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# HEAVY VEHICLE SIMULATOR AIDED EVALUATION OF OVERLAYS ON PAVEMENTS WITH ACTIVE CRACKS

A W Viljoen*, C R Freeme**, V P Servas*** and F C Rust*

## ABSTRACT

Conventional overlay life estimates are often invalidated by the reflection of existing cracks in a pavement through an overlay. This is attributable to a lack of understanding of the factors influencing relative crack movements and their mechanisms. Inadequate knowledge of the ability of overlay techniques to tolerate induced strains originating from the discontinuities in the existing overlay pavement also contribute to the problem.

This paper identifies the factors and mechanisms and illustrates their effects by means of field data from actual pavements. The South African Heavy Vehicle Simulator was also used to evaluate a variety of conventional and innovative asphaltic overlays on a severely cracked concrete pavement of which the mechanisms and extent of relative crack and joint movements were determined prior to overlay placement. The results of this testing programme are discussed with special emphasis on the ability of the overlays to inhibit reflection cracking.

It is believed that the improved knowledge of the parameters involved in reflection cracking will contribute to more realistic prediction models and result in more cost effective rehabilitation strategies.

## INTRODUCTION

Asphalt overlays are often used to rehabilitate flexible and rigid pavements. However, conventional overlay life estimates are often invalidated by the reflection of existing cracks through the overlay. The reflection of cracks generally occurs rapidly and can lead to other forms of early distress such as pumping which in turn can cause deformation and/or pot-holing. In many countries, including the USA and South Africa, special materials such as bitumen-rubber, geofabric interlayers and low-viscosity asphalt have been used in attempts to solve this problem. The results of such experiments have been inconclusive(1), indicating that reflection cracking could not always be successfully inhibited. This emphasizes the fact that the mechanisms of crack movement and the means of inhibiting the movement are not as yet fully understood.

In recent years the main thrust of the Heavy Vehicle Simulator (HVS) program in South Africa(2) has been increasingly directed at aspects related to pavement rehabilitation. At present, special emphasis is being placed on the understanding of the mechanisms and extent of load-associated crack and joint movements. A new instrument, the Crack Activity Meter (CAM), which fits between the dual tyres of a truck was developed to accurately measure differential crack and joint movements under various wheel loads(3).

Differential movement at discontinuities in the road surface is being studied in conjunction with other pavement parameters such as deflection curvature as well as material type and state. The aim of this paper is to show how these investigations resulted in an improved understanding of the mechanisms of load-associated crack movements.

A number of full-scale experimental overlays have been constructed on distressed pavements of which the extent and mechanisms of crack movement were determined prior to the placement of the overlays. These conventional and modified asphalt overlays are being monitored to establish their long-term ability to inhibit reflection cracking as a function of traffic and environmental variables. Because of the urgent need for knowledge of the behaviour of innovative rehabilitation measures, the Heavy Vehicle Simulator (HVS) has also been used to evaluate some of these overlays. The latter section of this paper deals with the results obtained from an extensive series of HVS tests conducted on experimental overlays placed on severly cracked concrete pavement. The trial sections included overlays of conventional asphalt of varying thickness, conventional asphalt with stress-absorbing interlayers such as bitumen-rubber and geofabric interlayers, rubber-modified asphalt and Portland cement concrete (jointed and reinforced) with asphalt bond-breaking layers. This experiment is unique in the sense that it allows for the direct comparison of a variety of overlay techniques on a pavement with well-defined relative crack and joint movement mechanisms.

## TRAFFIC-LOAD-ASSOCIATED CRACK MOVEMENTS

### The Crack-Activity Meter (CAM)(3)

The CAM was developed to measure the relative movements of cracks or joints in a road caused by moving wheel loads. It consists of two linear variable differential transformers (LVDTs), one of which is positioned vertically and one horizontally. During measurements, the instrument which is shown in Figure 1(a) is fixed to the road surface with quicksetting epoxy.

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* Research Engineer, National Institute for Transport and Road Research (NITRR)
** Head, Pavement Engineering Group, NITRR
*** Assistant Head, Maintenance and Construction Group, NITRR

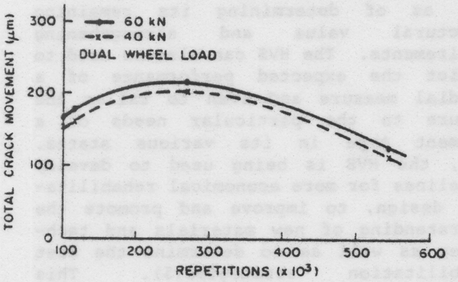

FIGURE 3

*CHANGE IN TOTAL CRACK MOVEMENT DURING HVS TESTING ON A CRACKED FLEXIBLE PAVEMENT*

Figure 4 is a graph of the crack movement plotted against the size of the blocks between cracks. It can be noted that the crack movement increased markedly when the block size became smaller than 1,0 m. Furthermore, there seems to be a critical block size at which the crack movement reached a maximum. Further deterioration of the blocks lead to a subsequent decrease in the crack movement. It is believed that the critical block size is dependent on the pavement structure and thickness of the layer under consideration.

