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TITLE The prediction and treatment of reflection cracking in thin bituminous overlays

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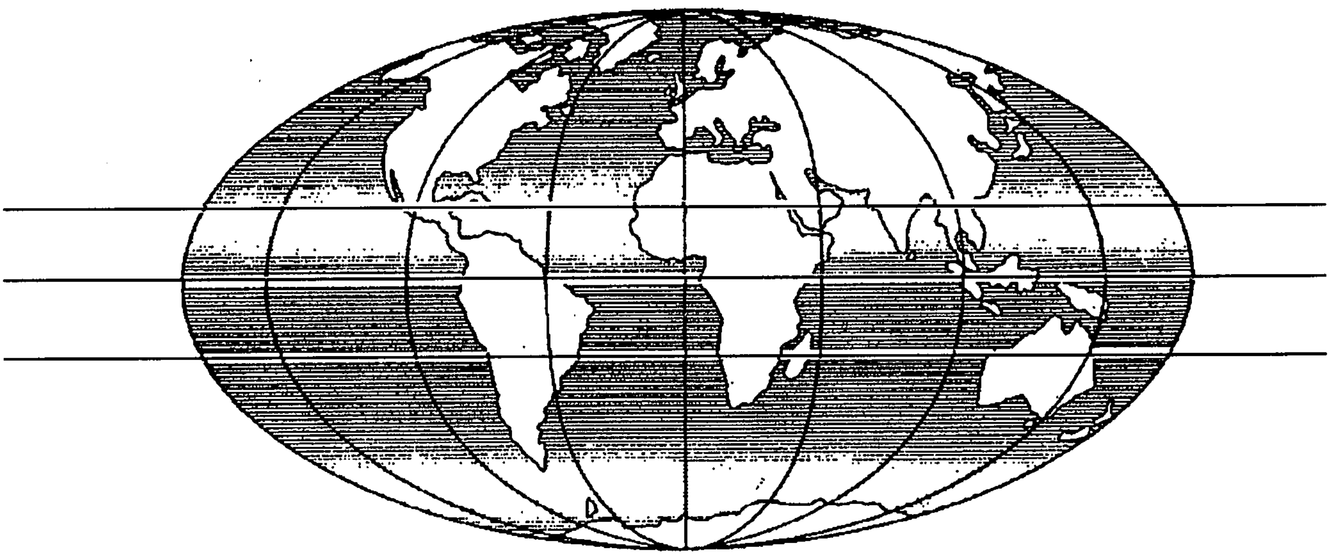

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THE PREDICTION AND TREATMENT OF REFLECTION CRACKING IN THIN BITUMINOUS OVERLAYS

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ABSTRACT

This paper describes aspects of three studies concerned with the treatment of cracked asphaltic concrete road surfacings. In the first study a model has been developed, based on five years data, which calculates the probability of reflection cracking occurring in thin bituminous maintenance overlays. The key factors influencing the rate of reflection cracking were the severity of cracking and the deflection prior to overlay, and traffic. In the second study the effectiveness of six alternative crack relieving interlayers have been tested on a heavily trafficked site and the paper describes the early performance of these alternatives. The third study is concerned with sealing cracks in asphaltic concrete surfacings. The effectiveness of a number of different techniques has been tested on a moderately trafficked site. All three studies were carried out under a joint research programme between the Public Works Institute in Malaysia (IKRAM) and the Transport Research Laboratory (TRL), UK.

1. INTRODUCTION

The Federal and State paved road network in Peninsular Malaysia is approximately 26,000 kms in length and is usually maintained by the periodic application of bituminous overlays. In the mid 1980's, these overlays fell into two categories. There were thin maintenance overlays constructed by the State Authorities, either by direct labour or under relatively small contracts. These overlays were 40mm thick irrespective of the structural capacity of the road or the future traffic loading. Alternatively, structural overlays were constructed to a thickness designed using the JKR procedure. In both cases the overlay material was asphaltic concrete as specified by the JKR.

