FATIGUE AND RUTTING PERFORMANCE OF CONVENTIONAL ASPHALT AND BITUMEN-RUBBER ASPHALT UNDER ACCELERATED TRAFFICKING

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Abstract

The Californian Department of Transportation commissioned a pilot project to evaluate the potential of the Heavy Vehicle Simulator (HVS) for conducting pavement studies. The effect of channelisation of traffic on the rutting behaviour of a continuously-graded asphalt overlay was investigated. Secondly, the cracking behaviour of a 75 mm thick continuously-graded overlay was compared with that of a 38 mm thick bitumen-rubber asphalt overlay. A laboratory evaluation of the materials was conducted by the University of California at Berkeley. The channelisation of traffic resulted in a 100 % increase in the surface rut rate compared with that under normal wandering traffic. A reduction of 50 % in layer thickness is justified to obtain similar resistance to cracking if conventional asphalt is replaced with bitumen-rubber asphalt.

1 INTRODUCTION

Accelerated pavement testing (APT) is conducted in a number of countries either by using stationary test equipment for the testing of trial sections or mobile units that can be used on in-service roads. South Africa's fleet of three Heavy Vehicle Simulators (HVSs) has been used to investigate pavement behaviour and performance over the last 20 years (Horak, 1). This work provided the foundation for the current state-of-the-art of new pavement design and pavement rehabilitation design in South Africa. The HVS has also been used to evaluate new technologies prior to their use on South African roads.

In April 1993, CALTRANS commissioned the University of California at Berkeley (UCB), Dynatest Consulting and the CSIR to conduct a pilot study to evaluate the potential of the HVS for conducting pavement studies for CALTRANS. The project included both HVS testing of field trials (conducted in South Africa) as well as a laboratory evaluation of field samples of the materials (conducted at UCB). The HVS was used to conduct a total of five tests to evaluate the behaviour of a continuously-graded asphalt with a conventional binder and a semi-open graded bitumen-rubber asphalt under accelerated trafficking. In the first two HVS tests, the conventional mix was evaluated at elevated and ambient temperatures for rutting under both normal wandering traffic as well as channelised traffic. In the second series of tests, the fatigue performance of the conventional mix was compared with that of the bitumen-rubber asphalt at controlled temperatures. For this purpose a special temperature control chamber was developed for the HVS. This device was used to control the road surface temperature of the test sections at 10 °C. In one instance, at the end of a test, the road surface temperature was reduced to -5 °C. Both the continuously-graded and bitumen-rubber mixes fall within the specifications of materials generally used in South Africa and the results of this work is therefore applicable in this region.

This paper discusses the results of the HVS testing. Due to the fact that the scope of the work for this pilot project was limited, suggestions are made regarding enhanced analysis of the data obtained from this work.

2. OBJECTIVES AND SCOPE OF THE STUDY

Apart from the general aim to evaluate the applicability of the HVS to conduct work for CALTRANS, this pilot study addressed two issues important to CALTRANS through the following specific objectives :

Objective I : Comparison of the rutting of a dense-graded asphalt mix under wandering traffic with its behaviour under channelised traffic

One of the pavement-related concerns regarding the implementation of Intelligent Vehicle Highway Systems (IVHS), is that traffic loading will be more channelised on IVHS roadways than is currently the case under normal traffic. This will affect the rate of rut development, which may affect IVHS vehicle pavement sensor interaction. A preliminary evaluation of the effect of traffic channelisation on rut development was carried out with the HVS system on a typical CALTRANS pavement section. To simulate channelised traffic, the loading beam of the HVS was fixed in one position, thus preventing any sideways movement during trafficking. During wandering traffic, the HVS is used in its usual mode resulting in a traffic pattern with a normal distribution.

Objective II : Comparison of the fatigue performance of a 38 mm open-graded bitumen-rubber asphalt under accelerated traffic with that of a 75 mm conventional dense-graded asphalt mix

CALTRANS has published a guideline allowing the use of reduced thickness of bitumen-rubber asphalt overlays in lieu of conventional mix overlays, based primarily on the Ravendale (Doty, 2) field test results. HVS testing in which the fatigue performance of a 38 mm open-graded bitumen-rubber asphalt overlay was compared with that of a 75 mm conventional overlay was conducted to verify the Ravendale results. In this case the traffic pattern followed a normal distribution.

In addition to the HVS testing, laboratory evaluations of the mixes used in the HVS test sections were conducted at the University of California at Berkeley (UCB).

