Abstract

In the UK, an extensive research programme has been undertaken to investigate the benefits or otherwise of pre-cracking semi-rigid pavements to minimise reflection cracking. Transverse pre-cracks in the cement bound base layer are intended to reduce thermal movements in the base layer and hence minimise reflection cracking. As a consequence, pavement life is extended with reduced maintenance intervention requirements and thinner asphalt surfacing. Ultimately, semi-rigid pavement construction becomes more financially competitive due to savings in the whole life cost of the pavement.

Twelve sections incorporating pre-cracked cement-bound bases were constructed as full-scale trials in 1996. The sections were at four separate locations in the UK and included 8 experimental and 4 control sections. The sections have been monitored since construction between 1996 and 2002. This paper presents the sites and the in-service performance data collected that assesses the initiation and growth of reflection cracks in trial and corresponding control sections. The experiments have been successful and in the UK have led to revised specification clauses and design standards, including compulsory pre-cracking for some semi-rigid pavements and reductions in the thickness of the asphalt surfacing.

1. Introduction

In the UK, semi-rigid pavements are constructed as cement-bound material (CBM) bases with asphalt surfacing. Transverse cracks occur in the surface of semi-rigid pavements as reflections of the naturally occurring thermal stress cracks in the base layer. The thermal stresses in the roadbase due to temperature changes create transverse cracks at a natural spacing of 5 - 30 m. The theory is that pre-cracking the roadbase at a closer spacing will reduce the magnitude of the thermal movements at individual cracks and hence the tensile stresses in the asphalt, thus reducing the occurrence of cracking in the
surface. If cracks are reflected, they should be much finer and less likely to lead to deterioration in the surfacing and hence the whole pavement stability should be maintained, see Figure 1. Pre-cracking is a construction method that is expected to introduce control over the location and size of any surface cracks. Minimising the size of the surface crack allows the pavement life to be extended and reduces future maintenance costs, not only in terms of maintenance works but also the cost to the road user of the delays during roadworks.

Figure 1 Schematic explanation of pre-cracking

TRL has been researching pre-cracking of cement-bound materials since 1995, on behalf of the Highways Agency. Full-scale trials of pre-cracking were constructed in the UK under the supervision of TRL in the Summer and Autumn of 1996. Four trial sites were constructed with the intention to assess pre-cracking techniques, the effect of pre-cracking on the structural strength of the pavement, and the occurrence of reflection cracking. Details of the twelve experimental sections that were constructed are given in Table 1 and have been fully reported by Ellis et al (1997). A brief summary of the pre-cracking techniques is given in section 2, including observations on the relative performance of each technique.

<table>
<thead>
<tr>
<th>Location</th>
<th>Section No.</th>
<th>Equipment</th>
<th>Asphalt Thickness (mm)</th>
<th>Base Type</th>
<th>Base Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A149 Ormesby Bypass, Norfolk</td>
<td>1 (Control)</td>
<td>None</td>
<td>130</td>
<td>CBM3</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Arrows Breaker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>VPM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>OLIVIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A605 Warmington Bypass, Northamptonshire</td>
<td>5</td>
<td>VPM</td>
<td>100</td>
<td>CBM3</td>
<td>150</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>VPM</td>
<td>200</td>
<td>CBM5</td>
<td>180</td>
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<td></td>
<td>8 (Control)</td>
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<tr>
<td>A256 Whitfield bypass, Kent</td>
<td>9</td>
<td>CRAFT</td>
<td>200</td>
<td>CBM4</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>VPM</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>11 (Control)</td>
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<td></td>
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<tr>
<td>A1(M), Alconbury</td>
<td>12</td>
<td>VPM</td>
<td>170</td>
<td>CBM4</td>
<td>180</td>
</tr>
</tbody>
</table>

Legend
VPM: Vibrating plate method.
CBM3/4/5 represents cement bound material strength at 7 days 10, 15 and 20N/mm² respectively.
The trial sites have been re-visited and monitored since construction and this paper presents the in-service performance data collected between 1996 and 2002. The data includes the results of visual surveys, and some core sampling, to determine the effectiveness of the induced crack technique to inhibit reflection cracking. In addition, Falling Weight Deflectometer and profile data have been collected to examine whether the pre-cracked pavements have a reduced stiffness or structural capacity compared to those without pre-cracks.

