Foamed Bitumen Stabilised Pavements towards Western Australia Experience

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ABSTRACT

Foamed bitumen stabilisation is a road construction technique where hot bitumen is converted to bitumen foam by injecting a small quantity of cold water into it. It is mixed into the road pavement to bind existing or imported granular materials to produce a bound but flexible pavement with superior structural properties to the original pavement. There have been trials and research projects undertaken in Australia by Queensland Main Roads, some regional road networks in New South Wales, and City of Canning, Perth, where the process has been adopted as a preferred rehabilitation method, but these projects did not develop a complete understanding of the characteristics and performance of in-situ foamed bitumen stabilised pavements for Australian conditions. This paper reviews the results of research undertaken into the stiffness and fatigue performance of insitu foamed bitumen stabilised pavement materials at various sites in the Cities of Canning and Gosnells in Western Australia. The aim of the research was to determine if a design relationship could be developed to predict the fatigue life of insitu foamed bitumen stabilised pavements, and if the visco-elastic properties of the bitumen binder were reflected in the stiffness and fatigue performance.

Keywords: Foamed bitumen, pavement, stabilisation, pavement rehabilitation, insitu recycling

1 BACKGROUND

In the Perth metropolitan area (the study area of this project), there is a high demand for road and highway rehabilitation using in-situ recycling techniques. Foamed bitumen stabilisation is a preferred option for pavement rehabilitation, as it has superior fatigue properties to cement stabilisation, and allows for the recycling of existing pavement materials. The process allows rehabilitation of road pavements in a much shorter time frame than any other method, minimising traffic delays, and provides a new structural pavement that is anticipated to provide a very long service life (subject to the adoption of a design model that accounts for the fatigue limits of the material). Experience has shown that some materials previously considered unsuitable for stabilisation are performing very well, whereas in other cases, materials that fall within current guidelines have suffered premature failure. Rising bitumen prices also affect the viability of the process, so design methods to optimise bitumen content and to predict long-term fatigue performance are essential(Leek 2001).

It can be said that in Western Australia, the foamed bitumen stabilised pavement has been initiated by the City of Canning since 1999 where the performance of foamed bitumen stabilised pavements has been continuously monitored and design process refined as pavements have been constructed and tested(Leek 2002).

The original foamed bitumen pavements for want of better information were designed as asphalt pavements where the fatigue life was predicted by the mathematical function of asphalt as shown in equation (1):

$$N = \left[\frac{6918(0.856V_B + 1.08)}{S_{mix}^{0.36}\mu\varepsilon} \right]^5 \quad (1)$$

where: N = allowable number of standard load repetitions; V_B = Bitumen percentage by volume in mix; $_{mix}$= mix stiffness (modulus) MPa; and $\mu\varepsilon$ = tensile strain induced by load (micro-strains)

The entire first project of foamed bitumen pavements was structurally designed based on equation (1) and then constructed with a design bitumen content of 4% with 1.5% quicklime by mass. As a result, almost all of these pavements exhibited transverse cracking, and the lime content was subsequently reduced to half for a second trial. No further cracking has been observed.

Following the success of the project, further eight pavement sections were rehabilitated in the City of Canning using the same design and construction processes of the first project in December 1999. There was the contribution from the City of Gosnells where also undertook the rehabilitation of a section of Kelvin Road and Orchard Road in early 2000. However, based on the information gathering of all foamed bitumen project constructed with respect to the asphalt fatigue life of equation (1), it could be remarked that the use of the asphalt fatigue equation for a foamed bitumen stabilised material was not justified as:

- the theory indicates that the bitumen only coats the fines providing a mortar that locks major aggregate particles in place,
- asphalt is produced in a plant where aggregate is heated and all particles are bitumen coated, and
- there is little control over the grading with foamed bitumen

There were then further investigations by which foamed bitumen slabs were cut from four pavement sections in the City of Canning and one location in the City of Gosnells. These slabs were again sent to the ARRB (Australian Road Research Board) Transport Research laboratory in Melbourne for flexural fatigue testing. In addition, extensive Materials Testing Apparatus (MATTA) testing was undertaken on cores cut from the pavement sections. The results of these investigations have been previously reported at the 20th ARRB conference in 2001 (Leek 2001).