3 DESIGN AND CONSTRUCTION OF TRIAL SECTIONS

3.1 Objectives and pavement selection

To address the stated objectives above, six trial overlays were constructed on the P6/1 from Bapsfontein to Bronkhorstspruit near Pretoria. The overlays were constructed using materials and mix design procedures conforming to CALTRANS specifications. The following sections were constructed :

- **Channelised vs wandering traffic**
  A 100 mm overlay was constructed on two adjacent 40 m long sections on an existing pavement with a granular base. These were used for evaluating the effect of wandering vs channelised traffic on the rutting behaviour of the conventional mix overlay.

- **Fatigue performance on the bitumen-rubber asphalt compared with the conventional mix overlay**
  The target surface deflection (80th percentile) for this experiment was 1,25 mm under a 40 kN wheel load on the existing pavement prior to overlaying. Based on the CALTRANS TM356 overlay design procedure, (Rust et al, 3) and for a TI equal to 7, this would call for a 75 mm overlay of asphaltic concrete. The "equivalent" bitumen-rubber asphalt overlay would be 38 mm thick. Two other bitumen-rubber asphalt overlays of 25 mm and 50 mm respectively, were constructed for additional testing, should the 38 mm layer last for either a longer or shorter period than anticipated.

A prerequisite was that the pavement should contain no cemented materials. Using both the Pavement Management System of the Transvaal Provincial Administration and Deflectograph surveys, road P6/1 was selected. The pavement structure prior to overlaying is shown in Figure 1. The condition of the pavement (1993) prior to overlaying was remarkably similar to the end condition of failure predicted by the HVS 14 years ago (Rust et al, 3, Maree, 4). The HVS tests conducted are summarized in Table 1.

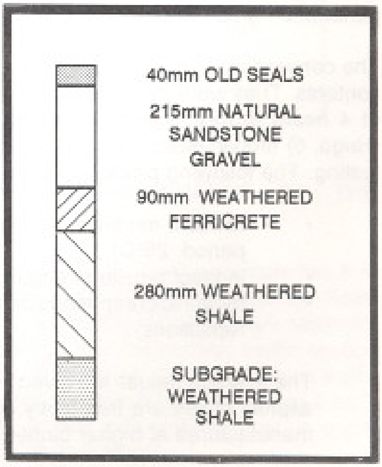

Figure 1: Pavement Profile on P6/1

3.3 Mix designs

The mix designs for the conventional and bitumen-rubber asphalt mixes were based on the Hveem method for determination of the optimum binder content. The aggregates and binders actually used in the project were used in the mix design. The target gradings, operating ranges and design binder contents specified for the project are given in Table 2. The coarse aggregate and crusher sand fractions consisted of Reef Quartzite. Small amounts of natural sand and mine sand were required to increase the fines and filler contents of the conventional mixes. The CALTRANS grading for the bitumen-rubber asphalt (US : Asphalt-Rubber Hot Mix Gap Graded) falls within the envelope of the South African BROG (Bitumen-Rubber Open-Graded). The conventional mix is very similar to a TPA medium continuously graded mix.

Table 1 : Summary of HVS tests conducted for CALTRANS

Section number	Overlay type	Type of traffic	Wheel load (kN)	Test temperature (°C)
379A3	100 mm conv.	Channelised	70/100	25/40
380A3	100 mm conv.	Wandering	70/100	25/40
381A3	75 mm conv.	Wandering	40/80	10
382A3	38mm b/r	Wandering	40/80	10/-5
383A3	25mm b/r	Wandering	40/80	10

The bitumen-rubber asphalt mixes were constructed with Arm-R-Shield^{TM} as binder. The asphalt rubber blend consisted of approximately 78% 80/100 penetration grade asphalt binder, 20% recycled rubber (of which 30% was natural rubber) and 2% extender oil. The conventional mix was manufactured with unmodified 60/70 penetration grade asphalt binder.

The conventional and bitumen-rubber asphalt mixes were blended at optimum binder contents. They were then conditioned by short term oven ageing (STOA) for a period of 4 hours at mixing temperature and compacted by means of the Hugo hammer (Hugo, 5) (impact-kneading compaction), after which they were subjected to dynamic testing. The following properties were determined on 100 mm diameter briquettes :

- resilient modulus (10 Hz haversine loading frequency, 0,9 seconds rest period, 25°C);
- indirect tensile strength (50 mm/minute, 25°C), and
- dynamic creep modulus (0,5 Hz square wave, 100 kPa, 40°C, 3,600 load repetitions).