From the above discussions, it is clear that the crack movements on a given road can be correlated with pavement structure, surface deflection, shape of the deflection bowl (radius of curvature) as well as with block size.

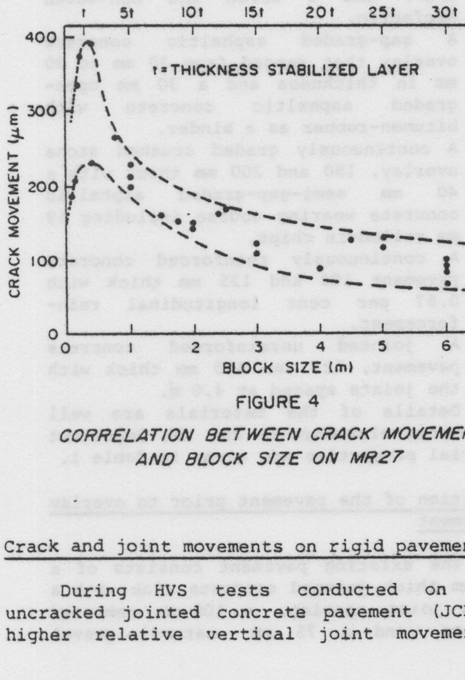

FIGURE 4

*CORRELATION BETWEEN CRACK MOVEMENT AND BLOCK SIZE ON MR27*

Crack and joint movements on rigid pavements

During HVS tests conducted on an uncracked jointed concrete pavement (JCP), higher relative vertical joint movements were obtained in the order of two times the horizontal movements. This was mainly due to the presence of a small void directly below the concrete slab in the vicinity of the joint. On a thin JCP (thickness ± 150 mm) this normally leads to early fatigue resulting in D-cracking close to the joint. On a thicker JCP (thickness ± 230 mm) the concrete layer can carry a substantial number of load applications (often more than 1 million applications of a 100 kN dual wheel load) before cracking occurs even with a void below the slab. High relative vertical joint movements (up to 1 mm under a 40 kN dual wheel load) were recorded on a 230 mm thick JCP with relatively weak supporting layers. Some 40 per cent of the relative joint movement could be attributed to the rocking of the whole slab. An extensively cracked JCP, however, acts more like a flexible pavement with higher relative horizontal than vertical movement.

The mechanism of crack movement on a continuously reinforced concrete pavement (CRCP) is mainly one of hinging of the blocks (defined by the shrinkage cracks) on the reinforcing steel which results in almost no vertical movement and very low horizontal movement if the pavement is well-supported. Therefore, few problems related to relative crack movement can be expected on a CRCP. Figure 5 compares the crack-movement behaviour during HVS testing of various concrete pavements under varying conditions.

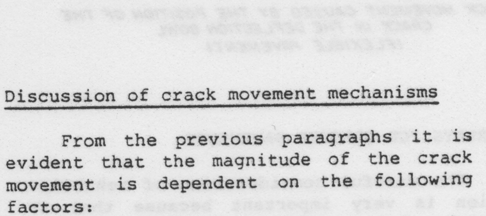

FIGURE 5

*TYPICAL CRACK OR JOINT MOVEMENTS ON RIGID PAVEMENTS*

Discussion of crack movement mechanisms

From the previous paragraphs it is evident that the magnitude of the crack movement is dependent on the following factors:

- The type of pavement and the structure thereof
- The magnitude of the surface deflection of the pavement as well as the shape of the deflection bowl under a given wheel load
- The size of the blocks between the cracks.

