TRANSPORT RESEARCH LABORATORY

Construction of full-scale trials to evaluate the performance of induced cracked CBM roadbases

Prepared for Quality Services (CE) Pavement Engineering Group, Highways Agency

S J Ellis, M A Megan and L A Wilde

TRL REPORT 289

First Published 1997
ISSN 0968-4107

Transport Research Foundation Group of Companies
Transport Research Foundation (a company limited by guarantee) trading as Transport Research Laboratory. Registered in England, Number 3011746.

TRL Limited. Registered in England, Number 3142272.
Registered Offices: Old Wokingham Road, Crowthorne, Berkshire, RG45 6AU.

CONTENTS

Executive Summary

This report delivers output number 2 for project E184D/HM: Pre-cracked CBM roadbase to inhibit reflective cracking, prepared for Mr J Mercer of Quality Services (CE) Pavement Engineering Group of the Highways Agency, Department of the Environment, Transport and the Regions.

The objective of this research is to investigate techniques developed elsewhere in the world for inducing cracks in CBM roadbases and to formulate a method suitable for application in the United Kingdom. Introducing induced cracks into flexible composite pavements is intended to diminish the effect of reflective cracking thus enabling the thickness of the flexible layers to be reduced. If this can be achieved, then it is expected that flexible composite pavement construction would become more competitive because of the savings with cost of initial construction and increased pavement life. Following stage one of the research, a detailed review of existing practices worldwide, full-scale trials have been constructed at four locations in the United Kingdom. This report describes the trials that have taken place and discusses the results of the initial monitoring that was carried out during construction.

From the research carried out elsewhere in the world it was apparent that there are a number of parameters which require clarification before induced cracking could be added to UK design standards (DMRB Vol. 7) and specifications (MCHW Vol. 2). The questions to be answered by full-scale trials are:

- which induced cracking method is most effective?
- how can induced cracks be retained?
- what effect could induced cracking have upon the thickness of upper pavement layers?

There were no flexible composite construction sites available through the Highways Agency at this time, so assistance of the Local Authorities and a DBFO consortium was obtained. In order to assess different upper pavement layer thicknesses, without requesting alteration to existing contracts, sites were sought with different pavement designs thus removing the need to vary pavement design at any location and reducing the onus placed upon the authorities where the road trials took place. Four trial sites were located. A149 Ormesby St. Margaret - CBM3 roadbase with 130 mm overlay; A605 Warmington CBM3 roadbase with 100 mm overlay and a section of the first CBM5 roadbase laid in the United Kingdom with 200 mm overlay; A256 Whitfield to Eastry - CBM4 roadbase with 200 mm overlay; and A1(M) Alconbury to Peterborough - CBM4 roadbase with 170 mm overlay. At all four sites cracks were induced using a simple vibrating plate with welded blade. In addition the OLIVIA automated process was brought over from France to trial in Norfolk together with an Arrows Breaker guillotine technique proposed by TRL. The CRAFT automated crack inducing process was also brought over from France to trial in Kent.

Initial monitoring during construction was carried out using the Falling Weight Deflectometer (FWD) and core samples. The FWD was used for two separate assessment methods. Firstly, the load transfer characteristics of the induced cracks were compared to natural cracks in the control section. Furthermore the stiffness of the induced cracked roadbase was compared to the naturally cracked control sections. Core samples were then taken at the cracks to confirm the results obtained for load transfer and assess the size and orientation of the cracks. In some instances it was not possible to locate the cracks by eye and the cores were subsequently vacuum pumped with fluorescent dye to help locate any fine cracks.

Analysis of the initial results has proved promising enabling the development of a draft specification. Four sections were constructed on the A149, three experimental sections (vibrating plate, guillotine and OLIVIA on CBM3) and one control. The results from this location all indicated positive benefits and showed that cracks were successfully created with minimal reduction in load transfer and a surprisingly beneficial effect on the overall stiffness of the roadbase layer. The second site was the A605 where four sections were also constructed, two experimental (vibrating plate on CBM3 and CBM5) and two control sections. The results at this site were less encouraging but nevertheless they illustrate the sensitivity of the technique to depth of inducement and roadbase compaction during construction. With the benefit of the experience on the A605, the later trials on the CBM4 of the A1(M) and A256 were carried out with greater attention being paid to the size of cracking blade and to the compactive effort.

The results to date are the preliminary analysis of the data obtained during construction. In order to establish the overall success of induced cracking, the trial sites will be monitored by visual inspection and further FWD testing until December 1998. During this period, the incidence of reflective cracking will be recorded and the validity of induced cracked CBM roadbases established.

Overall the introduction of induced cracking techniques is considered to be advantageous, with the potential for reducing the cost of flexible composite construction by the use of thinner overlays. The techniques can be carried out without interfering with the construction programme and the cost of inducing cracks is small compared to the cost of thicker upper pavement layers it replaces. Initial monitoring results are encouraging and further monitoring and analysis of the results of the FWD measurements will be carried out. This will enable an assessment of the technique to be made together with the criteria for implementation of induced cracking and the effects on the effective elastic modulus of an induced cracked pavement for pavement design.

1 Introduction

The objective of this research is to investigate techniques developed elsewhere in the world for the induction of cracks in cement bound material (CBM) roadbases and to formulate a method suitable for application in the United Kingdom. Introducing cracking to flexible composite pavements is intended to diminish the effect of reflective cracking thus enabling the thickness of the flexible layers to be reduced. Consequently, it is expected that flexible composite pavement construction would become more competitive in the market place due to initial construction cost savings and increased pavement life. This project report is the result of phase two of the research work, construction of full-scale trials, and follows on from project report PR/CE/5/96, ‘Pre-cracked CBM roadbases to inhibit reflection cracking’ (Ellis, 1996) which was an initial review of current crack inducing technology worldwide. All of the research work on this project is carried out by the Transport Research Laboratory (TRL) on behalf of the Highways Agency, QS (CE) Pavement Engineering Group.

Transverse cracks occur in the surface of flexible-composite pavements as a reflection of the naturally occurring thermal stress cracks in the cement-bound roadbase. The thermal stresses in the roadbase due to temperature changes create transverse cracks in the roadbase at a natural spacing of 10 - 20 m. The theory is that the introduction of cracks in 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. Induced cracking as a concept has developed as a way of controlling the location and size of 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.

The initial study (Ellis, 1996) surmised that the use of CBM roadbases in flexible composite pavements in the United Kingdom is limited by the reflective cracking that occurs due to thermal shrinkage. Current practice to minimise reflective cracking is to lay thick, and therefore expensive, bituminous surfacing making this construction less competitive. The preliminary research investigated the technique of inducing cracks in the roadbase to reduce the occurrence of reflection cracking and hence the thickness of bituminous surfacing and to extend the pavement life. An extensive review of the development of continental practices for induced cracking was carried out with a view to constructing full-scale trials in the United Kingdom to verify the effectiveness of such techniques under United Kingdom climatic conditions. The review of continental practice allowed detailed observations of the techniques practised in France and Spain to be made. The Spanish confirmed that, following 10 years of trials, they intended to proceed with extensive use of induced cracking throughout the country. An outline of all aspects involved with induced cracking was included in conjunction with details of continental trials and the design trials proposed in the United Kingdom. Overall, the review of current techniques suggested that similar techniques could be successful in the United Kingdom. Phase two of the project then proceeded by locating sites suitable for full-scale trials.

An update on current worldwide research is included in this report together with a description of the construction of full-scale trials and initial monitoring that took place to evaluate the effectiveness of induced cracking in the United Kingdom. A discussion of the initial results obtained is provided together with recommendations, including a draft specification, for further use of induced cracking in the United Kingdom.

2 Literature review update

Subsequent to the initial review of literature, a number of further documents have been produced which are relevant to induced cracking of CBM pavements. In particular, the third RILEM (Réunion International des Laboratoires d’Essais et de Recherche sur les Matériaux et les Constructions) conference on reflective cracking took place in October 1996 and included a number of presentations. These papers are discussed below together with other documents which have been found to be of interest.

Lefort (1996) summarised the progress made with induced cracking techniques and the current ‘state of the art’ in France. The techniques which are now established in French construction practice were outlined as CRAFT, OLIVIA and Joint Actif. All three techniques have been described by Ellis (1996) and the former two are described later in this report as they have formed part of the UK trials. A reference is made to the workability of the CBM material and to providing sufficient time in the works programme to ensure that compaction can be carried out prior to the cessation of workability. French experience to date was summarised by Lefort as the ‘unquestionable effectiveness of inducing cracks’. A reduction in the thickness of asphalt overlay was recognised as feasible, however the main feature of induced cracking was believed to be a reduction in maintenance costs rather than a reduction in initial construction costs. This factor is acknowledged as a sensible assertion for French pavements as they accept reflection cracking and maintenance thereof. In the United Kingdom it is believed more of a saving could be made in construction costs due to the current use of thick asphalt overlays (200 mm) to eliminate reflective cracking completely when the road is in service.

Verhée (1996) reported on the OLIVIA technique and results obtained to date where sites had been cracked using this technique. Table 1, taken from Verhée, illustrates the results obtained and the success of the OLIVIA technique in France to date.

Scarpass et al (1996) presented a RILEM paper which summarised a more comprehensive document by

Table 1 Use of the OLIVIA induced cracking technique in France

Location	*Date*	*Pavement structure*	*Traffic loading*	*Transverse surface cracks to January 1996*
RD-108 St Rogatien	October 1992	40 mm asphalt concrete 40 mm asphalt concrete Geotextile 200 mm grave laitier + OLIVIA 220 mm stabilised sub-base	150-300 c_v/l/d	None NOTE: $c_v/l/d = \frac{\text{commercial vehicles}}{\text{lane/day}}$
RN-124 Beegar	August 1993	60 mm asphalt concrete Geotextile 220 mm grave laitier + OLIVIA 250 mm stabilised sub-base	475 c_v/l/d	Main route: None **Control sections:** No geotextile, no OLIVIA = Some Geotextile, no OLIVIA = Some No geotextile + OLIVIA = None Geotextile + OLIVIA = None
RD-621 Tarn	June 1994	30 mm asphalt concrete 150 mm CBM + OLIVIA	150-300 c_v/l/d	Main route: Some **Control section:** No OLIVIA: erratic cracking every 3-5 m
RN-57 Epinal	October 1993	40 mm asphalt concrete 60 mm asphalt concrete Geotextile 250 mm CBM + OLIVIA 200 mm cement stabilised sub-base	1600 c_v/l/d	Main route: None **Control sections:** Geotextile + OLIVIA = None OLIVIA only = None Geotextile only = None

Gaarkeuken et al (1996). These documents deal with the finite element analysis of pavements and in particular the consequences of cracking. Two further documents which deal with the finite element analysis of temperature effects in pavements should be considered at the same time and these are by de Bondt (1995) and de Bondt and Steenvoorden (1995). Fundamentally all these documents deal with the theoretical analysis of composite pavements in order to assess pavement design and the benefits of anti-reflective cracking solutions. The finite element package used is CAPA, a system developed by Delft University of Technology with the support of the Netherlands Technology Foundation. CAPA has been developed to consider the arbitrary geometry, boundary conditions, loading, interlayer bonding and simulation of discrete cracks in the pavement and the interactions thereof. Although not specifically addressing the art of inducing cracks within composite pavements, the case studies presented do suggest that a fully theoretical assessment of induced cracking could be carried out and a detailed analysis of the size, spacing and effectiveness of cracks adjudged.