Since that report, 18 other pavement sections have been rehabilitated using insitu foamed bitumen stabilisation, and slabs were extracted from the following locations to undertake further fatigue testing:

- Bannister Road South St to Forum Canning Vale (2001)
- Nicholson Road Nth of Spencer Rd to Albany Hwy Lynwood (2001)
- High Road Nicholson Rd to Metcalf Rd Lynwood (2002)
- Bannister Road Baile Rd to Magnet Rd Canning Vale (2003)
- Willeri Drive Killara Dve to High Rd Riverton (2005)
- Orrong Road Leach Hwy to Ballantyne Rd (2005)

The purpose of these further investigations was to determine:

- A approach to predict the fatigue life of insitu foamed bitumen stabilised pavements
- If the flexural modulus was temperature dependent
- If the fatigue life was temperature dependent

Subsequent to the further testing, the fatigue equation has been refined as follows:

$$N = (1588/\mu\varepsilon)^6 \qquad (2)$$

where: N = allowable number of standard load repetitions and $\mu\varepsilon$= tensile strain induced by load (micro strains)

In 2008 after 9 years of service, two pavement sections, both of which demonstrated early transverse cracking, were sampled for repeat fatigue testing and another three sections were sampled for repeat resilient modulus testing. Resilient and flexural modulus testing has shown that resilient modulus is significantly greater than the flexural modulus, and that there is a change in modulus as the pavement depth increases(Leek 2010).

In addition to fatigue and modulus testing, extensive Falling Weight Deflectometer (FWD) testing has been undertaken on many of the stabilised pavements over time.

2 DEVELOPMENT OF FATIGUE LIFE MODELLING OF FOAMED BITUMENT STABILISED MATERIALS

In analysis of the results of fatigue testing, it is important to recognise the limitations of the fatigue test. Large aggregate pieces can be included in a test beam, which represents only a small cross section of the total pavement (see Figure 1). Stress concentrations will develop when this condition occurs, which can, and most probably will reduce the actual fatigue life of the beam in the test.

A total of 193 beams have been tested, 166 beams comprising pavements of all crushed materials and 26 of pavements containing rounded particles. The results of the fatigue testing are shown in the chart in Figure 2 which is the results of fatigue testing of two sites at age 9 years.

Figure 1. Example of a foamed bitumen beam section extracted from the pavement trial

In analysing the results, there is considerable scatter of data, as would be expected considering the nature of the stabilised materials with the inherent variability encountered in existing pavements. The number of sample sites is small, and the failure modes of the beams during test were not consistent.

Due to the high cost of testing and limited funds, only one site was tested at multiple depths to determine if the reduction of density with depth effects fatigue performance. This test was not conclusive, and the fatigue performance of the bottom layer, whilst well short of that predicted by the asphalt model, is not the worst performing case compared to some other locations.

Whilst bitumen contents and stiffness of a foamed bitumen stabilised material would be considered to contribute to fatigue life, and test temperature would be expected to affect stiffness, due to the scatter of individual results, there was no significant relationship between modulus and fatigue life or bitumen contents and fatigue life. Therefore, a simplified equation is proposed in line with that used for cemented materials, subgrades and indeed bituminous materials, but excluding specific reference to bitumen content and stiffness.

The results of the individual beam tests were plotted and using the inbuilt curve fitting functions in MS EXCEL, a best fit using the power function was determined. The power function was selected as this is the basis of the relationship used for predicting the performance of other pavement materials. Due to the statistical insignificance of test temperature, it was considered reasonable to bulk all results together to maximise the data available for determination of a fatigue relationship.

This trend line is a best fit relationship, such that many individual results fall either side of the equation, and thus if this equation were applied, 50% of the pavement would be likely to fail by fatigue cracking. By trial and error a 95th percentile equation was developed such that 95% of all results were included by the equation.