A preliminary survey of the performance of the thin maintenance overlays showed that because usually no remedial work was carried out prior to the construction of the overlays, deterioration occurred relatively quickly as cracks in the previous surfacing propagated through the new surfacing. Following this survey, three linked research studies were designed and implemented as follows:

Development of a model for predicting the occurrence of reflection cracks in thin overlays.
The first study was designed to examine the factors that control the development of reflection cracking and to identify the conditions, if any, under which the performance of thin overlays is likely to be acceptable. After three years of data collection, a model was developed describing the development of reflection cracking (Morosiuk et al, 1992). Monitoring of the overlay sites has continued and this paper presents an improved model based on five years of data.

Comparison of the effectiveness of various crack relieving interlayers.
Where a road pavement is not strong enough for the future traffic loading, it is normal to strengthen the pavement with a bituminous overlay. If the existing surfacing is cracked then areas of severe cracking are normally cut out and patched prior to overlay. However, there may be situations when either the cracking is so extensive or the cracked surfacing so thick that the use of a crack relieving interlayer under the new overlay offers a cost effective alternative to removing the cracked surfacing. This paper describes the early performance of a trial that compares a number of alternative methods of retarding reflection cracking in bituminous overlays.

Comparison of the effectiveness of thin bituminous seals for sealing cracked surfacings.
There are many paved roads in Malaysia, particularly State secondary roads, where traffic levels are low and maintenance treatments may not necessarily need to include a strengthening component. In this case it may be more appropriate to maintain the road using a thin bituminous seal which not only seals the cracks in the existing surface but also restores or improves the skid resistance properties of the surfacing. This paper describes the early results from a full-scale trial that compares the performance of several alternative bituminous seals used for this purpose.

2. PREDICTION OF REFLECTION CRACKING IN THIN OVERLAYS

During this study the performance of ten overlay sites, each one kilometre long, was monitored over a period of five years. The sites were chosen to be representative of the 40mm maintenance overlays constructed by the State authorities and were therefore situated throughout Peninsular Malaysia. The overlay material was asphaltic concrete wearing course as specified by the JKR.

At each site, the traffic lanes in both directions were sub-divided into 100 ten-metre blocks, each block being treated as a discrete unit for the purpose of measurement and analysis. The surface condition and structural strength of each block was measured both before and after overlay.

Research (Viljoen et al, 1987) has shown that the propagation of reflection cracking through new bituminous overlays is controlled by the changes in width of the crack, and hence the strain across the top of the crack in the pavement layer system. It was therefore expected that the factors affecting crack movement would prove to be statistically significant in the development of the prediction model. Thus factors describing the severity and intensity of existing cracks and factors describing the strength of the road and the movement of the road under vehicle loads were all tested in the analysis together with the number of repetitions of the loads themselves.

The cracking parameter specifically referred to throughout this paper is crack intensity (CI) and is defined as follows.

Crack Intensity	Definition
0	No cracks
1	A single crack
2	More than one crack - not connected
3	More than one crack - connected
4	Crocodile cracking

The structural strength of the road pavement was assessed using the Falling Weight Deflectometer (FWD). FWD measurements reported in this paper were standardised to a temperate of 35°C and a pressure of 700 kPa. Traffic flows were abstracted from classified traffic counts reported by the Highway Planning Unit. In this study, medium and heavy goods vehicles and buses were classified as commercial vehicles.

Those cracks that occurred relatively soon after the construction of the overlays were found to be coincident with areas of severe cracking recorded prior to overlay. The cause of the cracking was confirmed by cores which showed that the cracks in the new overlay were immediately above those in the underlying (former) surfacing. For the purpose of analysis, the overlay in a 10-metre 'block' was deemed to have cracked when more than five per cent by area showed visible cracks. With this definition, the model that was developed for predicting the progression of reflection cracking is:

$$P/(1-P) = \exp(a + bCV + c\,DEF)$$

where P = Probability of cracking (0 to 1)
CV = Cumulative commercial vehicles to cracking (x 10^3)
DEF = FWD deflection prior to overlay (mm)

The estimates of the constant 'a' and coefficients 'b' and 'c' are variable and depend on the intensity of cracking prior to overlay (CI). These values are given below.

