PREVENTION OF CRACKS IN PAVEMENTS:
ACHIEVEMENTS AND OPEN QUESTIONS

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Abstract
RILEM Technical Committees have been active since more than 15 years on the prevention of Reflective Cracking in Pavements. Papers published over that period in the proceedings of four RILEM international conferences devoted to this topic constitute an unmatched source of information for highway engineers. Extensive research, laboratory work, full scale trials and road condition surveys over the long term have been reported and in 1997 the information collected, joined to the practical experience gained by the RILEM committee members, was used to set up a state of the art report intended to be a reference for road engineers and practitioners.

The purpose of this paper is to summarize some achievements of the RILEM TC 157 PRC committee and to recall recommendations presented in the RILEM state of the art report. Another purpose of the paper is to open some questions that the author considers to be main future challenges for road construction and maintenance.

1. Introduction

The mode of distress, traditionally referred to as "reflective cracking" is a major concern to highway agencies. This important issue has led the RILEM Technical Committee157PRC "Systems to Prevent Reflective Cracking in Pavements" to organise four Conferences on this subject, two in Liège in 1989 [1]and 1993 [2] Maastricht in 1996 [3] and the last one in Ottawa in spring 2000 [4].

The main purpose of these Reflective Cracking Conferences was to gather information needed to finalise a state of the art report intended for highway engineers, contractors and authorities involved in road construction and maintenance.

This task was the result of very intensive committee work completed by many research and development activities in which all the members are very deeply involved. The RILEM Technical Committee has succeeded in this way to prepare a document which was the first handbook of this kind in a field which is in urgent need of information and practical recommendations [5]. The RILEM State of the Art Report is a summarizes the existing knowledge on systems to prevent reflective cracking.
It covers the full topic in a logical way divided in following seven chapters:
1. Cracking in pavements
2. Assessment and evaluation of the crack potential
3. Construction measures to prevent crack initiation or to reduce the crack severity
4. Anti-reflective cracking overlay systems
5. Experimental characterisation of interlayer products and overlay systems
6. Modelling and design of overlay systems
7. Implementation on the construction site

A brief summary of the different chapters is given in what follows.

2. Cracking in pavements: nature and origin of the cracks

Depending on their nature, the conditions under which they were constructed, and the in-service conditions of loading and stress, the various pavements and road structures may be subject to various forms of cracking.

Any cracks appearing at the surface always have a detrimental effect on the pavements. By their variable shape they may take, these cracks are also indicative of the type of damage that is occurring within the pavement. There are many cases where the identification of the type of cracking, completed by additional information on the pavement structure can help to understand the causes of the deterioration and find solutions to improve the situation.

It is indeed vitally important to correctly diagnose the nature and causes of cracks in a structure to be treated, as it is the diagnosis which will direct the choice to proper solutions.

The Rilem state-of-the-art-report [5] gives a thorough description of the different crack types appearing in the three major pavement structures: rigid, semi-rigid or flexible structures.

3. Assessment and evaluation of the crack potential

Although the phenomenon of initiation and propagation of cracks in a pavement structure is known since the existence of asphalt roads its fundamental knowledge is still misunderstood and the way it has to be considered in rehabilitation of roads has been neglected until the very recent period where more attention was devoted to the cost effectiveness of road maintenance.

The most current factors responsible for crack initiation are among others thermal effects, fatigue induced by traffic loads and shrinkage. Besides these classical causes of reflective cracks some other causes have to be mentioned and addressed such as the effect of highway geometry, construction procedures, cracks caused by expansive subgrade clay and frost heave in the northern countries.

Once they have been initiated, cracks propagate through the structure at a rate which is defined by a propagation law (Paris law) in which the "driving force K" is the stress intensity factor which depends on the loading conditions, material characteristics and the geometry of the structure. The understanding of this initiation-propagation process is a basis for interpretation and the design of any system or procedure intending to improve the situation.