The average results are given in Table 3. It should be noted that bitumen-rubber asphalt mixes are frequently used in South Africa but that they are generally manufactured at higher binder contents (up to 7 % by mass of total mix).

Table 2 : Target gradings and binder contents

Sieve Size (mm)	bitumen-rubber asphalt		conventional mix	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
19,0	100	100	95	100
13,2	90	100		
9,5	78	88	65	80
4,75	31	41	47	57
2,36	17	25	33	43
0,600	6	14	15	25
0,075	2	7	3	8
% binder/total mass	5,5	5,8	4,5	4,8

TABLE 3 : Average results of dynamic tests

Property	bitumen-rubber asphalt	conventional mix
Resilient Modulus (MPa)	1 509	2 747
Indirect tensile strength (kPa)	727	1 508
Dynamic creep modulus (MPa)	11,5	13,1

4 HVS EVALUATION OF THE RUTTING PERFORMANCE OF THE CONVENTIONAL MIX

Within the 80 m length of the 100 mm thick conventional mix overlay section, two 8 m sections were selected based on surface deflection data (measured with the Road Surface Deflectometer). The surface deflections at these two locations were relatively uniform and comparable. The average deflection on the channelised traffic section was 0,920 mm with a standard deviation of 0,037. In the case of the wandering traffic section, the average deflection was 0,885 mm with a standard deviation of 0,027. During the HVS testing the rut progression, temperature, surface deflections, in-depth deflections and in-depth permanent deformations were recorded.

During trafficking, the target surface temperatures were 40 °C for one half of the section and 25 °C for the other half. The temperatures were kept relatively constant by heating the surface with heavy duty heaters. The measured surface temperatures varied from 38,2 to 39,9 on the heated part of the sections and from 22,7 to 24,1 on the unheated parts.

4.1 Surface rutting

Both the sections rutted at a slower rate than was expected (based on results from limited laboratory tests), possibly owing to the flexibility of the support layers. Transverse profiles of the surface rutting of the two sections in their respective end states are shown in Figure 2. The effect of the channelization of the traffic is clear. The progression of maximum rut on the two sections are shown in Figure 3. It is clear that temperature had a significant effect on rutting. The increase to 100 kN caused a minor secondary settling in of the sections after which the rutting remained relatively constant.

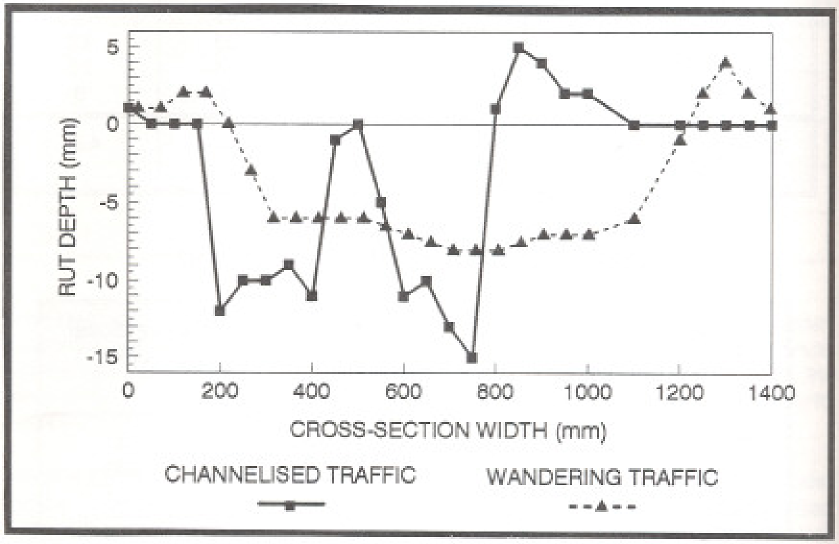

Figure 2: Rut profiles after 164 000 repetitions for the channelised and wandering traffic sections

The maximum rut depth on the channelised section after 150 000 repetitions was approximately double that of the wandering traffic section at the same stage. The rutting behaviour observed on both sections can be divided into three phases :

- Phase I : A "settling in" phase at the 70 kN wheel load during which significant rutting takes place over a relatively short period of time.
- Phase II : A phase during which the rutting takes place at a more constant rate under the 70 kN wheel load.
- Phase III : The final phase where the wheel load was increased to 100 kN.