a = -3.76	b = 0.00080	c = 2.07	for CI = 1
a = -2.62	b = 0.00066	c = 1.36	for CI = 2
a = -2.37	b = 0.00095	c = 1.19	for CI = 3
a = -2.20	b = 0.00111	c = 1.25	for CI = 4

Figures 1 and 2 illustrate the effect of crack intensity and deflection, before overlay, on the probability of reflection cracking. The figures show that there is a significant difference between those road pavements with interconnected cracks (CI 3 and 4) and those with individual cracks (CI 1 and 2). For example, for the stronger pavements (DEF < 0.5mm) the probability of reflection cracking for those with interconnected cracks is about twice as high as it is for those pavements with individual cracks, up to approximately 3 million commercial vehicle passes.

Of more significance, however, is that Figure 1 shows that under any circumstances, at least ten per cent of the road will have reflection cracking within the passage of 1 million commercial vehicles, and that for areas of road with interconnected cracks, 50 per cent will have reflection cracking after the passage of less than 2 million commercial vehicles. Only on the most lightly trafficked roads, with low deflections and no interconnecting cracking are thin overlays likely to last long enough to be cost effective.

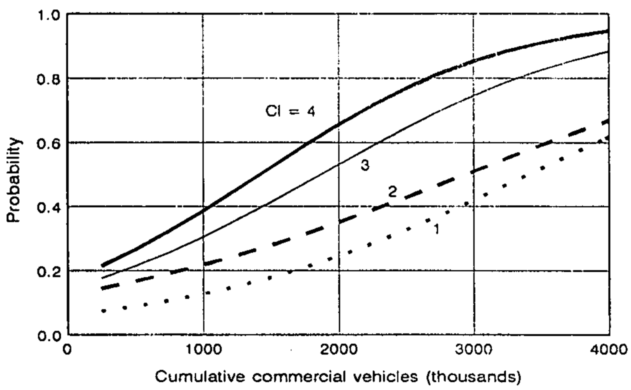

Figure 1 Probability of reflection cracking
Deflection = 0.5mm

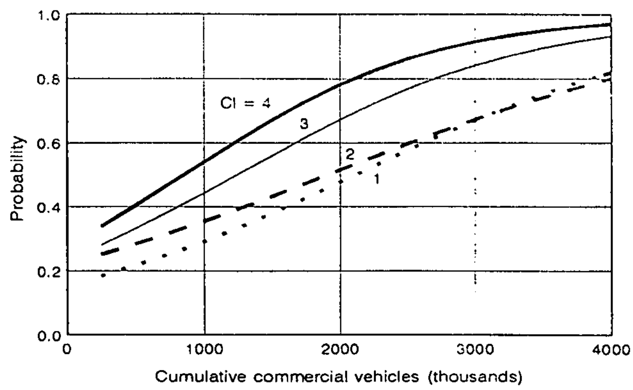

Figure 2 Probability of reflection cracking
Deflection = 1.0mm

3. PERFORMANCE OF CRACK RELIEVING INTERLAYERS

The length of road on Route 5 between Melaka and Muar that was used for the trial was typical of long lengths of the Federal and State network. The road had a single 7.3m wide carriageway and the pavement construction consisted of a gravel sub-base, crushed stone roadbase and dense bituminous surfacing. The road had been overlaid twice since its construction. The site was heavily trafficked having an ADT of 12,000 vehicles of which 18 per cent were commercial vehicles. The trial was built in June 1993 (Jones and Ford, 1993).

As discussed above, reflection cracking depends on the changes in width of the cracks and the strain induced in the overlying layer. This effect is illustrated in Figure 3. In causing the reflection crack to form, it is the opening of the crack, ie the tensile movement, that causes the material at the bottom of the new overlay to fail in fatigue. In this trial, the horizontal crack movement in the existing surfacing, prior to overlay, was measured using a 50mm Demec gauge. The tensile crack movement recorded under an 8 tonne axle load is shown in Figure 4. The figure shows that the tensile movement was relatively low for cracked surfacings having a small slab size, ie less than 100mm. However, as the size of the slab increased the crack movement increased, with maximum tensile movements occurring for slab sizes between 300 and 600mm. (For slabs larger than 1000mm the tensile movement caused by vehicle loading was again quite small but in many environments the strains induced by thermal stresses are expected to dominate under these conditions).