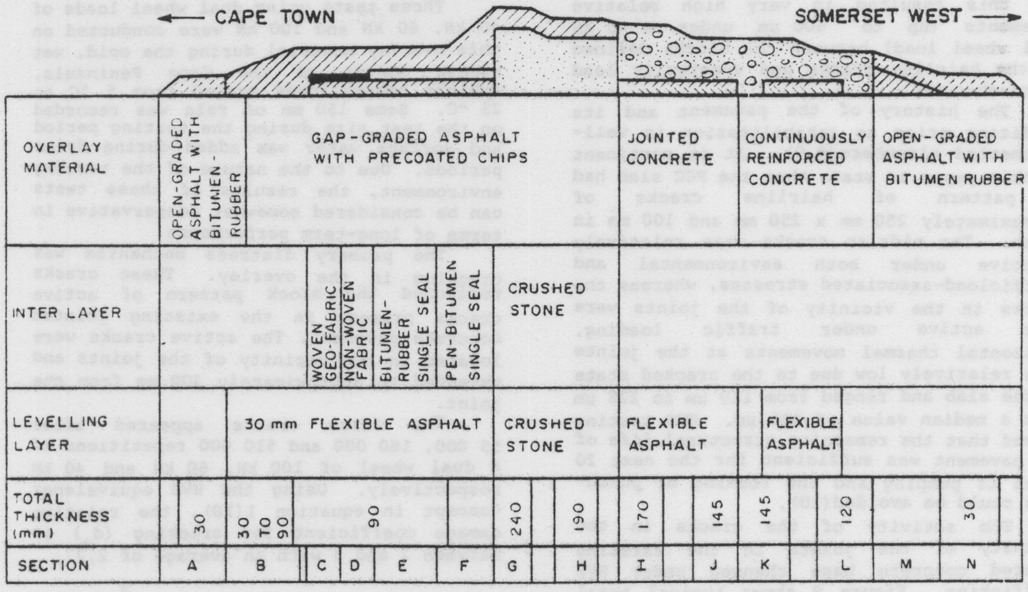

FIGURE 8

*LAYOUT OF EXPERIMENTAL OVERLAYS*

TABLE 1 - Material properties of experimental asphalt overlays

| | Material type | Semi-open-graded bitumen-rubber premix | Gap-graded asphalt | Fine continuously-graded asphalt | Bitumen rubber inter-layer | Penetration grade bitumen inter-layer |
|---|---|---|---|---|---|---|
| Mix properties | Binder Content % | 9,0 | 5,5 | 8,6 | - | - |
| | Marshall Stap (kN) | 2,6 | 8 | 7,0 | - | - |
| | Marshall Flow (mm) | 2,4 | 2,6 | 4,2 | - | - |
| | Stab/Flow (kN/mm) | 1,1 | 3,1 | 1,7 | - | - |
| | Marshall Density (kg/m³) | 2232 | 2323 | 2291 | - | - |
| | Rice Density (Kg/m³) | 2402 | 2465 | 2375 | - | - |
| | Compaction (% of Marshall Density) | 93 | 100,3 | 950 | - | - |
| | Dynamic Stiffness @ 25 °C (MPu)* | 1450 | 3000 | 2000 | - | - |
| | Voids in mixture % | 7,0 | 5,8 | 3,5 | - | - |
| Binder properties | Binder Penetration | 80/100 | 60/70 | 150/200 | 80/100 | 150/200 |
| | Rubber added (% by means of binder)*** | 20 | - | - | 20 | - |
| | Flow (mm) *** | 37 | - | - | 37 | - |
| | Resiliency (%) *** | 14 | - | - | 14 | - |
| | Ring and Ball Temp. (°C) *** | 59 | - | - | 59 | - |
| | Viscosity ** (Centi-poise)*** | 1800 | - | - | 1800 | - |
| | Application rate ℓ/m² | - | - | - | 1,8 | 1,8 |

* Measured using the dynamic indirect tensile test
** Determined with the Brookfield Viscometer
*** Bitumen-rubber Technical Sub-committee on Test Methods, Interim test procedures for bitumen-rubber binders, Pretoria, CSIR, December 1984.

selected subgrade over a deep layer of Cape Flats sand. Approximately five years after construction this plain jointed concrete pavement (JCP) between Cape Town and Somerset West, exhibited an unusually high incidence of hairline cracking. It was established that this was due to an alkali-aggregate reaction*(7). Traffic loading caused these cracks to continue developing in the vicinity of the joints

Other sections of this overlay have also been subjected to approximately 18 months of normal traffic as well as environmental stresses since March of 1983 and as yet no distress is visible.

### Gap-graded asphalt overlay (60 mm) with bitumen-rubber interlayer

This overlay (section E in Figure 8) consists of a 30 mm fine continuously graded asphalt levelling course (100 per cent passing 4,75 mm sieve) with 8,6 per cent of 150/200 pen bitumen. On top of this is a bitumen-rubber single seal followed by a 60 mm gap-graded asphalt layer. The bitumen-rubber interlayer has a 1,8 l/m² binder application.