3 Methodology

3.1 General

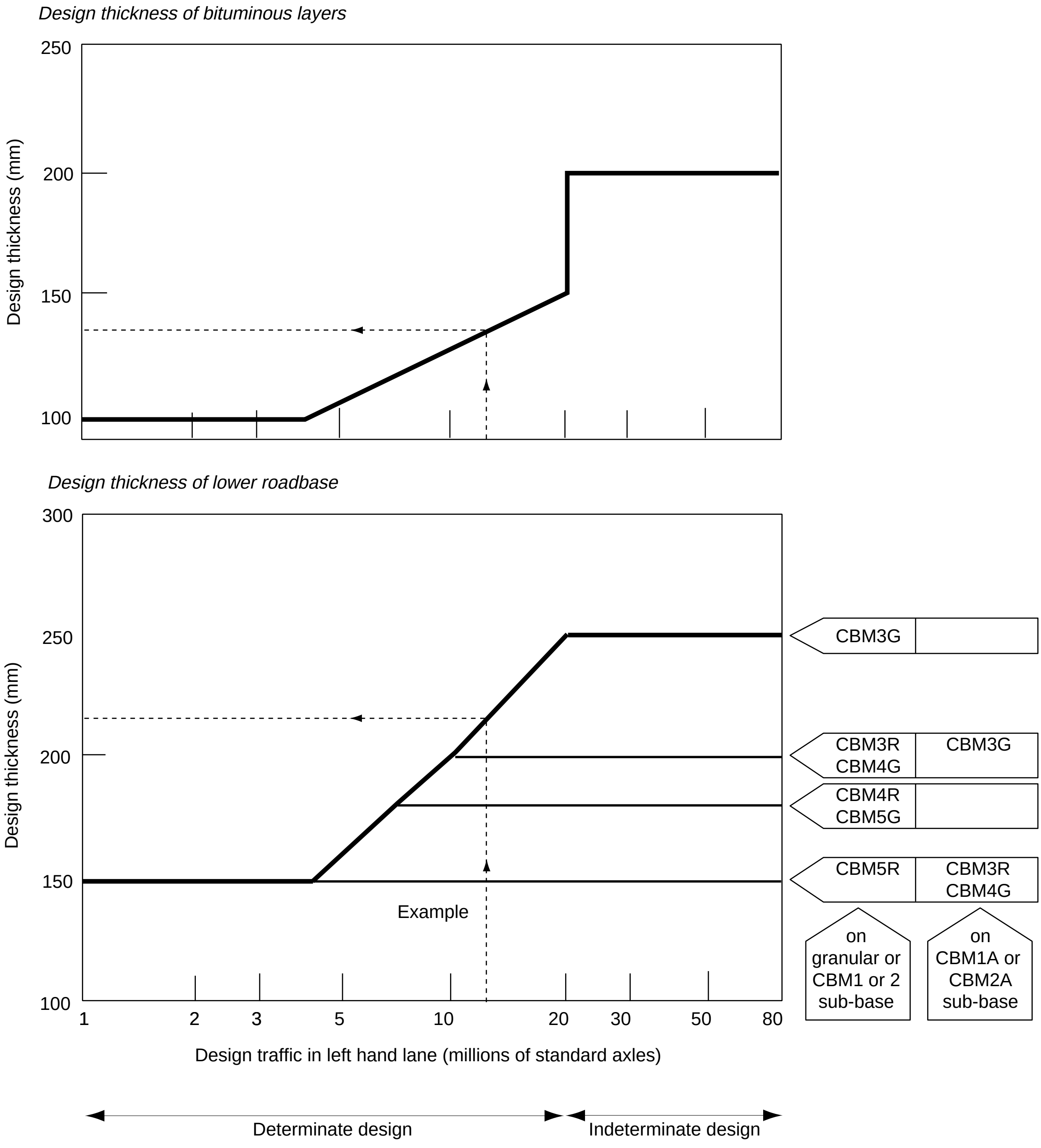
Induced cracking has been developed in continental Europe, and in particular in France. In the early stages of this research investigation a detailed review of techniques to induce cracks was undertaken. Inducing of cracks as a construction technique occurs during the laying of the roadbase material. Typically a groove is inserted into the fresh CBM material and a crack retention medium inserted prior to compaction. The purpose of the crack retention medium is to ensure that the crack does not close up completely, thus allowing a fine crack to remain and allow thermal movements to occur. An important consideration when using an induced cracking technique is the characteristics of the cement bound material to be cracked. The United Kingdom specification for cement bound materials is summarised below together with the requisites of the materials required to construct the full-scale trials. The induced cracking techniques which were previously investigated and used in the full-scale trials are also described together with the new TRL proposal for inducing cracks.

3.2 Materials

In the Design Manual for Roads and Bridges (DOT, 1994a) there are several categories of CBM which are specified for use in the construction of flexible composite pavements. The design chart identifying these is reproduced in Figure 1 and shows that there are currently four main categories, CBMs 1,2,3 and 4. In addition, category CBM5 is to be added to the design chart shortly. The differences between the CBM materials are summarised in Table 2.

As can be identified from Table 2, the materials to be considered for induced cracking are the CBMs 3, 4 and 5. The essential difference between these three materials is the overall material strength. The current thinking, which can be observed and confirmed during the construction of the full-scale trials, is that the spacing and the size of natural thermal stress cracks increases simultaneously with the strength of the material. This has previously been demonstrated by Potter et al (1985).

Figure 1 also identifies that there are different CBM aggregate characteristics relating to the thermal conductivity of the aggregate particles. Thermal conductivity is an additional feature which will affect the appearance of thermal stress cracks.



R = Roadbase having a coefficient of thermal expansion less than 10×10^{-6} per °C containing crushed rock aggregate
G = Roadbase containing gravel aggregate or Roadbase that has a coefficient of thermal expansion more than 10×10^{-6} per °C, containing crushed rock aggrgate

Figure 1 Design chart for Flexible Composite Construction (taken from DoT, 1994)

Table 2 Differences in CBM material characteristics

CBM Category		*Grading (% by mass passing)*										*7 day compressive strength (N/mm^2)*	*Usage*
Sieve size (mm)		50	37.5	20	10	5	2.36	.600	.300	.150	.075		
CBM1		100	95	45	35	25		8	5		0	4.5	Sub-base
CBM2		100	95	45	35	25	15-90	8-65	5-40		0-10	7	Sub-base
CBM3												10	Roadbase
CBM4	20 mm	-	100	95		35-55		10-35		0-8	0-5	15	Roadbase
CBM5	40 mm	100	95	45-80		25-50		8-30		0-8	0-5	20	Roadbase

In order to be more conclusive with the results of the full-scale trials it has been considered important to evaluate as many of the features as possible. Fortunately, the trial sites that were located and have been constructed will enable all three roadbase categories of material to be trialled. A summary of the full-scale trials is given in Table 3 to illustrate the range of materials that have been included. It should also be noted that three of the four trial site locations have pavement designs with cemented sub-bases. These sub-bases will affect the stiffness of the pavement as a whole and may affect the apparent stiffness of the roadbase. However, they are not thought to affect thermal movements in the roadbase and therefore they have not been cracked. During monitoring further determinations of the effects of cemented sub-bases may be made. Currently, the thermal movements of the sub base are not thought to be significant as the temperature change in the pavement reduces with depth. However, an important consideration would be the location of natural cracks in the sub-base in relation to formed cracks in the roadbase. It is important to ensure that these two features are not within close proximity otherwise the sub-base crack may play a role in the movements of the induced crack.

3.3 Crack forming equipment

3.3.1 Vibrating plate

The simplest and earliest use of a crack forming technique is that of a vibrating plate with a blade welded on to the bottom (Plate 1). In this process, the grader/paver lays the roadbase and applies initial compaction. The vibrating plate then traverses the pavement (Plate 2) and emulsion is inserted into the crack, typically by watering can (Plate 3). Finally vibration compaction of the roadbase takes place (Plate 4) ensuring that the crack closes up and load transfer characteristics through the medium are maintained. This technique has been used at all the trial site locations and will be used as a baseline for the other techniques which have been used at some of the sites.

Table 3 Full-scale induced cracked CBM trial sites in the United Kingdom

Location	*A149 Ormesby Bypass, Norfolk County Council*				*A605 Warmington Bypass, Northamptonshire County Council*				*A256 Whitfield to Eastry Bypass, Kent County Council*			*A1(M), RMG*
Date	*23-31 July 1996*				*20-30 August 1996*				*23-24 October 1996*			*28/10/96*
Equipment	*None*	*Arrows Breaker*	*Vibra -ting plate*	*OLIVIA*	*Vibra -ting plate*	*None*	*Vibra -ting plate*	*None*	*CRAFT*	*Vibra -ting plate*	*None*	*Vibra -ting plate*
Crack spacing (m)	None	3.0	3.0	3.0	3.0	None	3.0	None	3.0	3.0	None	3.0
Crack retention	None	None	★	●	★	None	★	None	★	★	None	★
Asphalt thickness (mm)	130	130	130	130	100	100	200	200	200	200	200	170
Surfacing type	HRA	HRA	HRA	HRA	HRA	HRA	SMA	SMA	HRA	HRA	HRA	HRA
Roadbase thickness (mm)	205	205	205	205	150	150	180	180	150	150	150	180
Roadbase type	CBM3	CBM3	CBM3	CBM3	CBM3	CBM3	CBM5	CBM5	CBM4	CBM4	CBM4	CBM4
Sub-base thickness (mm)	150	150	150	150	150	150	150	150	150	150	150	200 200
Sub-base type	CBM1	CBM1	CBM1	CBM1	Type 1	Type 1	Type1	Type 1	CBM1	CBM1	CBM1	CBM2 CMB2
Section No.	1	2	3	4	5	6	7	8	9	10	11	12

▨ Control section ★ Emulsion ● Plastic film

Plate 1 Vibrating plate equipment

Plate 2 Vibrating plate traversing CBM roadbase

Plate 3 Inserting emulsion into vibrating plate crack

Plate 4 Compaction of vibrating plate induced cracks

3.3.2 Craft

CRéation Automatique de Fissures Transversales (CRAFT, Automatic Creation of Transverse Cracks) is an automated cracking process developed by Laboratoires Régional des Ponts et Chaussées d'Autun (LCPC) and Cochery Bourdin Chaussée (CBC) in France during the late 1980s. The technique is identical to the vibrating plate in that an emulsion is inserted to retain the crack, however, it is an automated process operated by one man (see Plates 5, 6 and 7).

Plate 5 CRAFT crack forming equipment

Plate 6 CRAFT pivot arm to traverse pavement layer

Plate 7 CRAFT crack forming blade

3.3.3 OLIVIA

Outil que Laribe Inventa pour VIA France (OLIVIA) is an automated induced cracking process developed by Via France in France during the early 1990s. This machine uses a different technique of joint retention to the other methods. OLIVIA forms cracks at a rate similar to that of the CRAFT machine and inserts a strip of thin plastic film, between 40 and 80 µm thick in the fresh roadbase, see Plates 8, 9 and 10. The width of the plastic film is 60, 80 or 100 mm and is selected so that it can be inserted to between 1/3 and 1/5 of the roadbase thickness.

3.3.4 Guillotine technique

From TRL's experience of the 'crack and seat' method for maintaining concrete pavements, a proposed method was developed of using a 'crack' method during construction rather than as a maintenance method. The crack and seat method for maintaining pavements was developed in the United States and has been investigated in detail in the United Kingdom by TRL (Potter and Mercer, 1996). The 'crack' is used to form shorter discrete slab lengths in the concrete pavement to allow thermal movements to be reduced. The 'seat' is the final compaction by vibrating roller to ensure that fine cracks are created and that no further movements will occur once an overlay has been

Plate 8 OLIVIA crack forming equipment

Plate 9 OLIVIA crack forming blade

Plate 10 OLIVIA blade traversing CBM - plastic film roll

placed. To adapt the technique for inducing cracks, an Arrows breaker traversing guillotine was used to produce fine cracks in the CBM base at six-day strength prior to overlay with the flexible layers. This technique was used at one of the trial sites and is illustrated in Plates 11, 12 and 13.