For a crack width of 1mm, the maximum tensile movement of 0.04mm represents a tensile strain of 40,000 microstrain. Although this strain will be less after overlay it will inevitably be greater than the tensile strains at the bottom of an uncracked surfacing of a similar pavement structure, which would be of the order of 300 microstrain. The magnitude of the measured strain illustrates why reflection cracking in thin overlays can be expected to occur long before cracks that are initiated at the bottom of the bound layer, as assumed in normal analytical design procedures.

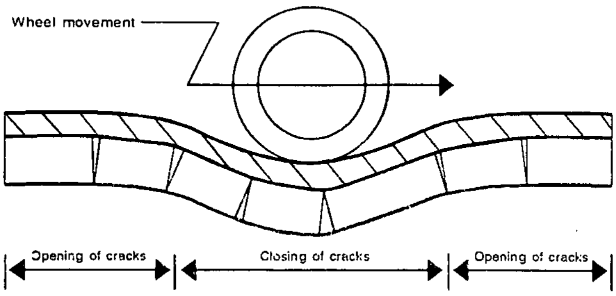

Figure 3 Crack movement in the deflection bowl (after Viljoen et al, 1987)

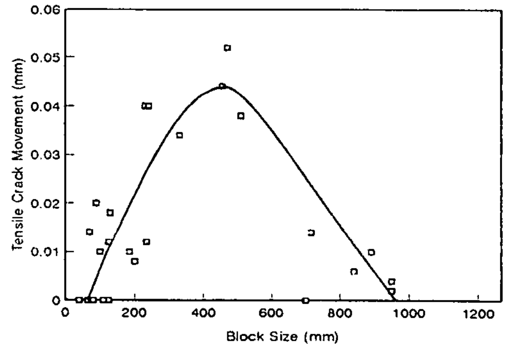

Figure 4 Crack movement under 8.0 tonne axle

The six different methods of preventing reflection cracking in a 50mm overlay that were used in the trial are summarised in Table 1. The relative performance of the six methods were compared with the performance of two control sections having overlay thicknesses of 50 and 90mm but with no crack retarding interlayer. All the sections were 210 metres long and the overlay material was that specified by the JKR.

Geogrids are claimed to retard crack propagation by reinforcing the new overlay immediately above the crack. The glass fibre geogrid selected for this trial had a mesh size of 30mm and had a tensile strength of 50 kN/m at 3 per cent strain.

The concept behind the use of needle-punched materials for this purpose is that the bitumen-filled fabric will dissipate the strain at the top of the crack thereby reducing the strain applied to the overlay and retarding crack propagation. The polypropylene needlepunched fabric used in this trial had a tensile strength of 9 kN/m and a minimum extension at ultimate breaking strength of 50 per cent.

'Cut and patch' is the standard JKR procedure and requires that '*surfaces with cracks of 4mm or greater in width should be removed and patched prior to the overlay being applied*'. In practice this usually results in 40mm of cracked material (ie the previous overlay) being removed and patched. It has been shown previously that the rate of propagation of reflection cracks is dependent on crack intensity (see Figure 1) and therefore areas of surfacing having a crack intensity of 3 or greater were patched in this section.

Previous research in Malaysia (Johari et al, 1992) has shown that interlayers with relatively high voids will also significantly reduce the rate of propagation of reflection cracking; strains cannot be readily transferred through a medium with substantial voids if the layer is sufficiently thick. This concept was employed during the design of two sections with interlayers constructed from surface dressings of different stone sizes and one section with a pervious macadam interlayer (BSI, 1988).

3.1 Cracking after 30 months

The condition of the overlays was assessed by dividing each 210 metre section into 10-metre blocks, 21 in each direction. These blocks were used as the basic unit for calculating the length of road affected by any type of pavement failure.

After 30 months, neither of the sections with geotextile interlayers had any reflection cracks, but on both sections the overlays were slipping at the interface between the old road and the geotextile. Twenty one per cent of the length of the geogrid section and 12 per cent of the section with the needle-punched fabric were affected by this type of failure. This behaviour reinforces the lessons of previous experiences in Malaysia and elsewhere (Barksdale, 1991) which indicate that field-related construction problems with geotextiles can often outweigh possible improvement in road performance.