2. Pre-cracking techniques employed

2.1 General
Four techniques were used to pre-crack the CBM pavement layers, for all sections the pre-cracks transversed the whole width of the base layer and were at 3.0m longitudinal spacing. Three techniques, the vibrating plate, OLIVIA and CRAFT, have been used previously in other countries. The fourth, the guillotine, is a similar method to crack and seat techniques, developed in the UK by TRL on behalf of the Highways Agency to prevent reflection cracking when applying structural asphalt overlays to existing concrete pavements during maintenance (Potter et al, 2000).

2.2 Vibrating plate
The vibrating plate method is the most basic method of pre-cracking. A vibrating compaction plate has a metal blade welded vertically to its compaction surface. The vibration of the plate allows the blade to pass through the un-compacted CBM, leaving a groove behind. The size of the blade is approximately half the depth of the un-compacted material. A bitumen emulsion is then applied to the groove, ensuring all sides are covered. The CBM is then compacted, as usual, by roller. The compaction process closes the grooves formed by the vibrating plate. The bitumen emulsion ensures a plane of weakness within the CBM that induces a fine crack, full width of the pavement, under thermal and traffic stresses.

2.3 CRAFT
CRéation Automatique de Fissures Transversales (CRAFT, Automatic Creation of Transverse Cracks) pre-cracks the pavement in the same manner as the vibrating plate. However, this system is vehicle mounted and the groove is formed and bitumen emulsion added in one operation. The equipment requires only one operator. This system was developed by Laboratoires Régional des Ponts et Chaussées and Cochery Boudin Chaussée

2.4 OLIVIA
Outil que Laribe Inventa pour VIAFrance (OLIVIA) is an automatic system similar to the CRAFT, except that a thin plastic film is used to prevent the CBM from bonding fully, rather than the insertion of bitumen emulsion.

2.5 Guillotine
The guillotine method differs from the other three in that rather than placing a plane of weakness within the CBM that induces a crack as the CBM cures, the guillotine method is used following curing of the CBM and produces a crack immediately. The guillotine
The method works by dropping a weighted blade on to the cured CBM, to produce a transverse crack across the pavement. The guillotine used in the trials had a narrow blade, a number of drops (10-15) of the blade being used along the same transverse line, to form the transverse crack over the full width of the pavement. The guillotine is vehicle mounted, and is a one-man operation. More recently, guillotines with wide blades (approximately 2.4m) have been used for crack and seat, and could be used for pre-cracking a CBM base, giving a quicker method of pre-cracking where only two or three drops of the guillotine would be needed to cover the whole carriageway width. The technique was applied 6 days after laying the CBM.

2.6 Comparison of techniques
The different techniques have different benefits. The French OLIVIA and CRAFT equipment were very quick and efficient in pre-cracking the pavement, and were one man operations. However, there was a disadvantage of a high cost and no backup should the equipment break down, a particular problem if they have to return to France for repair. Compaction of the CBM may be delayed, as it must be pre-cracked before compaction. The speed of operation of both items of equipment was greater than needed on normal UK construction sites and so their main benefit may not be realised.

The guillotine method has similar benefits, being a fast one man operation. The cost is likely to be lower than for the French equipment and the equipment is available within the UK. As the cracking must take place following curing of the CBM equipment breakdown is not so serious, and does not hold up the construction of the CBM. There are some reservations over whether this method may adversely damage the CBM, although as can be seen from the results presented later in this paper, this does not seem to have been a problem within the trials.

The vibrating plate method is the simplest method. The equipment is very cheap and so spare plates can be available on site in case of breakdown. The disadvantage is that three people are required to operate, two to move the plate, one to place the bitumen emulsion. Further labour and equipment may be required if the rate of construction is high. Again there is the possibility of delaying the compaction of the CBM if the pre-cracking operation is not performed quickly enough.

To date the pavements that have been pre-cracked in the UK have tended to use the vibrating plate method, due to its simplicity and the cost. One contractor has also developed a simple addition to a concrete train, to draw a blade across the CBM prior to placement of the bitumen emulsion.

3. Monitoring of full-scale trials

3.1 Monitoring
Four methods of monitoring the performance of the pre-cracked trials have been used. These are visual condition surveys, coring, Falling Weight Deflectometer (FWD) and High-speed Survey Vehicle (HSV). The surveys were conducted annually since construction in 1996 until 2002. Future monitoring is planned but no further data was available at the time for writing this paper. The data for the A605 and the A149 sites visual condition and FWD are presented below.
3.2 Visual Condition Surveys

Visual condition surveys were conducted to assess the success of the pre-cracking in reducing reflection cracking. The results, in terms of number and length of transverse reflection cracks observed in the trial sections, are presented in Figures 2 to 5.