Plate 11 Arrows breaker guillotine equipment

Plate 12 Arrows breaker - view of drop weight

Plate 13 Arrows breaker - view of ‘breaker’ head plate

3.4 Monitoring techniques

Initial monitoring during construction was carried out using the Falling Weight Deflectometer (FWD) and core samples. The FWD was used for two separate assessment methods, see Figure 2. Firstly, the load transfer characteristics of the induced cracks were compared to the natural cracks in the control section. Furthermore the stiffness of the induced cracked roadbase was compared to the naturally cracked control sections. Core samples were then taken at the cracks to assess and confirm by visual inspection the results obtained for load transfer and to assess the size and orientation of the cracks. In some instances it was not possible to locate the cracks by eye and the cores were subsequently vacuum pumped with fluorescent dye to locate any fine cracks.

At first, the stiffness characteristics were considered using mid-span deflections from the FWD. However, following a review of pavement design models and lengthy discussions with RMG (Roads Management Group, Construction Joint Venture), who are inducing cracks in the A1(M) Alconbury to Peterborough as part of their DBFO (Design, Build, Finance and Operate) concession, an assessment of stiffness characteristics from FWD deflections at 0.5 m spacing including at the crack location has also been undertaken.

All the results from the initial monitoring are reported and discussed in sections 5.0 and 6.0.

4 Trial sites

4.1 General

It is important to conduct full-scale trials in the United Kingdom because data from continental practice is limited and the technique could be affected by United Kingdom climate and material specifications. Trial sections were designed in 150 m lengths. The purpose of this length was to ensure that an adequate number of naturally occurring cracks would be produced in the control sections. The simple vibrating plate with welded blade was used at all sites, this technique then also acts as a control technique for the other techniques which were used at some of the sites.

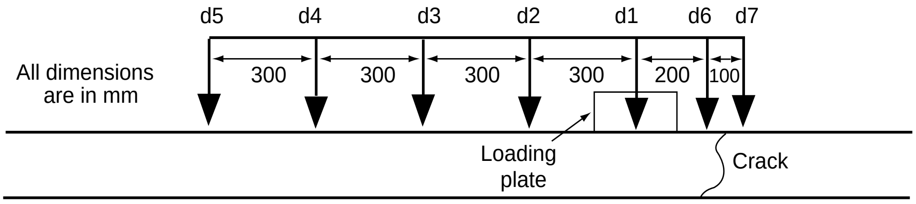
There were no flexible composite construction sites available through the Highways Agency at this time, so assistance of the Local Authorities and a DBFO consortium was sought. Sites were sought with different pavement designs thus removing the need to vary pavement design at any location. Four trial sites were located and the features of each trial have been illustrated in Table 3. The trial and control sections have been numbered consecutively from site to site thus minimising the risk of confusion between results from different sites. In the sections below the characteristics of each site are described in more detail and observations made during construction and initial monitoring are provided.

4.2 A149 Ormesby St. Margaret bypass

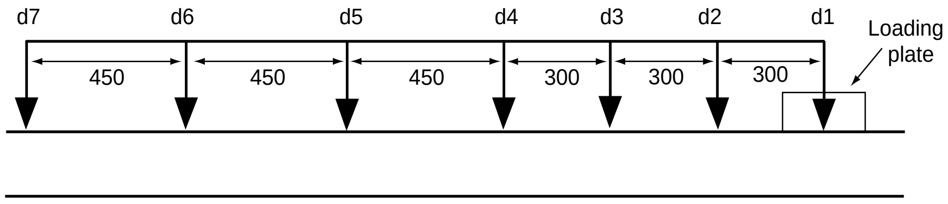
4.2.1 Background to project

The A149 Ormesby St. Margaret Bypass is a scheme constructed as part of Norfolk County Council’s (NCC) continued investment into their local infrastructure. The A149 is the inland Norfolk coast road running from King’s Lynn to Great Yarmouth. Ormesby St. Margaret is a village on the outskirts of Great Yarmouth. The new scheme consists of dualling up and redesignation of an existing single carriageway section of the A1064, a new roundabout junction on the A1064 and construction of a 9.3 m wide single carriageway across existing farmland to rejoin the existing A149 to the west and beyond Ormesby St. Margaret.

The scheme was known to be going ahead with a flexible composite construction when TRL contacted the Contractor. The Contractor agreed to trials subject to the approval of NCC. The Resident Engineer provided the contact for the NCC customer who was contacted and approval was given following a brief telephone discussion on the induced cracking principles and the agreement that no additional costs would be incurred by the contract. A site meeting was



(a) FWD geophone test configuration at crack



(b) FWD geophone configuration at mid-slab

Figure 2 FWD test configurations

held between TRL, the Contractor and NCC prior to the trial taking place. It was agreed that all four techniques could be used subject to the logistics of availability of plant and no interruption to the construction contract.

4.2.2 Pavement design and trial sections

There were several pavement design options included in the contract documents, fortunately for TRL the Contractor elected to use a CBM3 roadbase with 130 mm overlay. The foundation to the roadbase was quite substantial. Due to concerns by the design office over the effect of long term moisture content, a CBR requirement of 30% had been placed upon the Contractor. Therefore, the sub-grade was cement stabilised throughout the site, in addition crushed concrete replacement was used at several locations adjacent to services. The sub-base throughout the contract was CBM1. The aggregate used for both CBM materials was an irregular shaped flint gravel aggregate which was supplied from a nearby quarry.

The 130 mm overlay specified by NCC is suited to TRL’s monitoring purposes. NCC are aware that reflection cracking occurs in their flexible composite roads and have a monitoring plan to maintain reflection cracking should it occur. Based on TRL’s experience an overlay of 130 mm should be thin enough for there to be signs of reflection cracking within the control section within the timescale of this project.

Five sections were originally proposed for the A149 site, four test sections involving different induced cracking techniques and one control section. Unfortunately, the CRAFT machine broke down after it had arrived on site and returned to France unused. This reduced the number of sections to four, but did allow for a more varied approach at a later site when the CRAFT machine returned. A schematic of the site layout is provided in Figure 3.

4.2.3 Observations during construction and initial monitoring

In all four sections the crowned carriageway CBM was grader laid with a Caterpillar D4H Series II, this was followed by vibratory compaction using a Bomag BW160AD tandem roller (operating at 9 tons), final compaction with a Bomag BW100AD (1.5 tons) and final finishing with a common garden roller to remove surface marks. The material was nominally compacted by the grader and four passes with the vibratory compactor achieved the required density. The CBM was laid at a full width of 10.3 m in one rip without any longitudinal joints. Core samples were taken and showed the angular aggregate to provide a good interlocking medium, more discussion on the core results is provided in section 5.1. General observations made during construction and initial monitoring at each trial section are outlined below.

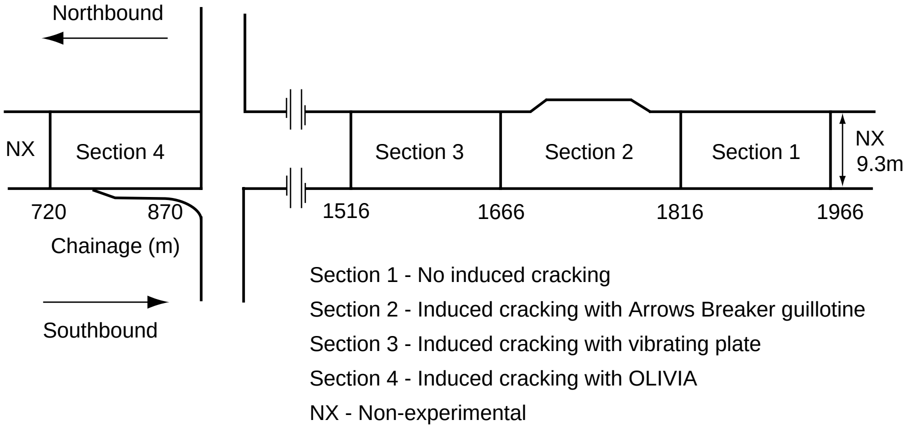
Section 1 - Control section

The section was laid as described above and the temperature range during the laying day was recorded at a maximum of 30.6°C and a minimum of 10.2°C.

After seven days, naturally occurring thermal stress cracks had appeared in the control section. The cracks were easily visible to the human eye and spaced, on average, at 15 m centres. Complete core samples were unable to be recovered at the crack locations as the cracks were fully developed and the material broke down completely during coring. From one small core section that was obtained (approximately $^1/_3$ thickness) the vertical orientation of the crack was irregular.

Section 2 - Arrows breaker guillotine

The section was laid as described above and the temperature range during the laying day was recorded at a maximum of 29.0°C and a minimum of 17.0°C. After six days the induced cracking technique was put to the test. The machine used was an Arrows Breaker, the drop weight had a load face of 16 in^2, weighed 625 kgs and had a load capability of 1,000-24,000 kN. Initially, problems were encountered whereby the surface of the roadbase suffered severe break-up even when the drop height was adjusted to a minimum. Different blades were tried until a tamper weight was found to be successful when fitted with an improvised steel bar bead. The latter reduced the amount



Section 1 - No induced cracking
Section 2 - Induced cracking with Arrows Breaker guillotine
Section 3 - Induced cracking with vibrating plate
Section 4 - Induced cracking with OLIVIA
NX - Non-experimental

All sections are 205mm CBM3 with 130mm overlay

Figure 3 A149 Ormesby St. Margaret Bypass, schematic layout of trial sections of spalling, was used to complete the 150 m trial length, and is the loading head illustrated in Plates 11, 12 and 13). During the cracking operation with the Arrows Breaker it was observed that increased spalling occurred at the crown of the carriageway where compaction appeared to be a problem at the upper surface. In addition from the cores taken no cracks were identified by eye.

During the initial cracking period core samples were taken to verify the effectiveness of the procedure. All cores were extruded in a complete state but no induced cracks were identifiable to the human eye. Further cores were taken on completion of the procedure, but again, no cracks were visible to the human eye. All the cores were returned to TRL for further analysis to see if fine cracks could be detected, and the results of this work are detailed in section 5.1. A possible reason for no visible cracks could be that there was insufficient reaction from the low strength CBM (i.e. 6 day strength). The pavement may have only deflected under impact without cracking and an older (higher) strength may be required to ensure crack propagation.

A further observation relates to the occurrence of natural cracks. No natural cracks were visible in the section 6 days after laying. Following the induced cracking a further visit was made six days later and still no cracks were observed in the section. Although the induced cracks are not visible to the eye, the lack of natural cracks implies that the induced cracking technique is functioning to some extent.

Section 3 - Vibrating plate

The section was laid as described above and the temperature range during the laying day was recorded at a maximum of 30.0°C and a minimum of 14.4°C. The vibrating plate technique was carried out as described in section 3.3.1 with the vibrating plate traversing the pavement once the grader had completed levelling of the CBM. Due to the technique of laying the CBM by grader, the induced cracking method did interfere with the usual laying programme. This was because a whole new phase had entered the programme. Under normal circumstances the grader laid and levelled approximately 40 m of CBM and this was followed immediately by 40 m of compaction. When the vibrating plate was introduced it had to crack the 40 m after the grader had finished and before the roller could start compaction. As the CBM was being laid in a 9.3+ m width the 2 hr compaction time frame was relaxed; the technique was fortunate that it was an overcast day and the workability of the CBM was maintained for a longer time period.

In addition, problems were encountered with the vibrating plate blade (different to equipment shown in Plate 1). The difficulty was that the length of the blade did not extend far enough along the plate base and meant that the groove was slightly closed by the compaction of the vibrating plate. To counteract this factor, on completion of the traverse, the groove was opened up by hand trowelling to allow the watering can to pour in emulsion to retain the crack.

