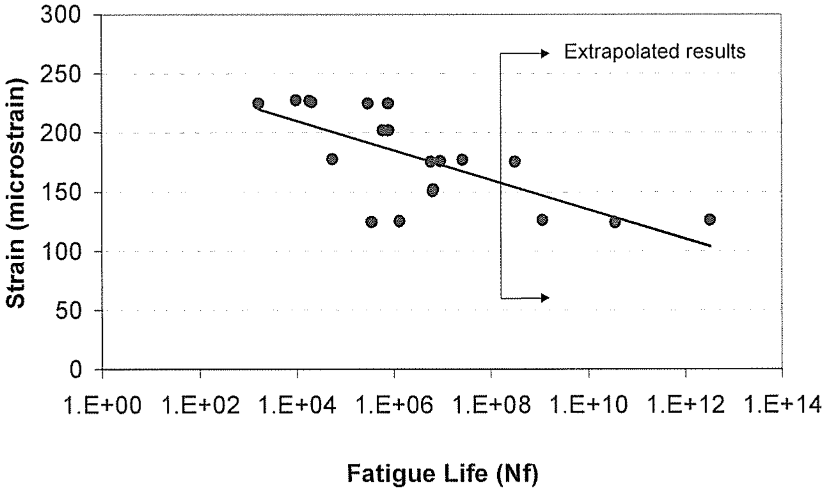

Figure 2.6: Strain dependency for Type 2 data sets (Source: Alderson, 2001).

It would seem apparent from the testing of Western Australian materials, that the foamed bitumen stabilised materials do indicate a trend towards fatigue, but as explained by Collings and Jenkins, this trend may be apparent for discontinuously bound materials but may not be the dominant failure mode or indeed a failure mode at all.

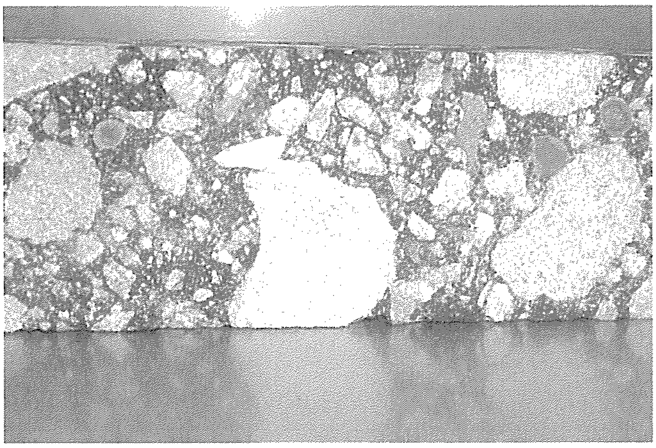

Figure 2.7: Cross section of beam showing effect of large aggregate size.

It must also be stated that the laboratory determination of fatigue using the Beam Fatigue Apparatus is itself problematic. The beam size used in this device is approximately 50 mm x 60 mm. The aggregate size in a foamed bitumen pavement can be relatively large. In WA, 75 mm crushed limestone is common as a subbase, and when the beam is trimmed, large pieces of aggregate can dominate the cross section as shown in Figure 2.7. This can lead to stress concentrations and give no reliable indication of fatigue performance.

Despite the conclusions of Collings and Jenkins, for the immediate present, the research to characterise the fatigue of foamed bitumen will proceed, but if Collings and Jenkins are correct, *in situ* foamed bitumen material is more likely to disintegrate to an unbound granular form, rather than form discrete blocks as in the case of asphalt fatigue.

2.4 FIELD OBSERVATION

It must be stated here that no fatigue type failure has developed in any Western Australian pavement to date, but given the design life of 30 years and the inbuilt conservativeness in the design process, this would be expected and there is no guarantee that fatigue type failures will not develop.