The rut rates (mm per 100 000 repetitions) as well as the total rut per phase, calculated from these results, are shown in Table 4. These results clearly indicate that the rutting took place mainly during the "settling in" phase after which the rut rate decreased. This behaviour is often observed with HVS tests. Usually a secondary "settling in" phase will be observed when the temperature or the wheel load is increased during a test. This is then usually followed by another "flattening off" of the rut curve.

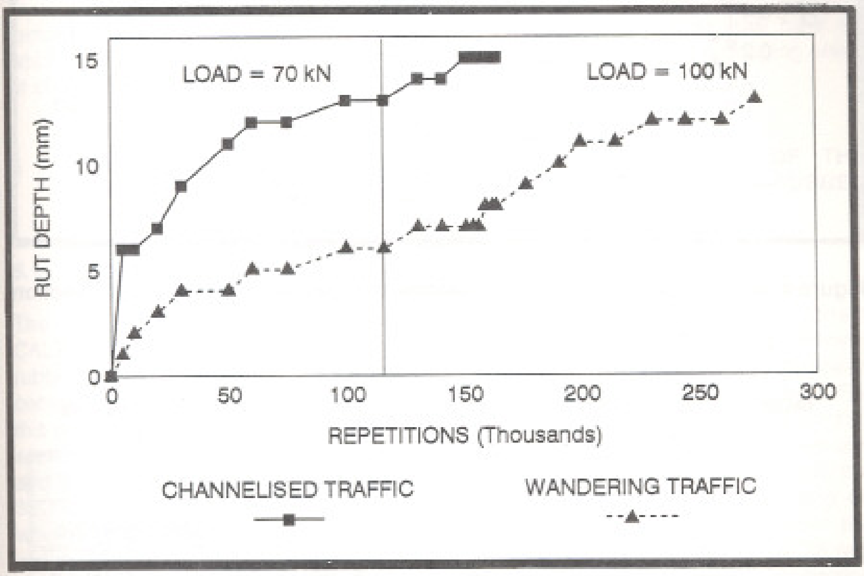

Figure 3: Progress of rutting on the channelised and wandering traffic sections

4.2 Deflections and moduli

The surface deflections measured with the RSD increased during the testing by approximately 25 % and were relatively high at the end of both tests - ranging between 1,0 mm and 1,4 mm for a 40 kN wheel load. The MDDs installed in each section were used to calculate the elastic deformations in each layer at various stages during the tests. Typical changes in in-depth elastic deflections for the channelised and wandering traffic sections are shown in Figure 4.

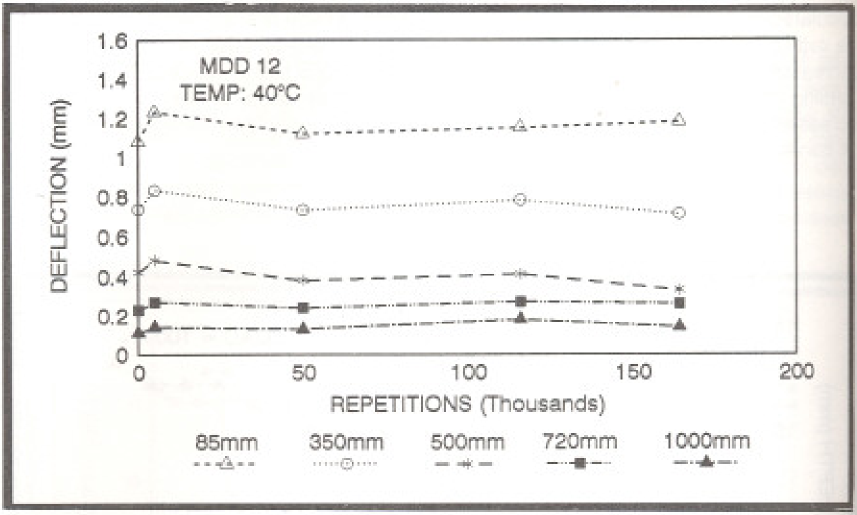

Figure 4: Multi-depth deflection measurements on the channelised traffic section

Table 4 : Rut rates per 100 000 repetitions and total rutting per phase

		Rut rate and total rut (mm)			
		Channelised traffic		Wandering traffic	
	Phase	Rate*	Total rut	Rate	Total rut
Ambient temp.	Ph I : 70	20,0	3,0	9,86	2,0
	Ph II : 70	1,02	1,0	1,05	1,0
	Ph I and II	3,43	4,0	2,58	3,0
	Ph III : 100	4,06	2,0	2,5	4,0
Elevated temp.	Ph I : 70	59,56	6,7	20,42	6,0
	Ph II : 70	6,27	6,2	1,17	1,0
	Ph I and II	11,14	13,0	6,03	7,0
	Ph III : 100	4,1	2,0	3,76	6,0