The emulsion used was bitumen emulsion A1-40 an anionic grade which was selected as the same emulsion being used as the CBM curing agent. Although a slower setting solution than the desirable cationic emulsion, the emulsion worked as required and from the cores that were taken produced the ideal result of a vertical hairline crack throughout the thickness of the CBM. The technique of using the watering can for emulsion insertion was adequate for the purpose. However, the volume of emulsion entering the crack was difficult to control and if too great, the emulsion was compressed out of the crack during construction and stuck upon the roller's drums. Ideally, a control to the emulsion entering the crack would be desirable and a faster setting solution may minimise any excess emulsion sticking to the roller drums. It is important that the emulsion sticks to the sides of the crack and does not just form a pool at the bottom of the crack.

Section 4 - OLIVIA

The CBM was laid by grader as described above and the temperature range during the laying day was not recorded. However, the range on days either side was a maximum of 28.3°C and a minimum of 10.1°C. The OLIVIA technique was carried out as described in section 3.3.3 with the OLIVIA equipment traversing the pavement in three sections once the grader had completed levelling of the CBM. Due to the technique of laying the CBM by grader, the OLIVIA equipment did slow down the laying programme. This was because a whole new phase had entered the programme as in the vibrating plate method above. Nevertheless, the OLIVIA equipment was a one man operation and performed much quicker than manhandling the vibrating plate and watering cans. The 2 hr compaction time frame was relaxed but not as much as for the vibrating plate and it was fortunately another overcast day and the workability of the CBM was maintained for a longer time period.

Overall, the OLIVIA equipment performed well and was a much faster and more clinical operation than that of the vibrating plate. The operator did encounter problems due to the differing design mix used in the United Kingdom. In France the CBM material closes up behind the blade whilst the traverse is continuing and assists with holding the plastic film in place. The CBM mixture in the United Kingdom is much drier and therefore less workable. After several attempts to adjust the equipment on site and hand holding the plastic during the traverse, the operator returned to the compound and was able to adjust the equipment in a way which improved this problem. Therefore there is a gap in the trial section where this break took place.

Unfortunately, when the return visit was made for initial monitoring the coring rig malfunctioned and no cores were able to be taken. However, at the same time operatives on the site were breaking out the CBM for gully locations and observations were able to be made of the plastic film within the CBM layer, see Plate 14. Observations were made at two locations, both of which included the plastic film at mid depth. In addition, at the location shown in Plate 14 the break out edge was across an induced crack and the surface where the plastic film had been was observed to be smoother and less irregular than elsewhere. This feature is

Plate 14 Gully break out at OLIVIA crack location

almost identifiable in Plate 14 and raises the question of load transfer capabilities, discussed in section 5.2.

4.3 A605 Warmington Bypass

4.3.1 Background to project

The A605 Warmington Bypass is a scheme constructed as part of Northamptonshire County Council's (Engineering Services Laboratory, ESL) continued investment into their local infrastructure. The A605 is an east west route from east of Peterborough to Wellingborough. Warmington is a village in rural Northamptonshire and a commuter village for Peterborough. The new scheme consists of constructing a new roundabout junction on the A605 to the west of Warmington and an off-line 9.3 m wide single carriageway across existing farmland to the north of Warmington to rejoin the existing A605 to the east.

The scheme was known to be going ahead with a flexible composite construction when TRL made an impromptu site visit to the Contractor. The Contractor agreed to trials subject to the approval of ESL. The Resident Engineer provided the contact for the ESL customer who was contacted and approval was given following a briefing document on induced cracking principles and the agreement that no additional costs would be incurred by the contract. The vibrating plate was illustrated as a suitable crack inducing technique and it was agreed to use it in the trial sections.

4.3.2 Pavement design and trial sections

The Contractor had elected to use a CBM3 roadbase with 100 mm overlay on side roads and a section of the first CBM5 roadbase laid in the United Kingdom with 200 mm overlay for the main line. The foundation to the roadbase was conventional Type 1 sub-base. The aggregate used for both CBM materials was an irregular shaped flint gravel which was collected from a nearby quarry.

A schematic of the site layout is provided in Figure 4. The 100 mm overlay specified by ESL suited TRL's monitoring purposes. Based on TRL's experience an overlay of 100 mm should be thin enough for there to be signs of reflection cracking in the control sections within the timescale of this project. In addition, the use of a CBM5 roadbase should produce thermal cracks in the control section at a larger spacing and therefore the individual cracks should be wider.

4.3.3 Observations during construction and initial monitoring

In all four sections the CBM was grader laid with a Caterpillar D4H Series II, this was followed by vibratory

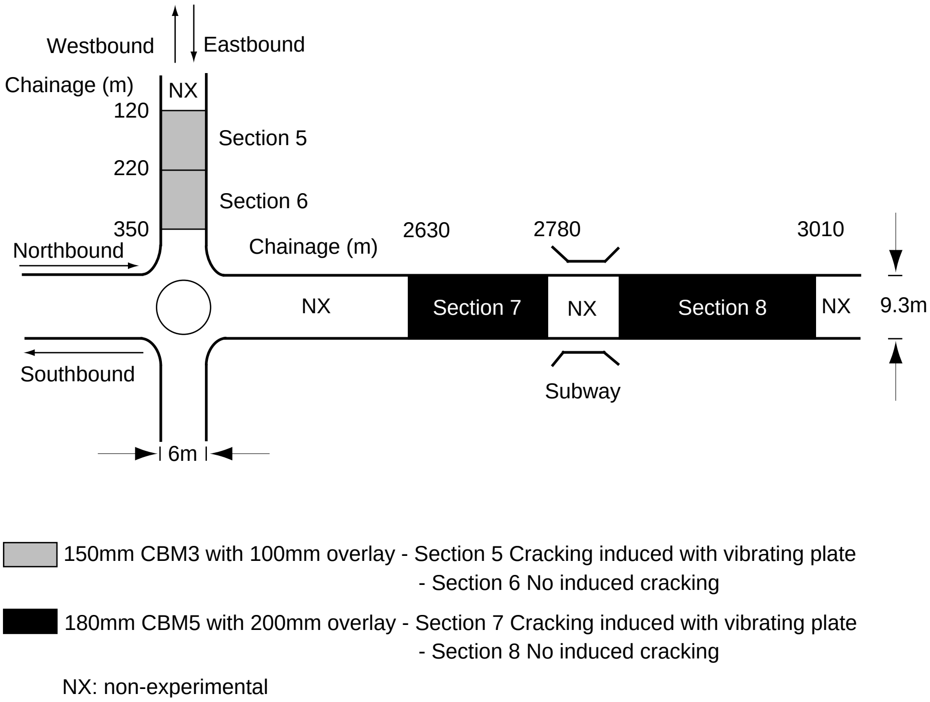


Figure 4 A605 Warmington Bypass schematic layout of trial sections

compaction using a Bomag BW160AD tandem roller (operating at 9 tons) and final compaction and finishing with a Bomag BW100AD (1.5 tons). The material was nominally compacted by the grader followed by one pass for the CBM3 and five passes for the CBM5 with the vibratory compactor to achieve the required density. The CBM was laid in one rip without any longitudinal joints at a full width of 6.0 m for the side road and 10.3 m for the main line. Core samples were taken and showed the angular aggregate to provide a good interlocking medium, more discussion on the core results is provided in section 5.1. General observations made during construction and initial monitoring at each trial section are outlined below.

Sections 5 and 7 - Vibrating plate

The CBM was laid as described above and the vibrating plate technique was carried out as described in section 3.3.1 with the vibrating plate traversing the pavement once the grader had completed levelling of the CBM. Due to the technique of laying the CBM by grader, the cracking method interfered with the usual laying programme as outlined in trial section 3.

The problems encountered with the vibrating plate blade in Section 3 were rectified for these sections and the equipment used is that shown in Plate 1. The depth of the crack inducing blade was 80 mm, assumed to be sufficient for the CBM3 layer at 150 mm and the CBM5 layer at 180 mm. From visual inspection and the core samples the blade depth appears more important than originally supposed. In the CBM3, a groove greater than half depth led to large visual cracks on the surface of the roadbase and wider cracks through the cores. Whereas for the CBM5 the 80 mm groove during construction (prior to final compaction) led to an emulsion discontinuity at only $^1/_3$ depth, very fine cracks and hence a suspicion that cracks may not be to full depth at all induced crack locations.

The emulsion used was bitumen emulsion A1-40 an anionic grade which was selected as the same emulsion being used as the CBM curing agent. It performed in the same way as when it was used on the A149 (described in section 4.3.2).

When the return visit was made to section 5 from visual inspection there were fears that the technique had not performed well. The induced cracks were either invisible or ‘apparently’ very wide. However, upon coring the samples taken showed fine cracks to full depth at each different visual observation site. In addition, the load transfer efficiency assessment, discussed in section 5.2, illustrates the perfect philosophy for induced cracking when compared to its control section. Thus when a specification is introduced, at this stage, it cannot be entirely based on visual observations during construction, but must also involve careful monitoring by at least a trial section at each site and the taking of core samples.

These sections were laid as described above and after seven days naturally occurring thermal stress cracks had appeared in both control sections. The cracks were easily visible to the human eye and spaced, on average, at 15 m centres in the CBM3 and 20 m centres in the CBM5. Core samples were taken and although extruded in one piece, easily separated on removal from the core barrel.

4.4 A256 Whitfield to Eastry

4.4.1 Background to project

The A256 Whitfield to Eastry is a road improvement scheme being undertaken for Kent County Council (KCC). The A256 runs from Dover, north to Margate on the Isle of Thanet on the Kent coast. The scheme consists of replacing 12 km of single carriageway with an off-line dual carriageway on adjacent farmland. The new road will connect the existing bypasses of Whitfield and Eastry.

TRL contacted the Contractor when informed that the scheme was going ahead as a flexible composite construction. The Contractor agreed to the trials subject to approval by KCC. The Deputy Resident Engineer acted as the contact for KCC. Following a site meeting and discussion of the principles and objectives of the trial, approval was given subject to no extra costs or delays being incurred on the contract.

4.4.2 Pavement design and trial sections

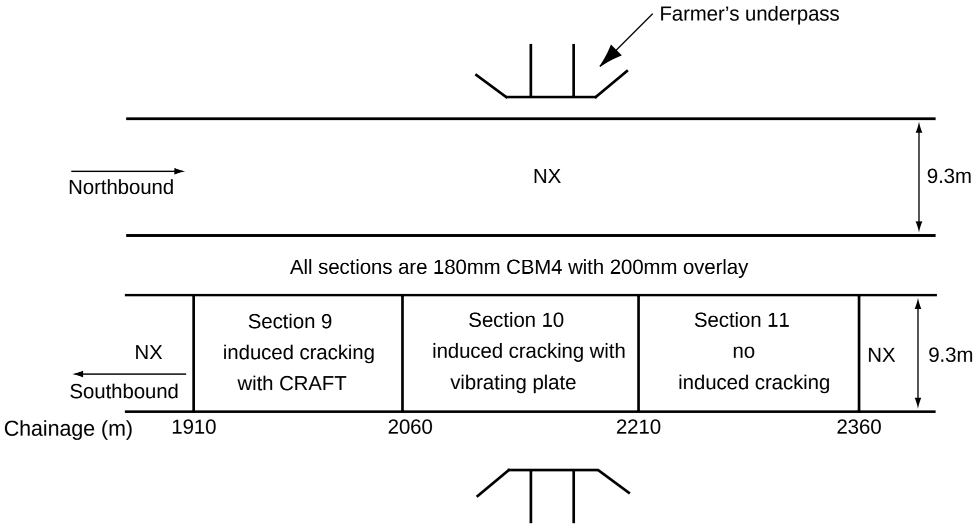
There were several pavement design options included in the contract documents, including two flexible composite options. The difference in these relates to the KCC specification for flexible composite construction. Although previously not acceptable by KCC, their specification for highway design does now permit the use of flexible composite construction with the proviso that if the overlay is less than 200 mm a geotextile membrane shall be inserted between roadbase and basecourse. The Contractor elected to use flexible composite construction, allowing this section of the A256 to fall within the scope of this trial, with a 150 mm CBM1 sub-base, 150 mm CBM4 roadbase and 200 mm of asphalt overlay. This design led to a substantial foundation to the pavement as the majority of the route is based on chalk bedrock. The aggregate used for both CBM materials was an irregular shaped flint gravel which was collected from a nearby quarry.