However shear failures have occurred, and initially this was attributed to two different factors:

- pavements where existing material consisting of natural laterite where rounded particles resulted in low shear strength.
- Isolated failures in pavements consisting of crushed granular materials were considered aberrations due to very isolated occurrence and were assumed (without confirmation) to be unintentional excessive bitumen.

Sometime around September 2011 a rapid and significant shear failure developed in one pavement that had performed well for 11 years. This pavement was originally asphalt surfaced with a crushed granite base and crushed limestone subbase. The shear failure is on the outer wheel path on a bend in Bannister Road as shown in Figure 2.8.

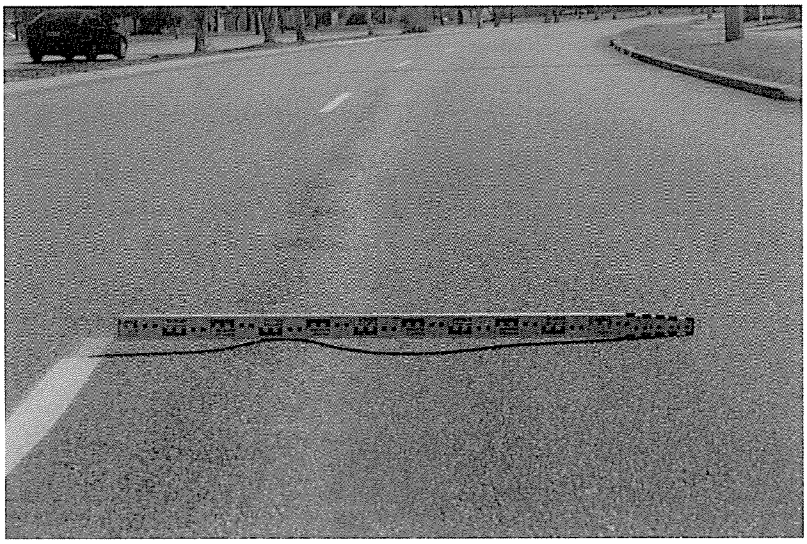

Figure 2.8: Shear failure Bannister Road

Other shear failures in pavements with heavy traffic and consisting of mixed crushed granular materials have previously been observed at intersections with slow moving traffic. These locations at the Bannister Road Forum Avenue intersection (Figure 2.9) and the Nicholson Road Spencer Road intersection Figure 2.10) exhibited shear failure relatively early in the life of the pavement.

Figure 2.9: Shear failure at Bannister - Forum intersection.

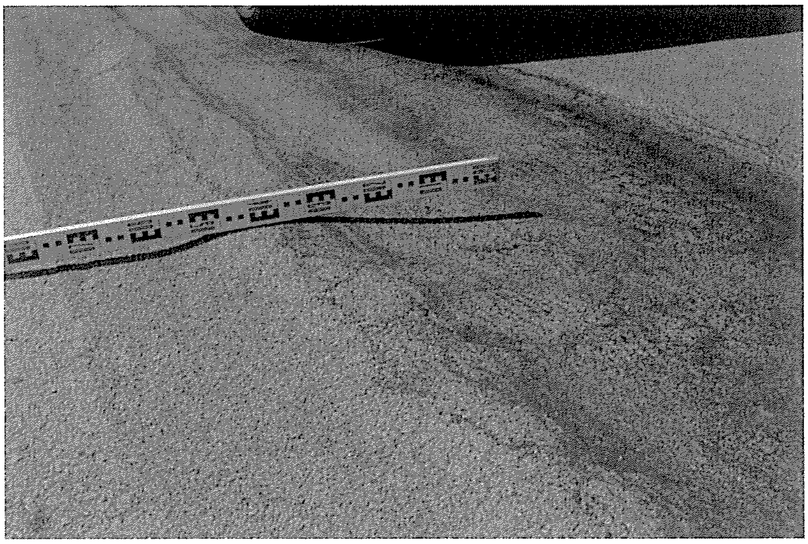

Figure 2.10: Shear failure at Nicholson - Spencer intersection.