However, consideration needs to be given to the inherent difference between accelerated loading test conditions, and that loading regime that actually occurs in the pavement. When the original 1987 Austroads Pavement Design Guide was published, it was thought that the Shell fatigue equation used in the guide included shift factors for vehicle wander and healing. Healing of bituminous pavements is thought to occur between repeated loads, and this does not occur under accelerated loading conditions.

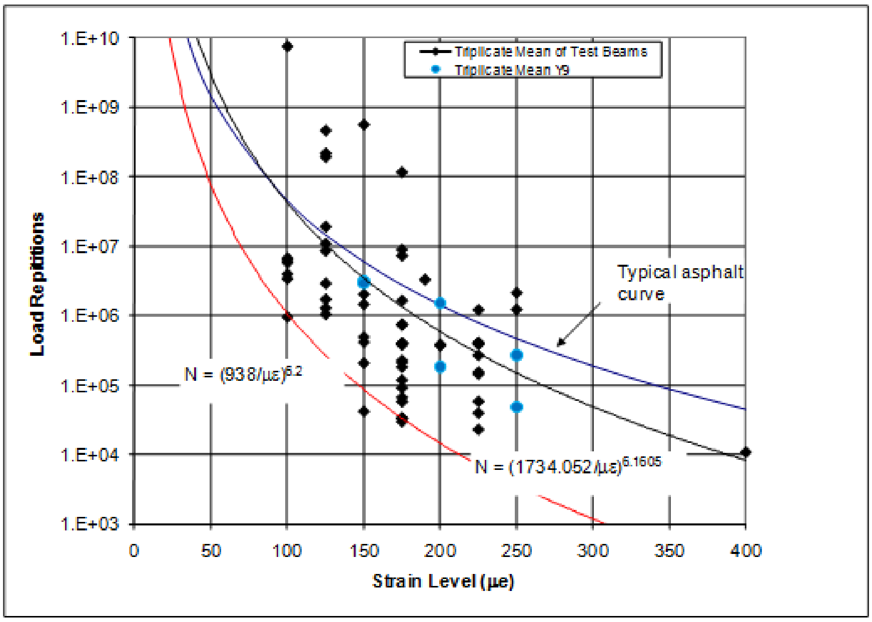

Figure 2. Plot of triplicate mean fatigue test results for pavements with crushed granular materials

Nevertheless, this was not the case, and the equation published by Shell was based on mean laboratory life. A shift factor of at least 10 should have been applied to convert to field life, but in the thicker layer high temperature situation applicable to Australian foamed bitumen pavements, a shift factor of up to 20 is more applicable(Claessen, Edwards et al. 1977).

The 2004 Austroads Pavement Design Guide includes both reliability factor, and a shift factor, in the reliability factor for asphalt pavements. The mean expected field life would be 10 to 20 times the mean fatigue life predicted by accelerated laboratory testing, but in the 2004 Guide, the reliability factor for a 95% confidence, which includes as mentioned the shift factor, brings this back to unity.

Given the size of the aggregate and associated stress concentrations when cut to a such a small size as in the beam fatigue test, in the case of foamed bitumen pavements, the best fit curve of Figure 2 is considered to be sufficiently conservative to use as a design model, allowing no shift factor for the conservative nature of the test regime.

The MS EXCEL generated equation of best fit of both individual test beams and triplicate mean analysis (black points and line) and a 95th percentile design equations (red line) is shown in Figure 2. Also shown are the points that would be generated by each of the beams if the modulus and bitumen volume were entered into the asphalt fatigue equation (blue line).

3 TEST RESULTS

3.1 Resilient Modulus

Cores were extracted from pavements and tested for resilient modulus. Where possible, cores were tested at 0-100 mm depth, 100-200 mm depth and 200-300 mm depth. Testing was undertaken in accordance with AS2891.13.1(Standard Australia 1995) Methods of sampling and testing asphalt Method 13.1 Determination of the resilient modulus of asphalt. Testing was undertaken at a range of temperatures and rise times and the results are shown in Table 1.