This site was initially intended to be set up at the same time as the A149 Ormesby Bypass, with the identical testing of four different induced cracking methods. However, the construction of the CBM roadbase did not coincide with that of the A149 and the alternative methods were programmed for the A149 which is a potentially more useful trial site due to its thinner overlay. The CRAFT machine could not operate at the A149 due to a malfunction with the emulsion pump and the A256 provided an ideal site to use for its return. The vibrating plate was also used, providing a common link between this site and the previous sites. Thus three sections were set up, two technique trials and one control.

A schematic of the site layout is provided in Figure 5.

4.4.3 Observations during construction and initial monitoring

In all three sections the CBM materials were paver laid with a Blaw Knox BK95, followed by vibratory compaction using a Bomag BW161AD tandem roller



Section 9 - Induced cracking with CRAFT
Section 10 - Induced cracking with vibrating plate
Section 11 - No induced cracking
NX - Non-experimental

All sections are 180mm CBM4 with 200mm overlay

Figure 5 A256 Whitfield to Eastry schematic layout of trial sections

(operating at 9 tons), and final compaction/finishing with a Bomag BW130AD (1.5 tons). The material was nominally compacted by the paver and four passes with the vibratory compactor achieved the required density. The CBM4 was laid in three rips to obtain a full width of 10.3 m without any longitudinal joints. The temperature range during the laying day was recorded to be between 10-16°C. Core samples were taken and showed the angular aggregate to provide a good interlocking medium, more discussion on the core results is provided in section 5.1. General observations made during construction and initial monitoring at each trial section are outlined below.

Section 9 - CRAFT

The section was laid as described above. It was found that the nominal compaction by the paver was insufficient for the equipment to drive on the layer without causing excessive rutting. To combat this problem an initial pass was made by the BW161AD allowing adequate support for the CRAFT. Once this problem had been rectified the method worked very effectively. There was no disruption to the laying programme once a sequence had been organised because the CRAFT method was a simple one man operation.

Two visits were made for initial monitoring due to the lack of natural cracks in the control section after seven days. On the second visit at 17 days natural cracking had occurred and full monitoring took place. From visual inspection it appeared that the induced cracks were only functioning after every 10 or so cracks (i.e.: the cracks in between were invisible). However, once complete core samples were taken at several different crack locations this was found not to be the case. Every core in this section exhibited a vertical full depth crack, typically as shown in Plate 17.

Section 10 - Vibrating plate

The vibrating plate technique was carried out as described in section 3.3.1 with the vibrating plate traversing the rip as soon as the paver moved on. There was no interference with the laying method however, the operation was much more arduous than on previous sites as the paver was in continual motion and the induced cracking operation had to follow at the same rate of progress. The emulsion used was bitumen emulsion K1-40 a cationic grade which was selected as the same emulsion being used as the CBM curing agent. There was still a problem of emulsion interfering with the rolling drum as described above and one of the site operatives developed a control for the emulsion pouring rate by fixing a block to the watering can outlet.

The appearance of the cracks was similar to those in Trial Section 9, and again, (as in Section 9) the cores did show vertical full-depth cracks at each induced crack location tested including those that were not visible at the surface.

Section 11 - Control

The section was laid as described above. As stated for Section 9, no cracks were visible at 7 day inspection and it was necessary to conduct a second visit at 17 days. On the second visit the cracks were easily visible to the human eye, complete core samples were taken at several locations and although extruded in one piece, easily separated on removal from the core barrel.

4.5 A1(M) Alconbury to Peterborough

4.5.1 Background to project

The A1(M) Alconbury to Peterborough is 12 km dual carriageway, three lane plus hard shoulder off-line widening of the existing A1. The scheme was included in tranche 1 of the DOT's private finance initiative. The tender process involved the development of DBFO consortia to bid for the design, construction and maintenance of several schemes. The tender for this scheme was awarded to the Roads Management Group (RMG) consortium which is made up of AMEC, Alfred MacAlpines, Dragados and Brown & Root.

TRL approached RMG to monitor a section of the site. This led to trial Section 12 without an associated control section.

A schematic site layout of the site is provided in Figure 6.

4.5.2 Pavement design and trial sections

After many deliberations by RMG the elected pavement design for the entire scheme is sub-grade (stabilised in places) overlaid by 200 mm CBM2, 150 mm CBM2 and a roadbase of 180 mm CBM4. The design loading for the pavement is in excess of 300 msa (million standard axles) and as such beyond the limitations of DMRB Vol. 7. Nevertheless RMG had employed French pavement analysis techniques to ensure design life. Once the strategy of a flexible composite pavement design had been decided the question turned to how much asphalt basecourse and surfacing would be required. From DOT standards a minimum of 200 mm was indicated. However, RMG took induced cracking techniques into account and have reduced the overlay to 170 mm.

The aggregate used for all CBM materials was an irregular shaped flint gravel which was collected from nearby quarries.

Once RMG had opted for induced cracking, their representatives attended some of the TRL trials in order to select a technique for induced cracking. Although the OLIVIA and CRAFT (not seen) appeared to be very efficient one man operations they were not considered cost effective and as such the vibrating plate technique was selected and is being used to induce cracks in the entire site.

4.5.3 Observations during construction and initial monitoring

Section 12 - Vibrating plate

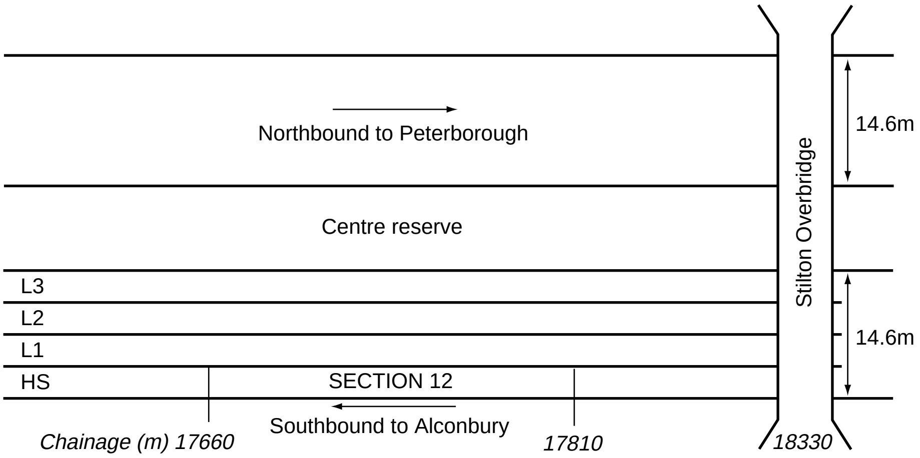
The vibrating plate technique was carried out as described in section 3.3.1. The cracking method did not interfere with the laying programme as it followed the routine described for Section 10. The emulsion used in joint retention was K1-40 cationic fast setting bitumen emulsion. This solution was ordered separately as the curing compound was a resin based aluminium spray. Several cores were taken and all exhibited full depth vertical cracks.

5 Results obtained from initial monitoring

5.1 Core samples

The core sample characteristics are identified in Table 4, and illustrated in Plates 15 to 17. The core samples in all the sections have aided the evaluation of the success of each induced cracking technique at each location.

In particular, at all locations it has been clearly shown that the natural cracks in the control sections (sections 1, 6, 8 and 11) were wider and the aggregate interlock insufficient to withstand loads due to coring. The natural



Section 12 - Induced cracking with vibrating plate

All sections are 180mm induced cracked CBM4 with 170mm overlay

Figure 6 A1(M) Alconbury to Peterborough schematic layout of trial section

Table 4 Core sampling characteristics

Section No.	*Crack No.*	*Direction*	*Chainage (m)*	*Thickness (mm) Design/Actual*	*Visibility of Crack at Surface*	*Crack Vertical Orientation*	*Remarks*
1	107	SB	1902	205 / NA	Core disintegration, therefore no judgements.		
	110	SB	1842	205 / NA			
2	202	SB	1813	205 / 210	None	NA	Fluorescent testing to be carried out to locate cracks
	203	SB	1810	205 / 210	None	NA	
	223	SB	1750	205 /	None	NA	
3	305	SB	1654	205 / 200	Very Fine	S0, F	Cracks only visible on wetting
	312	SB	1633	205 / 160	Very Fine	S0, F	
	327	SB	1588	205 / 205	Very Fine	S0, F	
	335	SB	1564	205 / 180	Very Fine	S0, F	
4			No cores due to equipment breakdown.				
5	505	WB	132	150 / 170	Medium	S15, F	Cracks cannot be seen to full depth for 2 out of 4; crack 518 has emulsion to full depth
	513	WB	156	150 / 170	Medium	S0, ½	
	518	WB	171	150 / 160	Wide	S15, F	
	528	WB	201	150 / 160	None	S0, ½	
6	604	WB	284	150 /150	Wide	S15, F	Cores separated on extrusion
	605	WB	300	150 / 140	Wide	S15, F	
7	702	NB	2633	180 / 200	Very Fine	S0, ½	Emulsion insertion has only reached $^{1}/_{3}$ depth at all locations
	726	NB	2705	180 / 190	Very Fine	S0, ½	
	732	SB	2723	180 / 195	Fine	S15, F	
	749	SB	2774	180 / 220	Very Fine	S0, ½	
8	802	SB	2865	180 / 210	Wide	S15, F	Cores separated on extrusion
	809	SB	3011	180 / 165	Wide	S15, F	
9	906	SB / L2	2040	150 / 140	None	S0, F	All emulsion is to full depth with a square widening of crack at the base
	907	SB / L2	2036	150 / 145	None	S0, F	
	909	SB / L2	2030	150 / 135	None	S0, F	
	923	SB / L2	1983	150 / 145	Medium	S0, F	
10	1024	SB / L2	2142	150 / NA	Fine	S0, F	Core at crack 1024 NOT to full depth; crack 1030 separated on extrusion
	1030	SB / L2	2124	150 / 160	Wide	S0, F	
	1039	SB / L2	2097	150 / 165	Fine	S0, F	
11	1103	SB / L2	2347	150 / 150	Wide	S15, F	Cores separated on extrusion
	1105	SB / L2	2307	150 / 165	Wide	S15, F	
12	1208	SB / HS	17790	180 / 160	Wide	S0, F	Core at crack 1228 NOT to full depth. All cracks were easily visible and 3 of the 7 cores have separated along the induced crack during storage
	1210	SB / HS	17784	180 / 160	Medium	S0, F	
	1217	SB / HS	17762	180 / 160	Fine	S0, F	
	1220	SB / HS	17753	180 / 185	Wide	S0, F	
	1228	SB / HS	17730	180 / NA	Fine	S0, F	
	1242	SB / HS	17690	180 / 150	Fine	S0, F	
	1244	SB / HS	17684	180 / 150	Wide	S0, F	

Vertical orientation: S0=Straight within 15 mm, S15= 15 to 30 mm, S30= >30 mm, F = full depth, ½ = half depth

crack cores that were able to be extruded to full depth separated easily upon removal from the core barrel, see Plate 15.

At each trial location the vibrating plate technique was used with favourable results. There are full depth cracks in the cores in all sections (sections 3, 5, 7, 10 and 12) though the widths and visibility do vary. In the CBM4 of sections 10 and 12 the cracks appeared to be wider and some of the core sections did separate on extrusion. However, for the CBM3 and CBM5 no separation has occurred and in some instances the cracks were very fine and only visible to full depth when drying out. It has been verified by the cores taken that if a crack is invisible at the surface it does not preclude the possibility of an induced crack being present. In addition, a review of the load transfer data from the FWD verifies that the appearance of the crack at the surface does not necessarily correspond to the width, shape or crack load transfer efficiency at any given location.