Figure 2.11: Shear failure Kewdale near Welshpool intersection 1999.

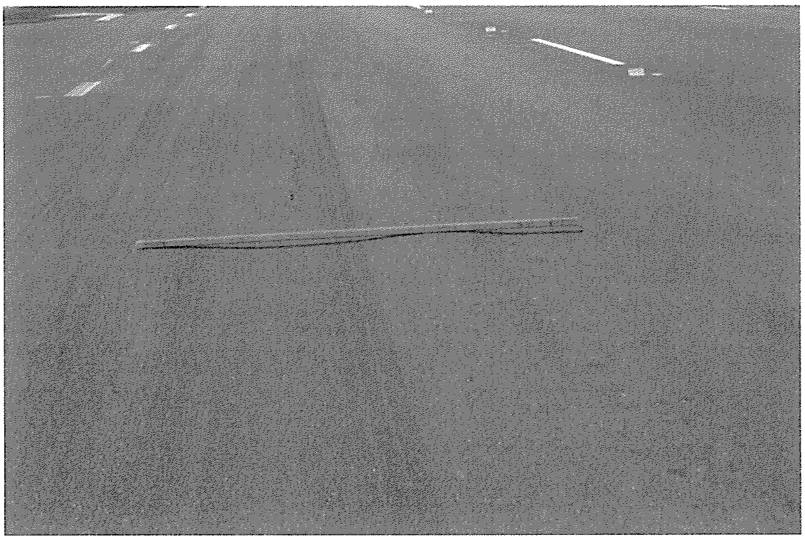

Figure 2.12: Shear failure Kewdale Dowd intersection 2012.

Other shear failures have occurred in materials containing laterite gravels, but only when subjected to very heavy traffic as evidenced by two examples from Kewdale Road as shown in Figure 2.11 and Figure 2.12. The rounded nature of the material in Kewdale Road (note only sections are natural gravel) is shown in Figure 2.13 compared to the more usual crushed materials found in Canning pavements as shown in Figure 2.14.

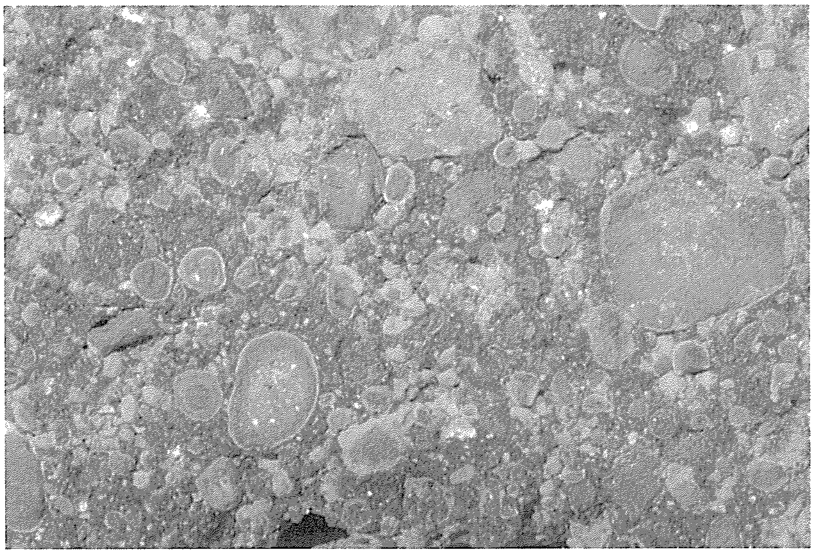

Figure 2.13: Typical cross section of Kewdale Road laterite gravel.