* Rut Rate in mm per 100 000 repetitions

4.3 Comparison of results with other HVS tests in the HVS database

To place the work conducted in this project in perspective, the results were compared with some information from the HVS database. Table 5 contains a summary of the **surface rutting rate** in pavements consisting of asphalt bases with cemented subbases obtained from a number of HVS tests. The previous tests conducted at 70 kN or 80 kN at ambient and elevated temperatures (marked * in Table 5) showed rut rates between 0,74 and 1,15 mm per 100 000 repetitions. This compares well with the results obtained from the wandering traffic section (1,05 to 1,17 mm per 100 000 repetitions). However, the combination of channelised traffic and elevated temperature resulted in a rut rate of 6,27 mm per 100 000 repetitions (see Table 5), which is significantly higher than the above. This is indicative of the damaging effect of channelised traffic compared with normal wandering traffic.

5 HVS EVALUATION OF THE CRACKING PERFORMANCE OF THE CONVENTIONAL MIX OVERLAY COMPARED WITH THE BITUMEN-RUBBER ASPHALT OVERLAYS

5.1 Trial sections

The main objective of the second part of the project was to verify the current CALTRANS policy which states that for a road with a specific deflection, a bitumen-rubber asphalt overlay of half thickness can be used instead of a full thickness conventional mix overlay for similar overlay performance (in terms of cracking). For this purpose, four trial sections were constructed: a 75 mm conventional mix overlay section and three bitumen-rubber asphalt overlay sections of thickness 50 mm, 38 mm and 25 mm. The testing was scheduled to allow the conventional mix overlay and the 38 mm bitumen-rubber asphalt overlay to be tested first and then, depending on whether the 38 mm bitumen-rubber asphalt overlay cracked before or after the conventional mix overlay, the subsequent testing of either the 50 mm or the 25 mm bitumen-rubber asphalt overlay. A section of road with an 80th percentile deflection of around 1,2 mm was selected on the P6/1 Bapsfontein to Bronkhorstspruit. Using the CALTRANS TM356 overlay design procedure, the life of the sections to cracking was predicted (Rust et al, 3). The average RSD deflection measured over the 40 m, 75mm conventional mix overlay section was 1,208 mm with a standard deviation of 0,146 mm. The predicted number of E80s (equivalent axle loads) to failure in cracking was 172 000.

5.2 Work procedure

All three sections were trafficked in exactly the same way. A 40 kN dual wheel load was used up to the predicted life of the overlay (175 000 repetitions) after which it was increased to 80 kN. The temperature was initially controlled at 10 °C, but lowered to -5°C at the end of the testing of the 38 mm bitumen-rubber asphalt overlay in order to induce cracking.

Table 5 : Typical surface rutting rates in asphalt base pavements tested with the HVS

Test	Temperature Conditions	Load (kN)	Grading	Rut rate (mm/100 000 reps)
201A3	ambient	80	semi-gap	1,23
162A3	ambient	80	semi-gap	0,66
343A3	ambient 40°C ambient 40°C	40 40 100 100	semi-gap	0,33 0,96 2,97 14,55
223A3	ambient	100	continuous	2,71
224A3	ambient ambient	40 150	continuous	0,65 82,44
215A3	ambient	100	continuous	2,26
217A3	ambient	100	continuous	2,06
233A3	ambient 40-50°C	70 100	continuous	0,74 * 32,69
234A3	ambient	70	continuous	1,04 *
235A3	ambient	40	continuous	0,22
183A3	40-50°C	80	continuous	1,11 *
193A3	ambient	40	semi-gap	2,29
140A3	40-50°C	40	semi-gap	3,48
367A3	20 °C	100	semi-gap	3,75
368A3	20 °C	100	semi-open	0,754
369A3	20 °C	100	continuous	0,868
370A3	30 °C	40	continuous	0,1
370A3	50 °C	40	continuous	0,4
379A3	25 °C	70**	continuous	1,02
379A3	40 °C	70**	continuous	6,27
380A3	25 °C	70	continuous	1,05
380A3	40 °C	70	continuous	1,17

** Channelised traffic

To control the temperature during HVS testing, a temperature control chamber was specially designed and constructed for this project. The chamber is shown in Figure 5. The roof is fixed to the frame of the HVS and two air conditioning units are suspended from it. The sides and ends of the chamber (consisting of the same insulation material as the roof) are fitted in such a way that they can be easily removed. With the sides and ends of the chamber removed, the HVS can be moved for short distances without having to remove the remaining equipment. At each end, a special sliding panel is fixed to the moving beam of the HVS allowing effective temperature control while the HVS is used in the wandering traffic mode (see Figure 5).