The observation of the cracks and the assessment of their activity is a major step in the pavement rehabilitation procedure. The methods to be used in this evaluation range from the simple visual survey to sophisticated investigation tools such as wave propagation or...
measurement of structural movements under running loads. They can be completed by sampling and drilling cores out of the road sections. These destructive or non-destructive methods have all been taken into account in the recommendations issued by the RILEM Committee.

4. Construction measures to prevent crack initiation or to reduce the crack severity

4.1 Cement treated base layers
The treatment of the cracking process is often considered as a rehabilitation technique intended for pavements reaching the end of their service life. However, the prevention or retardation of the cracks can be achieved at an early stage of a new construction. Such techniques have been developed for the case where crack initiation results from shrinkage cracks in cement stabilised base courses. Methods exist either to retard this phenomenon or to limit its severity by reducing the crack activity under thermal or traffic loads.

For the case of cement stabilised materials it has been emphasised that one must take into account the factors influencing the shrinkage effects in the choice of the component materials and aggregates, the design of the road structure and in the realisation on site.

New products for cement stabilised bases having a lower cracking potential are now proposed such as emulscement and slow setting binders. Their feasibility has been demonstrated on a laboratory scale. The results on the site are however variable in that the expected intermediate behaviour is not always achieved and obtained.

Precracking of cement treated layers is another preventive measure for which different methods have proven their efficiency. They are cheap and can be implemented without many constraints.

4.2 Rehabilitation of concrete slabs
Many concrete roads built in the fifties or even before were made of slabs. The construction joints had in most cases no load transfer; this resulted in the long term in differential setting of the slabs with loss of subgrade material by a phenomenon called "pumping" (see figure 2). Although these roads have fulfilled their task over the expected design life, their serviceability is often very poor; hence the restoration of an acceptable surface evenness is the main reason of maintenance and rehabilitation works. We know by experience that the past method of placing an asphaltic overlay is not durable and is not the most cost effective solution. A method which has been tried many times to improve the overlay efficiency consists in breaking the slabs in small pieces and stabilizing them in place by means of heavy rollers. This method called "crack and seat" has the advantage to suppress most of the thermal cracking movements while reducing the severity of the joints.

Crack and seat of concrete roads is not always needed, and better investigation methods and criteria are needed to improve decision making. The technique requires fine full depth cracks to be induced to enable the expansion contraction of the slabs to be distributed while load transfer remains possible through aggregate interlock. Evidence of the long term benefit of this technique has been provided. Crack and seat entails a certain loss of bearing capacity, this solution must therefore be decided on the basis of a careful analysis completed by a proper structural design of the overlay thickness.
5. Anti-reflective cracking overlay systems

We have learned since the first RC Conference in 1989 [1], from many positive or negative experiences that overlays behaving better than the traditional asphalt overlays are not simply the result of the interposition of a miraculous product. A successful result is rather a combination of different factors such as:

- common sense in the evaluation
- care in preparation work
- choice of the right interlayer
- skill in handling and laying the product
- mechanical performance of the asphalt layer to be placed on top
- compatibility between the different layers and component material of the pavement

One of the major achievements of the RILEM committee was to introduce the concept of overlay system and to clearly define the function of the different components within that system.

5.1 Definition of an overlay system

The general term of "overlay system" was proposed in order to describe the combination of a bituminous overlay, an interface system and a levelling course, placed on an underlying road structure. One or more of the components may be absent depending on the quality of the old road structure, the loading conditions and on the type of rehabilitation system which is chosen. In an overlay system such as the one schematically shown on figure 1, an appropriate "interface system" may be inserted between the old structure and the new overlay. The interface system consists of an interlayer product (stress absorbing membrane, non woven, reinforcement grid, etc...) with an associated appropriate fixing method and

Figure 1: Overlay system components
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placement procedure guaranteeing adherence with the underlayer. Successful solutions need a good expertise of each case and positive results can only be obtained if the right product is placed in the right way at the right place in the system and on the field. Elements to be taken in consideration in the design of an overlay system are given below.