Table 1 shows that only the 50mm control section with no interlayer and the section having an interlayer constructed with a 14mm surface dressing had any substantial reflection cracking after 30 months of traffic. In both cases 23 per cent of the blocks which had crack intensities of 3 or 4 prior to overlay had cracked.

Table 1
Reflection cracking after 30 months

Description of crack relieving interlayer[1]	Relative cost of interlayer[3]	No of blocks cracked[4,5] (%)
Geogrid reinforcement	1.36	0
Needlepunched fabric	0.45	0
Cut and patch - 40mm layer	1.82	0
Surface dressing - 14mm stone	0.73	23
Surface dressing - 10mm stone	0.73	4
No interlayer[2]	-	23
Binder course[2] - 40mm layer	1.0	0
Pervious macadam - 40mm layer	1.91	0

Notes
1. All sections were overlaid with 50mm of AC wearing course.
2. Control sections.
3. Relative costs are subject to change based on quantities.
4. Blocks having crack intensity 3 or 4 prior to overlay.
5. A block was deemed to be cracked after overlay if more than 10 per cent by length was cracked.

During construction, the 10mm surface dressing interlayer was trafficked overnight and overlaid the following day. However, because of the possible damage to vehicles caused by loose chippings, the 14mm surface dressing was overlaid on the same day as it was constructed. Because of this, the cut-back binder used for the surface dressing was not fully cured and this resulted in substantial amounts of the 14mm aggregate being incorporated in the overlay material by the paver augers. No such problem was encountered whilst paving the 10mm surface dressing and this probably accounts for its better performance.

The majority of sections have not cracked to date and it is therefore too early to compare the cost effectiveness of the various techniques used. However, the early results clearly illustrate the *minimum* improvement in performance that can be obtained by simply 'cutting and patching' areas of crack intensity 3 and 4 prior to the construction of thin overlays and it is recommended that this technique be carried out even when limited maintenance resources prevent the use of thicker overlays. The unit cost of 'cut and patch' is currently approximately twice that of laying a similar thickness of binder course material. Where the existing surfacing consists of a number of previous overlays, it may therefore be more effective to increase the thickness of overlay rather than 'cut and path' extensive areas of the existing surfacing.

4. PERFORMANCE OF THIN BITUMINOUS SEALS

The length of road selected for the trial was on Route 10 between Bahau and Rompin. The road had a crushed stone roadbase with a cracked asphaltic concrete surfacing. The site was moderately trafficked having an ADT of 3,500 vehicles of which 20 per cent were commercial vehicles. The trial was constructed in May/June 1994 (Ford and Smith, 1995).

The trial was primarily designed to compare the effectiveness of two types of traditional surface dressing in sealing cracks in the asphaltic concrete surfacing. The surface dressings were :

- a double surface dressing; and
- a racked-in surface dressing.

Each were applied to a one-kilometre length of road. In addition, three other techniques were tested over shorter lengths of road. These were :

- a single surface dressing;
- a double surface dressing over a geogrid; and
- a double surface dressing over a needlepunched fabric.

The glass fibre geogrid had a mesh size of 20mm, a tensile strength of 100 kN/m and a modulus of elasticity of 69 kN/mm^2. The polyester needlepunched fabric had a tensile strength of 8.0 kN/m and a minimum extension at ultimate breaking strength of greater than 50 per cent. The traditional seals were designed using Overseas Road Note 31 (Transport Research Laboratory, 1993) and the Road Surface Dressing Association guidance note (RSDA, 1992). The seals that incorporated the geotextiles were designed by the supplier of the geotextile. The nominal size of aggregate used for the single seal was 6mm. The aggregates used for the double and racked-in surface dressings were 14 and 6mm. The binder used to construct all the sections was a 200 pen bitumen.

4.1 Cracking after 18 months

The performance of the alternative seals was assessed in a similar manner to that described in section 3.1, with each length of road being divided into 10 metre blocks.