At sites where the other induced cracking techniques were used cores have also assisted with assessment of the techniques. Unfortunately, a mechanical breakdown on site means that there are no cores currently available for the OLIVIA technique (section 4) nevertheless it is planned to take cores at a later date.

For the guillotine technique using the Arrows Breaker (section 2) the cores were extracted where there was

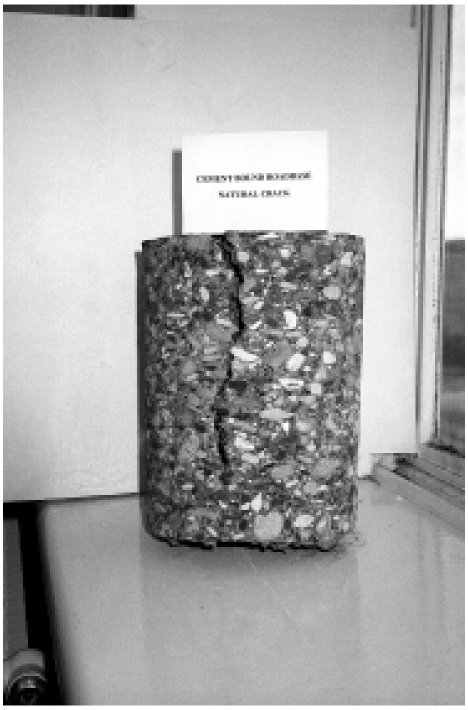


Plate 15 CBM core of natural crack

Plate 16 CBM core of crack formed using vibrating plate

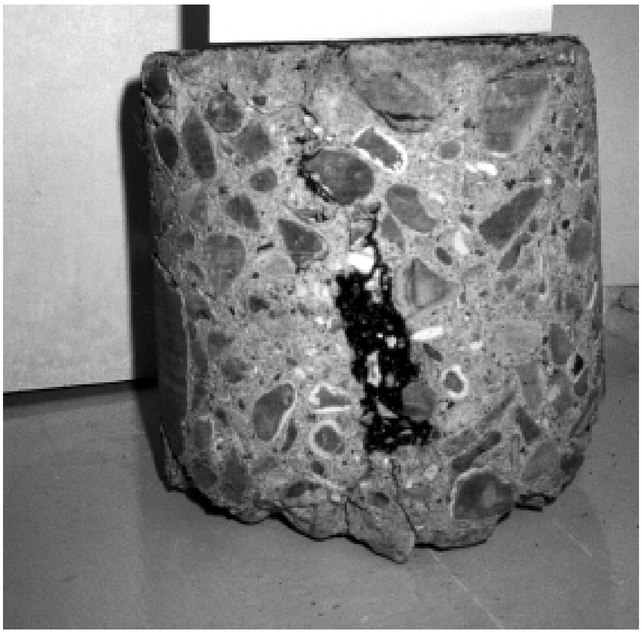


Plate 17 CBM core of crack formed using CRAFT technique

visible surface spalling at the crack locations. Below the surface spalling no further cracks can be seen with the human eye, including wet and dry observations. In an attempt to view the cores in more detail a technique has been tried of vacuum pumping the cores with fluorescent dye. This technique has proved successful for viewing cracks in concrete in the past but unfortunately no cracks could be identified at this time. Further laboratory work on vibrating plate cores, taken from the same material, will be carried out in an attempt to verify whether a plane of weakness is identifiable within the cores.

Finally, the CRAFT technique (Section 10) cores show the full depth emulsion coverage of the induced crack, see Plate 17. Despite the crack being invisible at the surface the cores clearly show emulsion cover to full depth and hence a definite discontinuity/induced crack at each location.

5.2 Load transfer characteristics

Monitoring of the load transfer characteristics is carried out to enable a study of the induced cracks compared to natural cracks. FWD testing was undertaken at crack locations to monitor load transfer efficiencies. The efficiency is evaluated by loading the slab on one side of a crack and measuring the deflections on each side of the crack. The geophone test configuration used was the recommended DOT method as described in DMRB Vol 7 (1996) and as shown in Figure 2, section 3.4. Results from the FWD are deflection measurements by geophones at a set distance from a known dropped weight. The deflection measurement at each geophone is firstly normalised to a standard load of 700Kpa as follows:

$$\frac{\text{load deflection reading}}{\text{actual load}} \quad (700)$$

The load transfer efficiency is then calculated as a percentage ratio of:

$$\frac{\text{deflection of unloaded slab}}{\text{deflection of loaded slab}}$$

$$\text{i.e.:} \quad \frac{(d7)}{(d6)}\,100 \qquad \text{(DOT method, DOT, 1996)}$$

$$\text{or:} \quad \frac{(d7)}{(d2)}\,100 \qquad \text{(SHRP method, SHRP, 1993)}$$

Acceptable load transfer efficiency is considered to be between 75 and 110%. At each trial section load transfer efficiency of all the cracks was recorded using the FWD. A summary of the results is shown in Table 5.

In the ideal situation the natural cracks in control sections would have low load transfer efficiencies compared to the induced crack sections. As a consequence it could be assumed that induced cracking had eliminated wide natural cracks at wide spacings. Therefore, the amount of movement due to thermal shrinkage at each crack would have been reduced, leading to a reduction in the occurrence of reflective cracking.

From Table 5 it can clearly be seen that the average (d7/d6) load transfer efficiencies in all the control sections are lower than their corresponding trial sections and the ideal situation has been obtained. The (d7/d2) results are provided as a further check on the quality of load transfer and although they vary in magnitude they represent the same overall picture. Variations above 100% in the (d7/d2) results are explained in Figure 7.

However, due to the large number of induced cracks per section, compared to natural cracks per section, it is necessary to look at the absolute number of low load transfer results obtained for a set carriageway length (i.e. the trial section length). Otherwise the possibility of a few induced cracks in each section operating as natural cracks, giving rise to an unchanged potential for reflective cracking, may be obscured by the majority of high load transfer efficiencies indicated by the average figures. For example, if ten out of fifty induced cracks produce low load transfer efficiencies, the resulting cracking in the surfacing may be the same as for the ten natural cracks in the control section, despite the presence of the forty good induced cracks in the experimental section. Table 6 shows the number of results obtained below 75% for each section. For the control sections 6 and 8, which were greater in length than their trial sections, the first 100m and 150m were considered respectively. To make full use of the available data both northbound and southbound results have been counted as both sets are valid, but they do not necessarily give the same values, due to loading on opposite sides of the crack and the relatively large distance between points of loading.

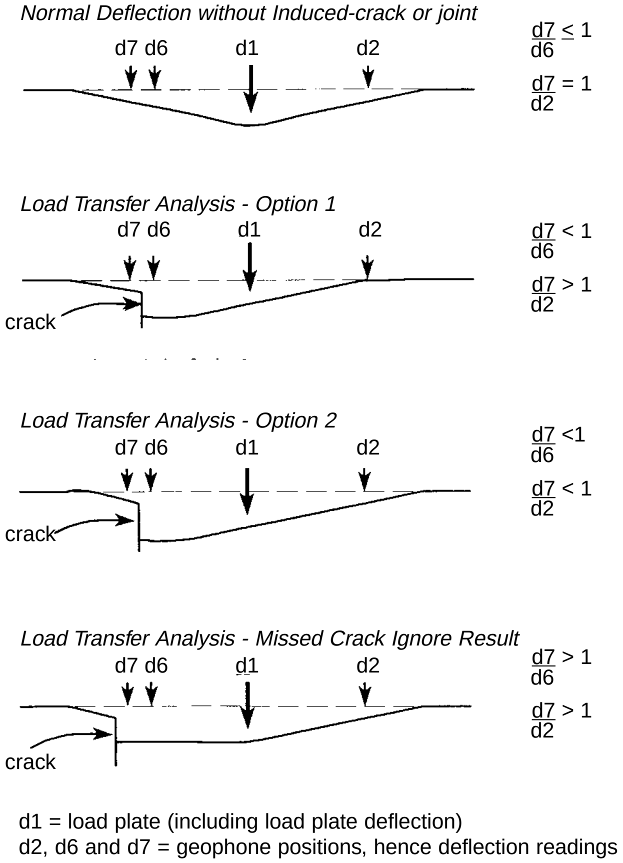


Figure 7 Explanation of variation in load transfer efficiencies

Table 6 shows that the trial sections 1-4, on the A149, have performed inconsistently, Section 2 performing comparably to the control, Section 3 faring worse and Section 4 performing well. Despite initial observations recorded in section 4.3.3, trial section 5 has performed well recording fewer low load transfer cracks compared to the control, especially when considering that four of the points counted are attributable to the end cracks which could be disregarded as they abut onto control sections with natural cracks. Sections 7 and 8 also show the vibrating plate to be performing well, with fewer low load transfer efficiencies on the treated section. Sections 9 and 10 have produced more low load transfer efficiencies than the control. Section 12, although without a control for

Table 5 Summary of load transfer efficiencies analysed from initial monitoring during construction

	Maximum efficiency %		*Average efficiency %*		*Minimum efficiency %*		
Section No.	*d7/d6*	*d7/d2*	*d7/d6*	*d7/d2*	*d7/d6*	*d7/d2*	*Remarks*
1	96.1	116.5	80.5	100.5	46.3	72.5	Control section for 2, 3 and 4
2	146.6	116.5	88.6	101.9	62.1	65.8	Test section - guillotine
3	98.5	110.3	89.3	96.8	56.5	67.0	Test section - vibrating plate
4	100.9	121.3	93.4	101.1	49.1	66.7	Test section - OLIVIA
5	96.5	128.1	84.0	105.5	35.5	61.9	Test section - vibrating plate
6	77.8	106.0	62.6	90.3	48.5	72.7	Control section for 5
7	100	123.4	91.0	102.1	66.9	82.4	Test section - vibrating plate
8	92.9	110.0	77.8	101.1	61.7	89.4	Control section for 7
9	114.0	135.1	82.1	102.2	51.7	50.7	Test section - vibrating plate
10	130.5	145.6	78.8	93.6	29.3	47.8	Test section - CRAFT
11	96.6	126.3	60.3	88.7	33.9	52.1	Control section for 9 and 10
12	96.7	107.9	91.2	101.3	72.2	89.6	Test section - vibrating plate

Table 6 Load transfer severity per section

Section No.	*(d7/d6) ≤75%*	*Remarks*
1	4	Control section for 2, 3 and 4
2	5	Test section - guillotine
3	9	Test section - vibrating plate
4	2	Test section - OLIVIA
5	9	Test section - vibrating plate
6	12	Control section for 5
7	1	Test section - vibrating plate
8	3	Control section for 7
9	10	Test section - vibrating plate
10	18	Test section - CRAFT
11	8	Control section for 9 and 10
12	1	Test section - vibrating plate

comparison, exhibits good load transfer characteristics with only one low result being obtained.

From these results the first conclusion to be drawn is that in respect of the simple analysis displayed in Table 6, the OLIVIA and guillotine techniques have performed better than the vibrating plate in terms of reduction in load transfer. However, it has also been shown that the vibrating plate can produce very successful results. By comparing the differing results of the vibrating plate at different sites, and also the similar good results on the two A605 trial sections (sections 5 and 7) despite differing construction techniques (e.g.. rolling regime), it would appear that the differences in performance between sites may well be caused by the differences in materials used or some other site dependant factor.

The CRAFT test section did not perform well with respect to the results in Table 6, again this may be attributable to the material used. As stated in section 4.4.2, it was necessary to make one pass with the roller on the CBM before the CRAFT equipment could be supported. Pre-rolling may have reduced the effect of the compaction after the cracks were induced. This may have affected the results on the A256 for the CRAFT technique compared to the vibrating plate which did not require pre-compaction. It should be noted, that for the different CBM design mix on the A149 site, pre-rolling was not necessary as the CRAFT, prior to the breakdown, was driven onto fresh CBM without excessive rutting.