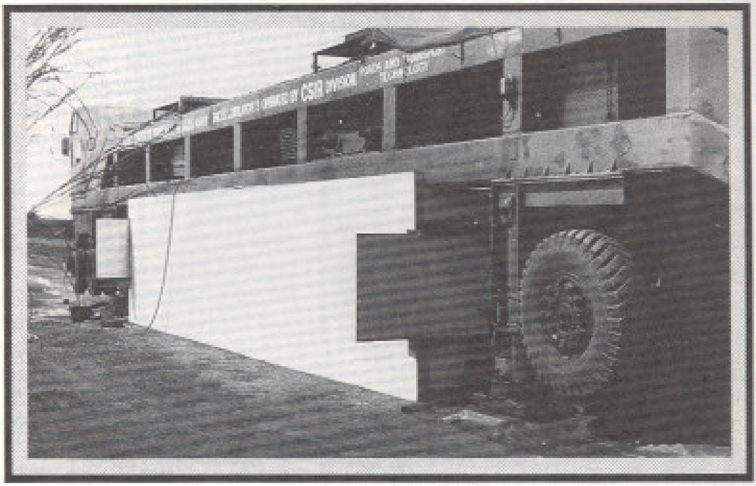

Figure 5: Temperature control chamber installed on the HVS

During the experiments it was found that the temperature could be controlled at 10 °C with ease. At the end of the testing of the 38 mm bitumen-rubber asphalt overlay, the temperature was lowered to -5°C. During this stage, the air temperature in the chamber reached a minimum of -26 °C.

5.3 Cracking performance of the sections

The 75 mm conventional mix overlay started to show hairline cracking after 100 000 repetitions. After 175 000 repetitions it showed substantial cracking. The wheel load was then increased to 80 kN for a short period of time. The final state of the cracking on the test section is shown in Figure 6.

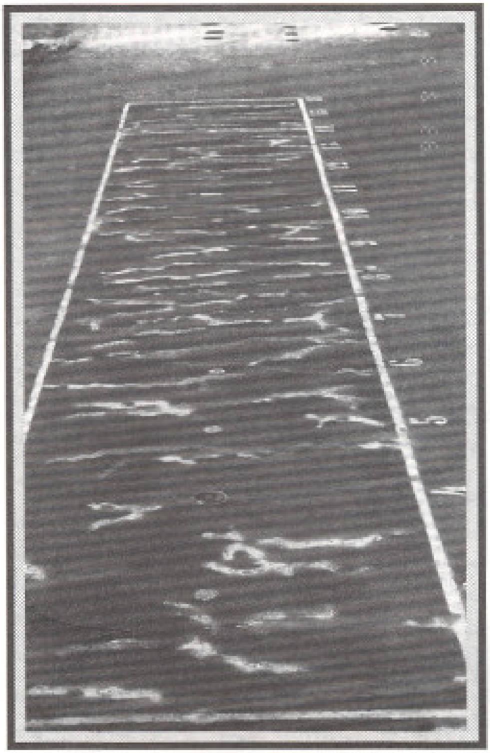

Figure 6: End state - conventional overlay

The same pattern of loading was followed in the case of the 38 mm bitumen-rubber asphalt overlay. However, after 175 000 repetitions no cracking could be observed. The wheel load was then increased from 40 kN to 80 kN up to 237 000 repetitions. Still no cracking occurred. At this point the temperature control of the chamber was set at its minimum. At the end of the test one half of the test section was cracked as can be seen in Figure 7. The road surface temperature at the end of the test was -5°C.

Due to the fact that the 38 mm bitumen-rubber asphalt overlay lasted longer than predicted, the 25 mm bitumen-rubber asphalt overlay section was subsequently tested. Once again no cracking was observed after 175 000 repetitions. The wheel load was then increased to 80 kN. After 237 000 repetitions, the test section had cracked without the temperature having been reduced. At the end of testing the 25 mm bitumen-rubber asphalt overlay it was completely cracked. For the purposes of this pilot study, failure due to cracking was not defined in terms of percentage cracking. Crack progression was simply visually observed and noted qualitatively.