5.2 Improving the asphalt layer
The most important component of an overlay system remains the bituminous layer itself. By its thickness and performance will definitely influence the final service life of the system even if it is placed on a functional interlayer product.

5.2.1 Higher overlay thicknesses have three positive effects:
1) increasing the fatigue life by reducing the strains at the bottom of the layer,
2) reducing the stress intensity factor K of the Paris crack propagation law,
3) increasing the distance to cover by the crack before it appears at the surface.
This straightforward solution is of course not very innovative and is moreover not possible when the pavement level constrains impose a maximum layer thickness.

5.2.2 Improvements in crack resistance can be obtained from the asphalt layer by modifying its composition or its components. The use of some types of fibres and/or polymer modified binders has proven very efficient by different authors. Sand asphalt interlayers can also be considered as good crack retarding materials if they are improved by fibres or polymer modified binders.

5.3 Interlayer products
Super products do not exist and in most cases improvements are the result of the combination and positive interaction of different functional layers in an "overlay system". A great variety of products covering a wide range of stiffness and functions is now available on the market. There is a need of a clear definition of where and how to use each product optimally.
The role of an interlayer system in the road structure depends mainly on its components. It may be:
- To take up the large localised stresses in the vicinity of cracks and, hence, reduce the stresses in the bituminous overlay above the crack tip. The product in that case acts as a reinforcement product. This is the case for grids and steel reinforcing nettings.
- To provide a flexible layer able to deform horizontally without breaking in order to allow the large movements taking place in the vicinity of cracks. This is the case for impregnated nonwovens, for SAMI's and for sand asphalt. This function is also often described as "controlled debonding". It is obvious that total debonding has to be avoided in all cases, otherwise fatigue cracking may appear already very shortly after rehabilitation.
- To provide a waterproofing function and keep the road structure waterproof even after reappearance of the crack at the road surface. This is often the case for nonwovens and SAMI's.
5.3.1 Reinforcing products
A given product will act as a reinforcement product if its overall stiffness modulus is higher than that of the bituminous overlay. This depends on the type of interlayer product and on the temperature in the actual road structure. The bituminous overlay material is highly temperature susceptible. Therefore, a given product can be reinforcing in medium and high temperature ranges, but not under winter conditions. Moreover, it is obvious that the overall stiffness modulus of the overlay decreases during the cracking process. This can imply that the reinforcing effect of a given product becomes only apparent during the crack propagation phase and not yet in the initiation phase.

Reinforcing products (grids) will be efficient if:
1) they are placed in such a way that they can take over the stresses of the asphalt overlay by bonding and granular interlock
2) they are placed stretched and without wrinkles or folds on a flat surface.
3) they are allowed to debond in a controlled way from stiff bottom layers otherwise they will break.
4) a minimum overlay thickness is required to allow a correct laying and compaction of the overlay and longer service lives.

Interlayer products are unable in any case to prevent the movements of cracks or joints pre-existing in the base layer whatever the bonding system.

5.3.2 Soft interlayers
Soft interlayers are generally efficient against mode 1 crack opening. But their performance is mainly determined by the amount and quality of the binder they are containing. Long term monitoring of several project has concluded to an increase of service life of two or three years but there is still some controversy about their cost effectiveness.

6. Modelling and design of overlay systems
One of the main purposes of modelling is the development of overlay design systems taking the reflective cracking process into account. Finite element modelling is becoming a powerful tool for the evaluation of overlay systems. Models and software products specifically developed for the reflection cracks and other forms of distress are existing and still improving.

There are different approaches possible to predict crack initiation and propagation: the fatigue law to predict crack initiation and Paris law for crack propagation.