It must also be recognised that even where low load transfer efficiencies have been recorded this only shows, at this stage, where there is less aggregate interlock than would initially be hoped for. The load transfer results show that cracks have been induced consistently at all sites. Thus cracks either side of the low load transfer cracks, in the induced cracked sections, should still be present. If this is the case any thermal movements will still be distributed over an increased number of cracks and so horizontal and vertical movements will be reduced at low temperatures. This means that all sections are still expected to perform better than their control sections, even where a larger than desired number of low load transfer efficiencies were recorded. Further monitoring, particularly at low temperature will clarify this situation. In summary, although the initial results are inconclusive for some trial sections the first assessments are favourable and possible beneficial aspects of induced cracking cannot be disregarded at this stage. All the cracks have been surface marked for reference and FWD monitoring in future years will use these results as a baseline for the final evaluation of induced cracking.

5.3 Condition of pavement layers

5.3.1 General

There are two methods of interpreting the FWD data for pavement condition. The simpler method is to use deflection results directly and the alternative is to analyse the data to give stiffness values for layers of the pavement. Both types of analysis were carried out on all sections.

5.3.2 Deflection analysis

By using the FWD deflections obtained, an assessment can be made of the condition of pavement layers in accordance with DMRB Vol. 7 (DOT, 1994b). The geophone set-up for analysis of stiffness characteristics is shown in Figure 2, from this set-up the condition of different pavement layers can be determined by the deflection values at d1, d1-d4, and d6. The value d1 gives an indication of the general performance of all pavement layers, value d1-d4 shows the condition of approximately the top 300 mm (normally the bound layers), and the value d6 represents the condition of the sub-grade.

5.3.3 Stiffness analysis

The measurements made by the FWD outline the deflection bowl produced in the pavement when the load is applied. The shape and size of the bowl is controlled by the stiffness, thickness and position of the various layers within the pavement structure. Using a back analysis technique, and knowing the thickness and position of the various layers, it is possible to calculate a value for the stiffness of the materials within the pavement. This process can be carried out by various computer programs, for this application the program used was MODULUS.

MODULUS was used to analyse all sites based on a two layer model. The first layer comprises the cement bound layers and the second consists of any granular layers and subgrade combined. A three layer model was also used on the sites with cemented sub-bases, in order to distinguish between the sub-base and roadbase. However, this was unsuccessful as the analysis program could not distinguish between the two similar adjacent layers. As a result the stiffnesses of these experimental sections were compared to the control sections as a combined sub-base and roadbase stiffness.

5.3.4 Summary

The stiffness and deflection results, measured at the mid point between cracks, showed no discernable differences between the sections with induced cracks and the control sections.

There were only two abnormal occurrences within the stiffness results, the first was caused by a farmers underpass beneath the pavement in trial section 10. The second was attributed to the crossing of a major utility within trial section 3.

Although there was some variability within the calculated CBM stiffnesses, they have nevertheless, provide a baseline for comparison in future monitoring.

The stiffness values of the foundations of trial sections 1 to 8 and 12 are all above 150MPa and generally around 200MPa. The foundation stiffness of trial sections 9 to 11 is higher, at 600 to 1000MPa, due to the pavement being founded on the chalk bedrock. These figures show that the foundations on all sites are good, and excellent on the A256.

6 Discussion

Analysis of the initial results has proved promising enabling the development of a draft specification which is included in Appendix A. Clauses 1.2.4 to 1.2.8 refer to the induced cracking technique. This section of the draft Specification will be amended in the light of the performance of the relevant sections in the trials.

A major finding during the initial assessment of the trial sites is that there is no apparent loss of roadbase strength/ stiffness modulus by the introduction of induced cracks. A substantial number of results have illustrated this factor in the slabs between cracks. To further investigate this factor at the final trial section a number of FWD readings were taken for stiffness analysis using a drop spacing of only 0.5 m, thus allowing an assessment of the variation of pavement condition with respect to induced crack location. The results of these readings are presented in Figure 8. By inspection of this diagram it can clearly be seen that the FWD deflections do not increase at induced crack locations, in fact at some crack locations there is a distinct decrease in deflection implying an increase in pavement stiffness. In addition, the peaks in the deflections at chainage 17,793 m, caused by an underlying old stream bed, do not extend to the crack location where it might have been anticipated.

Four sections were constructed on the A149, three experimental sections (vibrating plate, guillotine and OLIVIA on CBM3) and one control. The results from this location all indicated that cracks were successfully induced with minimal reduction in load transfer and no adverse effects upon the overall stiffness of the roadbase layer. From assessment by load transfer efficiency and stiffness modulus all three trial sections appear, prior to trafficking, to be performing better than the corresponding control section.

The second site was the A605 where four sections were also constructed, two experimental (vibrating plate on CBM3 and CBM5) and two control sections. The results at this site, by visual inspection appeared less encouraging. However, from the core samples the vibrating plate method is performing as intended and from the analysis of load transfer efficiency and stiffness modulus both trial sections are, at this stage, performing better than their corresponding control section.

The third trial on the A256 currently repeats the experience gained on the A605. By visual inspection the induced cracking methods do not appear to be performing well. However, from the core samples both the CRAFT and vibrating plate have created full depth cracks at all crack locations, despite different appearances. Thus when a specification is introduced, at this stage compliance cannot be based on visual observations alone.

Existing pavement design models have been reviewed in an attempt to establish the design values to be applied when using an induced cracking method. Of prime importance is the value of stiffness modulus, as an

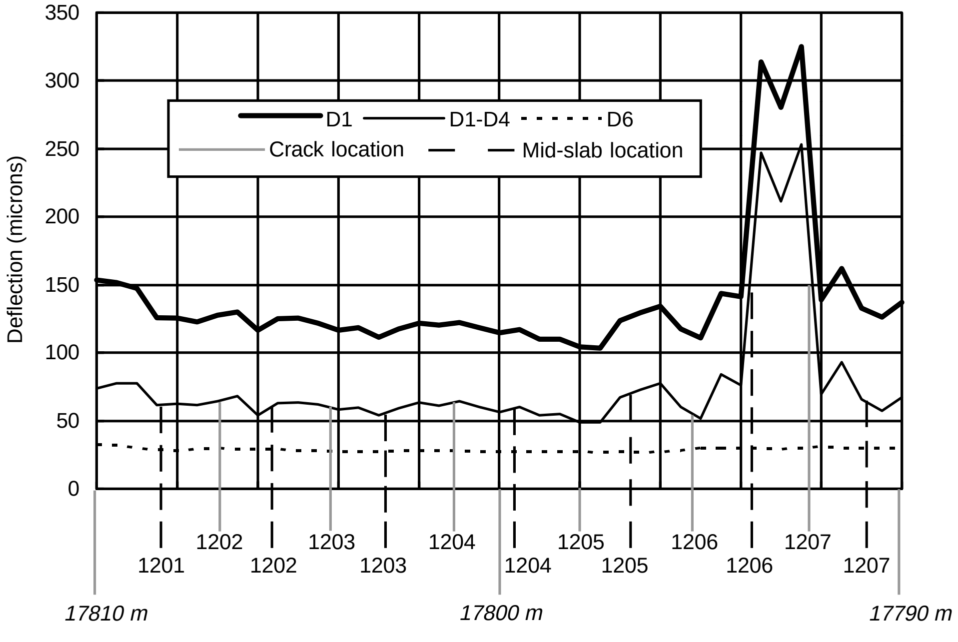


Figure 8 FWD stiffness analysis using 0.5m drop spacing - Section 12 A1M Alconbury to Peterborough

indication of pavement strength, to be used when considering the design life for a pavement. It is apparent from the full-scale trials that the mix design of the CBM, the properties of the composite materials and the inherent variability of CBM mixes could affect the success of an induced cracking technique. It may be possible that a variation in crack spacing could rectify the situation for mix variations and the creation of an analytical technique to assess these characteristics would be advantageous to the progress of the introduction of induced cracking techniques into the UK. To date 3.0 m has been used as it is the most commonly used spacing of induced cracking techniques worldwide. A finite element method would be an appropriate means of understanding the mechanisms of cracking in relation to material characteristics and induced cracking techniques. The introduction of a finite element method may allow sensitivity testing of the spacing of induced cracks to be carried out.

7 Conclusions and recommendations

The results to date are the preliminary analysis of the data obtained during construction of the road trials. In order to establish the overall success of induced cracking, the trial sites will be monitored by visual inspection and further FWD testing until December 1998. During this period, the incidence of reflective cracking will be recorded and the validity of inducing cracks in CBM roadbases established. To date, construction of the full-scale trials has yielded the following factors with regard to induced cracking technique:

- the technique of inducing cracks eliminates the occurrence of wandering transverse natural cracks in a CBM roadbase
- the simple vibrating plate technique has proved effective at all sites producing fine, full-depth vertical cracks
- the vibrating plate technique interferes with the construction method substantially when the roadbase is grader laid however, when paver laid there was no disruption caused during the inducing of cracks
- the CRAFT and OLIVIA techniques performed well during construction and reduced the disruption to the construction method compared to the vibrating plate when grader laying of CBM was being used - when the CBM is paver laid there is no disruption
- the CRAFT and OLIVIA techniques were both one man operations without manual effort, whereas the vibrating plate technique was essentially a three man operation requiring much manual effort
- despite the visual surface characteristics of the CRAFT technique and the appearance that the cracks were performing as natural cracks every 10 or so cracks, all the cores taken, including those where the cracks could not be seen, have shown full depth cracks or emulsion discontinuities
- despite much evidence of surface spalling the guillotine technique performed well, there was no disruption using a guillotine machine and the lack of any transverse natural cracks in the trial section suggest the technique has successfully produced an induced crack scenario, however, there is no evidence of induced cracking from the cores taken at the crack locations
- all the techniques appear to produce planes of weakness which should develop into cracks
- there is no evidence from the trials to suggest that inducing cracks causes a loss of roadbase strength as stiffness modulus values have remained consistent with control sections.

Following the conclusions above, current progress on the project is in the following two areas:

- assessment of flexible composite construction, including techniques to induce cracks, by finite element analysis using validation from the full-scale trials and allowing an extensive theoretical evaluation of the effect of induced crack spacing, overlay thickness, cracking technique and CBM mix design
- monitoring of all the full-scale trial sites.

Overall, from construction of the full-scale trials, the introduction of induced cracking techniques into the UK may be advantageous, with the potential to reduce the cost for flexible composite construction by using thinner layers of asphalt. The techniques can be carried out with minimal interference with the construction programme and the cost of induced cracking is small compared to the cost of thicker upper pavement layers it replaces. Initial monitoring results are encouraging and further monitoring and analysis of the results of the FWD measurements will be carried out. This will enable an assessment of the technique to be made together with the criteria for implementation of inducing cracks and the effects on the effective elastic modulus of a cracked pavement for pavement design. Once the monitoring has been carried out for two years and two annual climate cycles have taken place the performance of lengths of flexible composite construction with cracks induced should be known. Subject to favourable long term monitoring results from the full-scale trials induced cracking techniques could be introduced into the UK via the design standards (DMRB Vol. 7) and specifications (MCHW Vol. 2).

8 Acknowledgements

The author acknowledges the assistance provided by M. François Verhée (Via France), M. Jean-Pierre Marchand (Cochery Bourdin Chaussé), who provided the French equipment for the full-scale trials. In the United Kingdom the author is grateful for the assistance received from Mr David York (Sitebatch (Contracting) Ltd) who assisted with the locating of the trial sites, provided the vibrating plate for trial at each site, and provoked thought through many lengthy discussions that have taken place.

The TRL Pavement Consultancy provided the monitoring equipment and the effort put in by their operator for the majority of the monitoring, Mrs Katrina Hayes, is gratefully acknowledged.