This result indicates that a reduction of at least 50 % in layer thickness to obtain similar performance in fatigue mode is justified if conventional mix is replaced with bitumen-rubber asphalt. However, the reduction in structural capacity (protection of the underlying layers) due to the reduction in layer thickness should be taken cognisance of. The results obtained are given in Table 6 below.

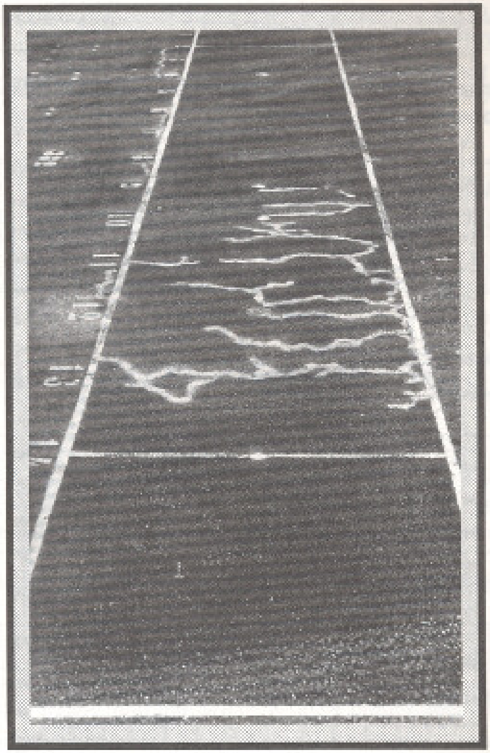

Figure 7: End state - bitumen rubber overlay

5.6 Rutting and deflection behaviour

As the tests were conducted at low temperatures, surface rutting was not expected to be of major importance. The conventional mix overlay section showed virtually no surface rutting (2 mm of rut at the end of the test). This is to be expected as the conventional mix layer was relatively stiff at 10 °C, thus providing a higher resistance to deformation and also, on account of its thickness, improved protection to the underlying layers. The surface rutting at the end of the predicted life of the bitumen-rubber overlays was less than 5 mm.

A typical result of in-depth deformations recorded with the MDD on the conventional overlay is shown in Figure 8. In this case, very little permanent deformation was observed (as expected). In the case of both the 38 mm and the 25 mm bitumen-rubber asphalt overlay sections, some deformation took place in both subbase layers and the bitumen-rubber asphalt layer. The increase in wheel load to 80 kN had a noticeable effect on the permanent deformation of the subbase layers. This behaviour was not observed in the case of the conventional mix layer - once again indicating that the higher stiffness of the conventional mix layer and its thickness provided protection to the underlying layers.

Table 6 : Cracking life of the 75 mm conventional mix overlay and the bitumen-rubber asphalt overlays

Repetitions	Wheel Load	conv. mix (75mm)	bitumen-rubber asphalt (38 mm)	25 mm bitumen-rubber asphalt
0 to 100 000	40 kN	Fine cracks at 100 000	-*	-
100 000 to 175 000	40 kN	Block cracks at 175 000	-	-
Wheel load changed to 80 kN				
175 000 to 200 000	80 kN	Completely cracked	-	Fine cracks
200 000 to 237 000	80 kN	Test stopped	-	Completely cracked
Surface temperature reduced to -5 °C				
237 000 to 250 000	80 kN	Test stopped	One half of section cracked	test stopped

* - indicates no visible cracking

In the case of the conventional mix overlay, the surface deflection increased gradually from 0,75 mm to 1,30 mm. In the case of the 38 mm bitumen-rubber asphalt overlay, the surface deflection increased from 1,4 mm to 1,7 mm during trafficking with the 40 kN wheel load. The change in wheel load from 40 kN to 80 kN had a significant effect on the rate of change of surface deflection and at the end, the surface deflection recorded was 2,6 mm.

In the case of the 38 mm bitumen-rubber asphalt overlay section, the in-depth deflections at the bottom of the overlay were significantly higher at MDD12 than at MDD4 (2,7 mm vs 1,4 mm). It is important to note from the photograph in Figure 7 that this section cracked only in the half of the section where MDD12 was installed.