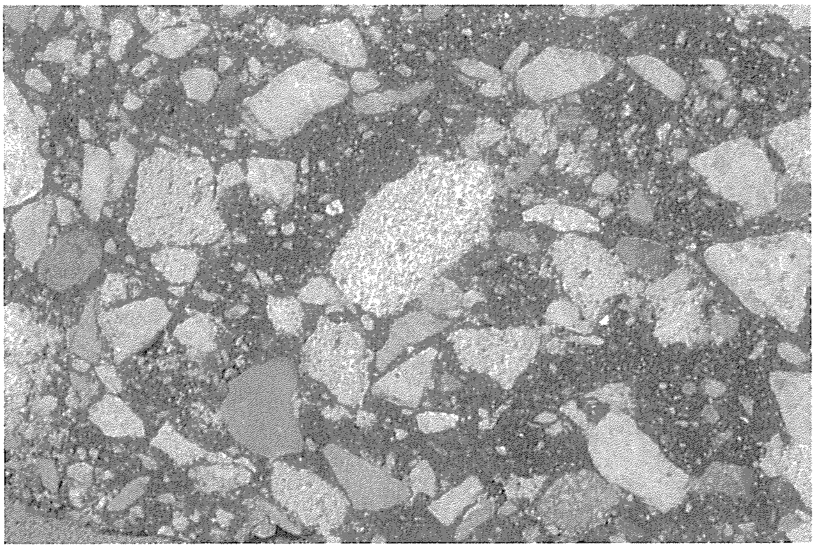

Figure 2.14: Typical crushed material comprising most of Canning roads.

3 CONCLUSIONS

Work by Collings and Jenkins does question the validity of the Australian design methods of assuming that *in situ* foamed bitumen stabilised pavements will fail by fatigue. Failures to date at pavements constructed in City of Canning do support Collings and Jenkins theory.

Notwithstanding this, considerable effort and research has gone into developing fatigue and, as equipment and samples have progressed as far as they have, fatigue will not be discounted completely at this stage. Owing to the higher bitumen contents traditionally used in Australia, and the results of four point bending beam tests, fatigue type failure whilst not evidenced to date, may still be a possible failure mode.

So it is considered important that Australian researchers do need to consider other failure modes, in particular shear, and research into development of models to predict the time to shear may be equally or more valid that determination of models for predicting fatigue performance.

4 FUTURE RESEARCH

As part of an ongoing Austroads project, with cooperation from City of Canning, a section of Kewdale Road in has been constructed at such a thickness (100 mm and 150 mm with 30 mm asphalt surfacing) that, if fatigue is a failure mode, it should develop relatively quickly. In a collaboration with Main Roads WA, AARB Group and Curtin University, the pavement is being closely monitored with regular FWD testing and rut depth.

Curtin University has purchased an IPC Global UTM 25 with a 4 point beam test rig that can test samples 250 mm wide and 150 mm deep, and has in cooperation with City of Canning, constructed slabs in a purpose built mould 3 m x 1.5 m x 0.175 m using materials mixed on site in several foam jobs. These will be tested for fatigue.

Curtin University has also purchased a large wheel tracking machine with a full size truck wheel, and this will be used to parallel test for shear performance.

Based on this research, where Curtin will be collaborating with ARRB group, it is hoped that a better understanding of the failure modes of *in situ* foamed bitumen materials will be realised.

5 REFERENCES

Alderson A. (1999). Laboratory Fatigue Resistance of Foamed Bitumen Samples. ARRB Transport Research Contract Report RC90209

Alderson A. (2001). Ancillary information: Fatigue properties of bitumen/lime stabilised materials

ARRB Transport Research Contact Report RC1488 - E

Collings D. and Jenkins K. (2011) The Long-Term Behaviour of Bitumen Stabilised Materials (BSMs) 10th Conference on Asphalt Pavements for Southern Africa, KwaZulu-Natal, South Africa (CAPSA) 2011

Jenkins K and Ebels J. (2007) Mix Design of Bitumen Stabilsed Materials: Best practice and considerations for classification University, Matieland Proceedings of the 9th Conference on Asphalt Pavements of Southern Africa (CAPSA) 2007