The assistance received at each trial site cannot go unmentioned and in particular the authors would like to thank the people listed below:

A149 Ormesby Bypass - Mr Peter Hinchcliffe, Mr Colin Gibbon both of Norfolk County Council, Mr Peter Broome, Mr Perry Dale both of Jackson Group, and Mr Ken Andrews of Comcol Ltd supplier of the Arrows Breaker and operator for trial section no. 2.

A605 Warmington Bypass - Mr George Beskabi of ESL and Mr Andrew Spence and Mr Nick Osbourne both of Birse Construction Ltd.

A256 Whitfield to Eastry - Mr Graham Wickenden of Kent County Council and Mr Mike Robinson, Mr Rob Cullen and Mr Dave Tennant of M J Gleeson Group PLC.

A1(M) Alconbury to Peterborough - Mr Peter Smith, Roads Management Group (Parkmans).

In addition the support from Mr John Potter, the TRL supervisor for the project has been much appreciated.

9 References

Department of Transport (1994a) *HD26/94 Pavement Design. Design Manual for Roads and Bridges. Volume 7, Section 2, Part 3*. London: HMSO.

Department of Transport (1994b). *HD29/94 Structural Assessment Methods. Design Manual for Roads and Bridges. Volume 7, Section 2, Part 3*. London: HMSO.

Department of Transport (1996). *HD29/96 Structural Assessment Methods DRAFT. Design Manual for Roads and Bridges. Volume 7, Section 2, Part 3.* London: HMSO.

De Bondt A H (1995). *Effect of temperatures on Pavement Response.* Faculty of Civil Engineering, TU Delft. Report no. 7-95-203-13. Delft: TU Delft.

De Bondt A H and Steenvoorden M P (1995). *Theoretical Analysis of Temperatures in Pavements.* Faculty of Civil Engineering, TU Delft. Report no. 7-95-203-21. Delft: TU Delft.

Ellis S J (1996). *Pre-cracked CBM roadbases to inhibit reflection cracking*. TRL Unpublished Project Report PR/CE/5/96. Crowthorne: Transport Research Laboratory. (*Unpublished report available on direct personal application only*).

Gaarkeuken G, Scarpas A and De Bondt A H (1996). *The causes and consequences of secondary cracking.* Faculty of Civil Engineering, TU Delft. Report no. 7-96-203-23. Delft: TU Delft.

Lefort M (1996). *Technique for limiting the consequences of shrinkage in hydraulic-binder-treated bases*. Proceedings of the Third International RILEM Conference. London: E & FN Spoon. pp 3-8.

Potter J F and Mercer J (1996). *Performance of the crack and seat method for inhibition of reflection cracking*. Proceedings of the Third International RILEM Conference. London: E and FN Spoon.

Potter J F, Sherwood P T and O'Connor M G D (1985). *The use of pulverised fuel ash in lean concrete roadbases: Part 3 Field Studies.* TRRL Supplementary Report SR 842. Crowthorne: Transport Research Laboratory.

Strategic Highway Research Programe (1993). *LTPP manual for FWD testing*. SHRP report 5009. Washington DC: SHRP, National Research Council.

Scarpas A, De Bondt A H, Molenaar A A A and Gaarkeuken G (1996). *Finite elements modelling in pavements*. Proceedings of the Third International RILEM Conference. London: E & FN Spoon. pp 82-91.

Verhée F (1996). *Préfissuration par film plastique*. Proceedings of the Third International RILEM Conference. London: E & FN Spoon. pp 47-54.

10 Abbreviations

CBM	Cement Bound Material
CRAFT	CRéation Automatique de Fissures Transversales Automatic Creation of Transverse Cracks
DBFO	Design Build Finance and Operate
DMRB	Design Manual for Roads and Bridges
DOT	Department of Transport
ESL	Northamptonshire County Council (Engineering Services Laboratory)
FWD	Falling Weight Deflectometer
MCHW	Manual of Contract Documents for Highway Works
NCC	Norfolk County Council
OLIVIA	Outil que Laribe Inventa pour Via France
RILEM	Réunion International des Laboratoires d'Essais et de Recherche sur les Matériaux et les Constructions
RMG	Roads Management Group, Construction Joint Venture

Appendix A: Draft specification for the induced cracking of cement bound material roadbase pavements

A1 Induced cracking of cement bound material roadbase (CBM)

A1.1 General

1.1.1 Where specified in Appendix 7/1, the CBM roadbase pavement layer shall be cracked with approved plant and equipment to comply with this Specification prior to laying the asphalt basecourse and wearing course layers as specified in Appendix 7/1.

A1.2 Induced cracking

1.2.1 Induced cracking of the CBM roadbase pavement layer shall be carried out to comply with this Specification and in accordance with the special requirements of the Schedule at clause 1.6.

1.2.2 Transverse cracks at the pre-set spacing described in Appendix 7/1 or in section 1.2.3 shall be induced by suitable plant and materials. Cracks may be induced either: in the fresh CBM material prior to compaction as described in section 1.2.4; or after 6 days using suitable plant as described in section 1.2.5.

1.2.3 When cracks are to be induced in fresh CBM the spacing of cracks shall be at the pre-set spacing UNLESS laid upon a CBM sub-base. This being the case, at the location of transverse shrinkage cracks in the sub-base the crack spacing shall be adjusted by no more than 1.0 m to ensure that the pre-crack is NOT induced within 0.5 m of a transverse crack in the layer below.

1.2.4 Transverse cracks shall be induced by grooving the fresh CBM surface to a depth which leaves a groove not less than half the roadbase thickness after compaction. A crack retention material, as specified in section 1.6, shall be inserted into the groove prior to compaction. Upon compaction the grooves shall have ‘closed up’ and during the curing period hairline cracks shall propagate vertically to the base of the CBM roadbase layer.

1.2.5 Transverse cracks shall be induced by suitable plant capable of delivering variable preset impact loads to the CBM surface. Cracks shall be induced by one strike of the impacting head of such plant without producing (undue) surface shatter. The plant and impact head shall be of sufficient mass and geared to prevent head bounce and any associated surface damage arising therefrom. The impact load shall be adjustable to achieve the cracking specified and the minimum load consistent with no surface shatter.

1.2.6 The induced cracks shall be predominantly vertical and transverse to the direction of the road. They shall extend the full width of the carriageway.

1.2.7 Where cracks cannot be induced over the full width of the carriageway with one pass of the crack inducing plant, further parallel passes shall be made as necessary so that all subsequent cracks are aligned with those from the preceding pass within the tolerances specified in Clause 1.6.

1.2.8 The Contractor shall be responsible for varying his equipment and methods so that the crack pattern is maintained and areas of concrete roadbase are in the opinion of the Engineer, rendered suitable for overlaying. The plant used to induce crack in a fresh cement bound pavement layer prior to compaction shall be such as to minimise rutting of the pavement layer. When cracking is to be induced after compaction of the roadbase the plant shall be self-propelled with wheels having rubber (pneumatic) tyres.

A1.3 Trial lengths

1.3.1 The Contractor shall demonstrate that the plant, equipment and methods that are proposed for inducing cracks in the CBM layers are capable of producing the required type and pattern of cracks by first executing a trial over a minimum length of 100 metres of new carriageway. The location of the trial shall be as directed by the Engineer. The Contractor shall demonstrate that the tolerances of the cracking operation can be achieved consistently.

1.3.2 Unless agreed by the Engineer completed CBM shall be cured for a minimum period of seven days in accordance with clause 1035.

A1.4 Assessment

1.4.1 Compliance with the crack inducing requirements shall be assessed as follows:

i The surface pattern of cracking shall be checked by applying clean water to saturate the surface of the cracked concrete allowing it to dry naturally or artificially rendering it surface dry and visually inspecting the resultant induced crack pattern.

ii The depth of cracking shall be determined by coring through the full depth of the cement bound pavement layer symmetrically (at about) the crack position. The coring shall take place once the cracks are visual at the surface and as a minimum six days after compaction. Sets of 10 cores will be taken within the trial area at locations selected by the Engineer. These locations will generally be where cracks are not visible in the surface. The trial area shall be deemed acceptable if 8 of any adjacent set of 10 cores are cracked and the cracks are predominantly vertical and in accord with the requirements specified in clause 1.6.

iii To monitor the cracking in the main works, cores shall be taken at a rate not less than one for every 300 m^2 of cracked pavement. The cores shall be located by the

Engineer as described in paragraph (ii). The cracking shall be acceptable if at least 4 cores in any adjacent set of 5 cores are cracked throughout the full depth of the concrete.

iv Holes from which core samples have been extracted shall be backfilled with CBM material and be well compacted in layers not exceeding 50 mm.

A1.5 Approval and Acceptance

1.5.1 Approval to use the plant, equipment and methods shall be given following a successful demonstration in the trial length that the induced cracking complies with the requirements of the specification. The Contractor shall not proceed with the main works until the plant, equipment and methods used in the trial length have been approved by the Engineer.

1.5.2 When approval has been given, the plant, equipment and methods shall not thereafter be changed, except for normal adjustment and maintenance of plant, without the prior approval of the Engineer. Should it be necessary for the Contractor to change any plant, equipment and/or method the Contractor shall carry out a further trial length.

A1.6 Induced cracking of CBM roadbase pavement layers

1.6.1 Location:

A trial area in accordance with cl. 1.3.1 shall be carried out on each separate design mix of the CBM material.

1.6.2 CBM pavement layer:

Shall be constructed to Appendix 7/1 and in compliance with the appropriate clauses of the 700 and 1000 series

1.6.3 Cracking:

i Spacing of transverse cracks :

ii Category of crack : Hair line transverse cracks.

iii Finished depth of crack : Full depth of CBM pavement layer. The cracks shall be vertical through the CBM layer.

iv Alignment of tolerance : Longitudinal - N/A. Transverse - ± 50 mm.

1.6.4 Crack retention treatment in fresh CBM:

i Emulsion : K1-40 bituminous spray to Clause 920.

1.6.5 Sealing of induced cracks when induced six days or longer after compaction:

i Hair line (just visible) : General surface application of K1-40 bituminous spray to Clause 920

ii and Narrow (> 0.5 mm) : min 0.5 l/m^2

iii Medium (0.5 < > 1.5 mm) : ‘over-banding’ with 50 or 70 pen bitumen

iv Wide (1.5 mm <) : chase out and seal with 15D x 10W sealant to BS 2499 (1993).

Abstract

The use of cement bound material roadbases in flexible composite pavements in the United Kingdom is limited by the reflective cracking that occurs due to thermal shrinkage. Inducing cracks during construction is a technique proposed to minimise reflective cracking. This report describes full-scale trials that have taken place and discusses results of the initial monitoring that was carried out during construction. Four trial sites were located with different roadbase materials and upper pavement thicknesses. All sites had cracks induced by using a simple vibrating plate with welded blade. In addition at individual sites the OLIVIA and CRAFT automated cracking processes were brought over from France and a guillotine technique as proposed by the Transport Research Laboratory were used.

Initial monitoring during construction has been carried out using the Falling Weight Deflectometer and core samples. Load transfer characteristics of the cracks and elastic modulus of the induced cracked roadbase have been assessed by comparing with the naturally cracked control sections. Core samples have been taken at the cracks to confirm the results obtained for load transfer and assess the size and orientation of the cracks. Analysis of the initial results has proved promising enabling the development of a draft specification. In particular the sensitivity of induced cracking with respect to mix design, depth of induced crack and compactive effort is discussed.

Related publications

PA3134/96	*Performance of the crack and seat method for inhibition of reflection cracking*. (Paper presented at the Third International RILEM Conference. 1996. (price £10)
SR842	*The use of pulverised fuel ash in lean concrete roadbases Part 3 - field studies* by J F Potter, P T Sherwood and M G D O'Connor September 1985. (price code AA, £10)

Prices current at November 1997

For further details of these and all other TRL publications, telephone Publication Sales on 01344 770783 or 770784, or visit TRL on the Internet at http://www.trl.co.uk.