The section was trafficked with the HVS during the mid-summer period of 1985 and asphalt temperatures ranged from 19 °C to 46 °C. A 60 kN dual wheel load was used. The asphalt exhibited some plastic deformation when asphalt temperatures exceeded 40 °C. The deformation was mainly due to the transverse displacement of the asphalt perpendicular to the direction of loading. After approximately $3,2 \times 10^5$ repetitions, rutting of 7 mm was measured and faint longitudinal surface cracking was observed. These cracks were not confined to the vicinity of the joints in the existing concrete pavement where high load-associated crack movements (630 μm) were measured prior to overlay placement. Closer inspection (using fluorescent fluid impregnation of the cracks and coring) revealed that the cracks originated in the gap-graded asphalt layer above the rich bitumen-rubber interlayer. The layer acted as a weak plane and horizontal slippage probably contributed to the lateral movement of the gap-graded asphalt layer. The first evidence of reflection cracking propagating to the surface was observed after some $5 \times 10^5$ repetitions of a 60 kN dual wheel load. This is equivalent to approximately 2,7 or 4,5 million standard 80 kN axle loads (E80s) for relative damage coefficients of 2,7 (as determined on the 30 mm bitumen-rubber premix overlay) and the more generally used value of 4,0 respectively. Other sections of this overlay have also been subjected to normal traffic for about 18 months and environmental stresses for approximately three years with no evidence of cracking.

### Gap-graded asphalt overlay (60 mm) with 150/200 pen bitumen interlayer

Apart from the difference in binder type used in the interlayer, the design and construction of this overlay (section F in Figure 8) is identical to the overlay described in the previous paragraph. The section has not been trafficked with the HVS but has been subjected to normal environmental stressed for three years and carried some 18 months of normal traffic. At this stage no evidence of reflection cracking or other types of distress is visible. All indications are that it will behave similary to the previous section where bitumen-rubber was used in the interlayer.

### Gap-graded asphalt overlay with woven and non-woven geofabric interlayers

During the construction of these two overlays (sections C and D in Figure 8) geofabric layers were placed on top of the same 30 mm levelling course described previously, followed by the 60 mm gap-graded asphalt layer. In the case of the non-woven geofabric (Bidim U24), a single layer was laid. The layer was soaked with a 60 per cent stable grade emulsion by spraying one l/m² prior to laying and 0,5 l/m² after laying the geofabric layer. The woven geofabric was a 20 mm square mesh made of a bitumen-impregnated polyester fibre called Hatelit. After the layer was placed, 0,6 l/m² stable grade emulsion was sprayed on the layer prior to paving it with a 60 mm layer of gap-graded asphalt.

Within 12 to 18 months after construction, both these sections reflected the joint pattern of the existing jointed concrete pavement in the form of fine cracks. All indications are that the cracking was due to thermal movements in the existing concrete pavement. Traffic-load-associated crack movements in the existing concrete pavement have not reflected through the overlay after some 18 months of normal traffic.

### Conventional gap-graded asphalt overlay (30 mm to 90 mm thick)

This overlay (section B in Figure 8) consists of conventional gap-graded asphalt (with no interlayers) and varies in thickness from 30 mm to 90 mm. Within 10 to 20 months after construction, the joint pattern of the existing JC pavement reflected to the surface of the overlay. The longer periods generally corresponded with the thicker overlays. Again these cracks are attributed to thermal movements. After approximately 18 months of normal traffic, no evidence of reflection cracking originating at the cracks in the existing concrete pavement was found.

### Other overlay types

Another three overlay types were evaluated with the HVS. These are the 150 mm crushed stone overlay with a 40 mm gap-graded asphalt surfacing, the 115 mm and 145 mm unbonded jointed concrete (JC) overlays with a 4,0 m joint spacing, and the 90 mm unbonded continuously reinforced concrete (CRC) overlay. Details of the test results are documented elsewhere(10) and in the interest of brevity, only the major findings are summarised here.

of the pavement will generally be required to reduce crack movements. This can for example be done by adding a structural layer, by milling and re-compacting the cracked layer or by replacing severely cracked areas.

In the case of the concrete pavement under consideration, traffic-load-associated crack movements were in the order of 600 μm in the vicinity of the joints. These areas were replaced using low shrinkage concrete which proved to be very successful under HVS loading. Traffic-load-associated crack movements were reduced to levels below 50 μm for some 12 million E80s. The pavement is now being overlaid with a rich bitumenrubber interlayer and a 40 mm bitumen-rubber overlay.

## CONCLUSIONS

It has been shown that traffic-load-associated crack and joint movements are dependant on many factors including the type and state of the pavement, surface deflection and the shape of the deflection bowl as well as the size of the blocks defined by the cracks or joints. Because most of these factors change with time and traffic loading, relative crack and joint movements are difficult to predict over a period of time. Two basic mechanisms of relative crack or joint movements were identified, namely the tilting of blocks and the relative position of the discontinuity in the deflection bowl created by the wheel load. The influence of these factors as well as the mechanisms are illustrated by using field data from actual pavements.

The available results of a comprehensive experiment designed to evaluate the ability of a variety of overlay techniques to inhibit reflection cracking are provided and discussed. The HVS fleet played a major role in the understanding of the factors influencing crack movements and their mechanisms as well as the evaluation of conventional and innovative overlay techniques.

## ACKNOWLEDGEMENTS

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