Different trials to model loading conditions in which shear and opening mode are combined appear promising and innovative. Models allow a better insight of the behaviour of overlay systems and may suggest improvements in the design. However they depend on:
1) the quality and relevance of the assumptions
2) the quality and accuracy of the input data.

Validation and long term field verification is still lacking in all the models to allow the practical implementation of reliable overlay system design methods.

7. Experimental characterisation of overlay system components
Materials testing is mandatory for
- the determination of material properties
- the qualitative ranking of interlayer products
the evaluation of performance under realistic conditions
Specific testing procedures and simulation tests have been developed to fulfil this purpose. As shown below, they widely vary according to the type of product and the expected functional properties.

7.1 Asphaltic overlay
The basic laws governing crack initiation (fatigue) and propagation (Paris law) are both empirical relations with at least two material parameters. Numerous testing methods exist for the determination of these materials characteristics but there is a lack of information on the influence of mix composition and their temperature dependence and loading time sensitivity.

Paris law is the only tool we have to predict crack propagation although we know that the conditions of homogeneity, isotropy and linearity are not fulfilled. Moreover the testing results of this law are generally presenting a large scatter.

7.2 Bonding conditions
Bonding conditions are important in that they influence the load transfer and strengthening effect of reinforcing materials. This bond strength is also temperature dependent and widely different types of behaviour can appear. Splitting tests have been proposed as an alternative approach to characterise interlayer bonding and non elastic material properties.

7.3 Tests for interface products
Some properties of the interlayer products are needed either as identification parameters, as mechanical characteristics for modelling and structural evaluations or as requirements in Standard tender specifications. Test methods have recently been proposed by the RILEM Technical Committee for their experimental determination and relevant indicative values of the different parameters for nonwovens and grids have also been proposed.

7.4 Simulation tests
Testing facilities and methods have been improved during these last years. They are now simulating in a more realistic way the loading conditions of traffic and temperature shrinkage. Many tests are intended for qualitative ranking of products under well defined testing conditions. Tests are now also often used to supply the parameters needed for modelling in Finite element methods. On the other hand the results of most of the simulation tests are never or seldom adjusted to full scale results on the same overlay systems. And there are even less cases where this adjustment is made on the basis of statistic data from several test sites.

8. Implementation on the construction site
The importance of the placement procedure has been pointed out many times. Although this seems obvious we have to insist on the fact that the best possible solution on any point of view – (material performance, modelling, testing and even successful large scale implementations) can turn into a disaster if some of the basic rules of good practice are not carefully followed on the site. For the interlayer products these rules must be clearly defined and validated by the producers. The laying procedure for interlayer systems generally
comprises the following consecutive stages: preparatory works, application of a fixing, application of the interlayer product, placement of a protective layer (if required) and application of the bituminous overlay.

9. Open questions

Cracking is undoubtedly one of the major sources of deterioration of the road and therefore it must be one of the main criteria in the structural design of pavements and decision making for maintenance. We have shown that there are many solutions proposed for the retardation of different types of cracks. However, the RILEM RC conferences were focused so far on the problem of reflective cracking.

The aim of the present conference is to extend the attention on a wider range of cracking modes such as fatigue or top-down cracking.

Fatigue cracking is important in that it is the phenomenon that is responsible for the initiation phase of cracking. In spite of the literature devoted to it, we are still far from its full understanding and any contribution to this is thus welcome.

The top-down cracking phenomenon, on the other hand has not received the same attention although we believe that it is also a major source of road deterioration.

As already stressed in former meetings other problems that were hardly dealt with, deserve more attention such as:

- Reclaim and recycling of interlayer products
- Effect of ageing corrosion and chemical reactions on these products

Another purpose of this conference is to pay more attention to the prediction of the long term performance and the evaluation of risk. This last issue presents a growing interest since nowadays the policy of road construction is such that contractors and road engineers are bound to include long term maintenance activities within the costs of a project.

We hope that this conference will succeed the challenge of putting some steps forward into these directions.

9. References