This testing clearly shows that the stabilised material is very stiff, bound and that there is a distinct density (and hence modulus) profile within the stabilised pavement structure. It also shows that there is a great variation in modulus within pavements. All of the pavements considered in this analysis are of similar makeup, that is, a mixture of asphalt, crushed roadbase and limestone.

Table 1: Resilient modulus test results

Depth from Surface			0-100		100-200	200+
Temp ^{0}C	Rise Time	Mean Modulus (MPa)	Standard Deviation	90th Percentile Value	%age of Top Layer Modulus	%age of Top Layer Modulus
20	25	10562	4262	5525	80.60%	51.50%
	50	9540	3893	4903		
	100	8519	3542	4406		
25	25	9544	3737	5454	74.40%	53.70%
	50	8505	3476	4453		
	100	7465	3271	3740		
30	25	7656	3508	3852	75.00%	50.20%
	50	6710	3064	3266		
	100	5764	2659	2623		
35	25	9403	3598	6064	97.70%	25.50%
	50	8208	3322	5118		
	100	6945	3121	4086		

3.2 Flexural modulus

Flexural modulus was obtained as a result of the fatigue beam testing. The results are summarised in Table 2. These results indicate that flexural modulus which is used in the design input, is approximately 60% of the resilient modulus. Based on this research, the modulus values shown in Table 3 have been adopted for design purposes of all pavements composed of crushed granular materials.

Table 2: Flexural modulus

Details	All results	
	Mean Modulus (MPa)	95th %ile Modulus (MPa)
Granular Pavements all temperatures	6494	2618
Granular Pavements at 20^{0}C	6459	2608

Table 3: Adopted flexural modulus for designs

Depth below stabilised surface	Design Modulus
0 – 100mm	4300MPa
100 – 200mm	3600MPa
>200mm	2600MPa

3.3 Deflection tests

FWD testing was undertaken on pavements both immediately after construction and in following years. Table 4 shows typical results of FWD testing undertaken in 2009 at age 10 years. These results show very stiff pavements and there has been little change in the deflection and curvature values since around 6 months after construction.

4 CONCLUSION

Based on the research undertaken in WA, the following generalized observations are provided:

- Insitu foamed bitumen stabilisation provides an effective method for pavement rehabilitation.

- The asphalt fatigue equation is not considered applicable to the design of foamed bitumen stabilised pavements.
- The variability in flexural and resilient modulus on cores extracted from the pavement would indicate that there may be little value in attempting to characterise materials in the laboratory when data is available from pavements stabilised in the past using the same materials.
- There is a distinct compaction profile with significant modulus reduction with depth, and as such, a foam bitumen pavement should be modeled in three layers of decreasing stiffness.
- The fatigue equation developed in this research is based on the testing of small cross section beams, and may be conservative.
- A shift factor to account for accelerated loading may be applicable to insitu foamed bitumen pavements has been adopted in the recommended equation.

The conclusions are a vital part of the paper and should state concisely the most important outcomes of the paper as well as the author's views of the practical implications of the results.

Table 4: Results of FWD testing in 2009

Pavement Section	Construction Year	Mean Deflection (mm)	Mean Curvature (mm)
Bannister – Magnet to Baile	1999	0.17	0.03
Bannister – Forum to Hodges	1999	0.14	0.01
Vulcan – Magnet to Coulson	1999	0.21	0.01
High – Willeri to Meadowbrook	1999	0.21	0.02
Nicholson – Metcalf to Bridge	1999	0.13	0.01
Nicholson – Bridge to Woodloes	1999	0.14	0.02
Railway – Radium to John	1999	0.20	0.02

5 RECOMMENDATIONS FOR FUTHER RESEARCH

Curtin University has commissioned a large beam tester to enable fatigue testing of beams 150 mm deep, 250 mm wide and 1 m long. This will be used to test larger beams extracted from completed pavement sections in order to develop a more reliable assessment of fatigue performance of stabilised pavement materials that will be less subject to stress concentrations at larger aggregate particles.

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