![Figure 2 A149 Occurrence of reflection cracking](image1)

![Figure 3 A149 Length of reflection cracking](image2)

With the exception of sections 5 and 6, all the pre-crack sections and their respective controls are 150m long, and so can be compared directly. Section 5 is 100m and its control, section 6 is 130m. Section 6 has 3.8 cracks per 100m length, and an equivalent 1m length of reflection cracking. Due to differing environmental and traffic conditions, as well as the different thickness of overlay the sections must be compared to their respective controls.
All the pre-crack sections are exhibiting a lower number, length of cracking than their respective controls. The severity of reflection cracking has also been recorded, at Warmington (sections 5-8) there does not seem to be a severity affect versus pre-cracking or not. Whereas at Ormesby there is a marked difference with early occurrence of reflection cracks and a fast progression of severity in the control section compared to the experimental sections. Section 5 and 6 present the least convincing data, but this is based on a very low number of small cracks. The concept of pre-cracking has been shown to work well. The different techniques have given a range of performance, the guillotine method (Section 2), is performing particularly well so far. Section 3, pre-cracked using VPM is not performing as well as the guillotine section, though this is suspected to be largely due to the inexperience of workmanship for the construction of the first pre-cracking trial in the UK. On the A605 section 7, also pre-cracked using a
VPM, the performance is excellent with no cracking having yet occurred, despite virtually 100% number of reflection cracking having occurred within the associated control, Section 8. With these variations in performance between sites, it is not possible to conclude that one pre-cracking method is definitely performing better than another.

3.3 Falling Weight Deflectometer
The Falling Weight Deflectometer (FWD) was used to assess the pavement stiffness using a back-analysis technique applied to the shape and size of the deflection bowl (MODULUS, Texas Transportation Institute, 1995). The analysis of all sections was based on a two-layer model. The first layer comprises all the bound layers (asphalt and CBM) and the second consists of any granular layers and subgrade combined. The nominal construction thicknesses were used throughout. The stiffness of the combined asphalt and CBM is not adjusted for the temperature of the asphalt. The measurements are made at the same time each year and this will help to minimise variation in the asphalt temperature. A typical example of the stiffness results is shown in Figure 6. In the diagram the results may not be clear for each period, however, for all sections the variation at each time period crossed previous records both higher and lower in stiffness.

![Figure 6, A149 Variations in back analysed stiffness results](image)

There has been no evidence of reduced stiffness in the pre-cracked sections, compared to the controls. On the A149 Ormesby, section 1, the control, has an average stiffness value that is similar to sections 2 and 4. Section 3 has a much higher stiffness, though this is to do with anomalies in the construction such as the granular sub-base used instead of the CBM sub-base and the associated services. This can be clearly seen in, where the stiffness values in section 3 are much less consistent than the other sections. As the bound layers contain an asphalt layer there will be some degree of temperature
dependence in the results. No temperature correction is available for concrete, so no 
temperature correction has been applied to the combined layer stiffness results presented. 
This means that results should be compared relative to the control in the relevant year. It 
can be seen that the pavement stiffness has not changed appreciably between 1996 and 
2002. Similar results have been obtained for sections 5 to 11.

4. Conclusion

A specification for pre-cracking has now been published in the UK Specification for 
Highway Works and the inclusion of pre-cracking does now permit a reduction in the 
asphalt overlay thickness for UK designs. The specification has been developed to 
recognise the importance of the correct placement of pre-cracks, sufficient crack 
protection and confirmation throughout the contract by coring and visual inspection of 
the surface to monitor the crack spacing.

The evidence from these trials, plus the experience in other European countries, has been 
sufficient to propose the pre-cracking of all new semi-rigid pavements in the UK. 
Industry in the UK considers the reduction in the asphalt thickness to be conservative. 
Though the current reduction of 10mm gives due deference to the high traffic levels in 
the UK that make maintenance costly in terms of traffic disruption. It is still believed 
that benefits in the form of reduced construction costs and reduced maintenance will be 
gained by the application of pre-cracking. This has been borne out by the increase in the 
UK of semi-rigid pavement structures for recent contracts. The Highways Agency are 
also undertaking further research into a revised analytical design method that is likely to 
give improved recognition to the inclusion of pre-cracking in semi-rigid pavements. The 
improved recognition is likely to be in the form of further reductions in the asphalt 
thickness.

5. Acknowledgements

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