After 18 months there was no significant difference in the amount of cracking that had reappeared in the double and racked-in surface dressings. The cracks reappeared in approximately 17 per cent of those areas having initial crack intensities of 1 or 2 and in 34 per cent of those areas having intensities of 3 or 4. The 6mm single seal was far less effective in sealing the cracks, with over 50 per cent of the cracks in the existing surfacing reappearing after 18 months.

The two short lengths of road that were sealed with a double surface dressing over geotextiles have both performed well to date. In the double surface dressing over the geogrid, cracks only reappeared in one of the seven blocks which had a crack intensity of 3 or 4 before sealing. No cracks reappeared in the double surface dressing over the needlepunched fabric. It should be noted that construction costs of these seals are considerably higher than traditional techniques and further monitoring is needed to establish their cost effectiveness.

Table 2
Cracking after 18 months

Type of seal	No. of blocks cracked[1] (%)	
	Crack intensity 1-2 before sealing	Crack intensity 3-4 before sealing
Single surface dressing	>50	>50
Racked-in surface dressing	17	35
Double surface dressing	16	33

Note 1. A block was deemed to be cracked after sealing if 10 per cent by length was cracked.

5. CONCLUSIONS

- The development of reflection cracking in 40mm bituminous overlays was found to be dependent on the initial crack intensity before overlay, the pavement deflection before overlay, and the commercial vehicle flow after overlay. At a deflection value of 0.5mm, 50 per cent of cracks of intensity 1 and 2 had reflected through after the passage of approximately 3.0 million commercial vehicles and 50 per cent of cracks of intensity 3 and 4 had reflected through after approximately 1.5 million commercial vehicle passes.

- It is recommended that the use of thin overlays alone is restricted to maintaining roads having a mean deflection below 0.5mm and commercial vehicle flow of less than 500 vehicles per day. All areas of the surfacing having crack intensity 3 and 4 should be cut out and patched prior to overlay.

- Although it was not yet possible to rank the cost effectiveness of the different crack relieving interlayers under thin bituminous overlays, the early results illustrate the improvement in performance that can be obtained by simply 'cutting and patching' areas of crack intensity 3 and 4 prior to overlay.

- Early results indicate that double and racked-in surface dressings are equally effective in sealing cracked asphaltic concrete surfacings, with only 17 per cent of cracks having intensities of 1 or 2, prior to sealing, reappearing after 18 months. The rate of propagation of cracks having intensity 3 and 4 was considerably faster and it is therefore recommended that areas of the surfacing that have cracking of this intensity should be cut and patched prior to sealing.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

BARKSDALE, R D (1991). Fabrics in asphalt overlays and pavement maintenance. Synthesis of Highway Practice 171. Transportation Research Board, Washington DC.

BRITISH STANDARDS INSTITUTION (1988). Coated macadam for roads and other paved areas. BS 4987:Part 1 1988, London.

FORD, W G and H R SMITH (1995). Use of surface dressings for crack sealing: Construction of a full scale trial in Malaysia. Report PR/ORC/056/95. TRL, Crowthorne.

JOHARI EMBY, C R JONES and SHAFII MUSTAFA (1992). The use of hot surface treatment to rehabilitate cracked asphaltic concrete surfacings in Malaysia. 7th REAAA Conference, Singapore.

JONES, C R and W G FORD (1993). Prevention of reflection cracking in bituminous overlays - Construction of a full scale trial in Malaysia. TRL Project Report PR/OSC/027/93. TRL, Crowthorne.

MOROSIUK, G, W G FORD and A MUTALIF (1992). Reflection crack propagation in asphaltic concrete overlays in Malaysia. 7th REAAA Conference, Singapore.

VILJOEN, A W, C R FREEME, V P SERVAS and F C RUST (1987). Heavy vehicle simulator aided evaluation of overlays on pavements with active cracks. RR 504, National Institute for Transport and Road Research, CSIR.

TRANSPORT RESEARCH LABORATORY (1993). A guide to structural design of bitumen-surfaced roads in tropical and sub-tropical climates. Overseas Road Note 31. TRL, Crowthorne.

ROAD SURFACE DRESSING ASSOCIATION (1992). Racked-in surface dressing. Guidance Note 87/1. RSDA, Matlock.