6 LABORATORY TESTING OF MATERIALS

As part of the project the materials were tested at the University of California at Berkeley according to some of the latest SHRP (Strategic Highway Research Programme) procedures. The following special tests were conducted :

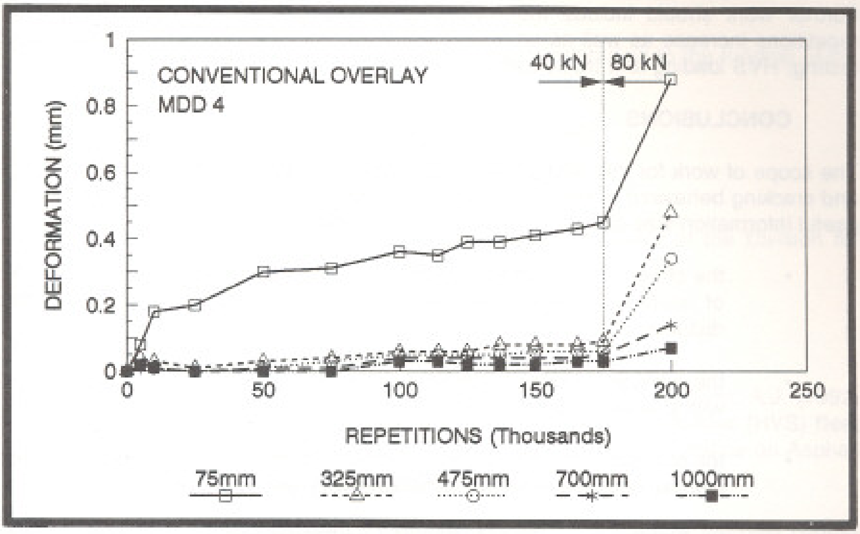

Figure 8: Multi-depth permanent deformation - conventional overlay

- the SHRP A-003A repetitive simple shear test at constant height to evaluate the materials' resistance to deformation
- fatigue testing with the SHRP A-003A beam fatigue test
- stiffness (beam test)
- the effect of long-term oven ageing on the shear modulus and phase angle

A comparison of the permanent deformation resistance of the two field mixes showed that the bitumen-rubber mix was less resistant to deformation than the conventional mix (at 20 C). The same result was obtained when the mix was compacted to 10 % voids in the laboratory. However, when compacted to 5 % voids, the mix showed deformation resistance similar to that of the conventional mix. This corresponds with the dynamic creep moduli measured (see Table 3).

A comparison of the laboratory-developed fatigue life vs strain relations indicated that the bitumen-rubber mix had a longer fatigue life than the conventional mix for the same strain levels which corresponds with what was found under the HVS. However, predictions of field fatigue life using the same strain/fatigue relations and elastic layer theory, indicated that the conventional mix would have a longer fatigue life under 40 kN loading than the bitumen-rubber overlay with the opposite under a 80 kN wheel load (using a 20 °C fatigue/strain relation). This indicates possible limitations in the process of predicting fatigue life using linear elastic theory. Furthermore, some of the cracking may have been caused by reflection of the crack pattern in the underlying old surfacing.

Further work should include the modelling of changes in mix stiffness as load repetitions increase as well as an investigation into shift factors between laboratory testing, HVS loading and traffic loading.

7 CONCLUSIONS

The scope of work for this pilot project was limited and focused mainly on the rutting and cracking behaviour of the two materials. However, in spite of the limitations very useful information was obtained. It can be concluded that :

- the channelization of traffic caused an approximate doubling of the rate of surface rutting compared with a traffic pattern with a normal distribution;
- the surface rut rates measured under wandering traffic compared well with previous results obtained with the HVS;
- the calculated life to cracking failure according to the CALTRANS TM356 overlay design procedure correlated very well with the HVS result;
- the half-thickness (38 mm) bitumen-rubber asphalt layer performed better (in terms of cracking) than the life calculated according to TM 356 - probably due to the relatively low stiffness of the material as placed in the field;
- the reduction of 50 % in the layer thickness when replacing conventional asphalt with bitumen-rubber asphalt seems to be justified;
- although the laboratory testing by UCB indicated results similar to that obtained with the HVS, further work needs to be done to investigate relationship between HVS testing and the SHRP laboratory test procedures, and
- this pilot project has shown that HVS technology can be used effectively to conduct pavement behaviour and performance studies for CALTRANS.

Usually analysis of the data acquired during HVS testing is done in more detail and additional work on comparisons of the results with previous HVS tests and further structural analysis of the pavement at various stages of HVS testing will enhance the findings.

Certain aspects were not investigated during the HVS testing in this pilot project, and future work could once again enhance the result significantly. This could include the effect of ageing of both the materials; the effect of the stiffness of the support layers and the effect of the test temperature on the HVS test results.

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