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FIELD MEASUREMENTS OF CRACK ACTIVITY AND LABORATORY SIMULATION OF CRACK REFLECTION PHENOMENON IN PAVEMENTS OVERLAYS

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ABSTRACT

ABSTRACT: This paper shows a field measurement of the crack activity of longitudinal and transversal cracks with a Crack Activity Meter. The Crack Activity Meter was used to measure load associated differential vertical and horizontal movement between the two sides of a crack in pavements before overlay. The crack movements after overlay were calculated with a finite element model. The crack activity before overlay was used to estimate, with a finite element model, the crack activity after overlay function of overlay thickness and material stiffness.

The laboratory simulation of reflection cracking was undertaken with the Reflective Cracking Device. The Reflective Cracking Device used with the shear machine introduced by SHRP program, was employed to simulate in laboratory the crack activity patterns measured in the field and the crack activity movements calculated with the finite element model.

Key words: Crack activity, Reflective cracking, Fatigue life,

INTRODUCTION

Overlays are the most commonly used method for pavement maintenance. However, they often do not perform as desired due to the existing cracks, which propagate through the new pavement layers. This type of cracking is known as reflective cracking and it is a result of vertical and horizontal movements at the crack tip. Those movements, caused by thermal stresses, traffic loads or by a combination of these two mechanisms, induce stress concentrations in the overlay. Thus existing cracks of the old pavement propagate through the new pavement layer. It is usual to see the overlays cracked after few years of service.
This paper presents an approach to evaluate the reflective cracking in pavement overlays based on laboratory tests with the Reflective Cracking Device (RCD) designed by Sousa et al (1996). Old pavement crack differential movements were measured in road with the Crack Activity Meter (CAM) designed by Rust.(1987) and produced by CSIR in South Africa.

CRACK ACTIVITY

Load associated reflective cracking is governed simultaneously by an horizontal opening and/or closing and a vertical shearing at the crack zone. The simulation of this process must consider the simultaneity of these two modes of opening in the analysis of this problem.
The CAM is composed of two LVDT (Linear Variable Differential Transformers), one placed vertically and the other placed horizontally allowing the measurement of both differential movements. Figure 1 shows a schematic representation of the CAM placed over the crack.

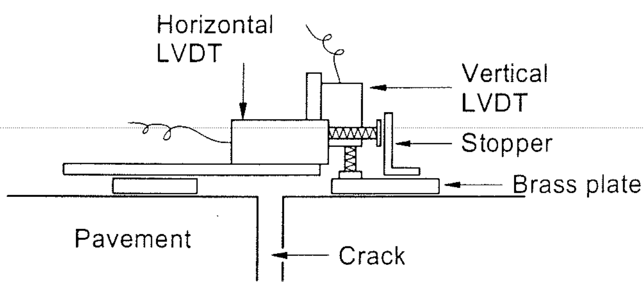

Figure 1. Crack Activity Meter.

Crack activity measurements

The evaluation of the crack activity before overlay was made in 16 cracked cross sections, with 500m long, in the Portuguese road network and only flexible pavements were studied. 13 transversal cracks and 11 longitudinal cracks were analyzed.
The typical crack activity for a longitudinal crack is shown in Figure 2, and represents the crack activity of the cracked pavement used for this study. Figure 3 shows the typical crack activity for transversal cracks. Horizontal positive values represent opening of the crack while negative values represent crack closing.

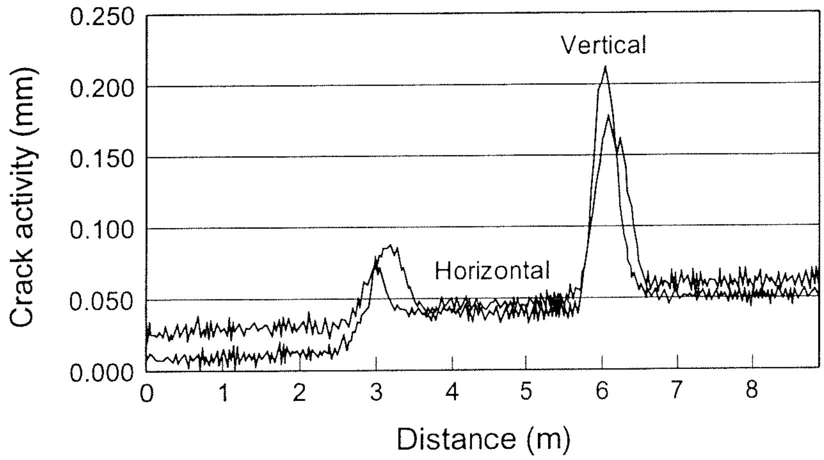

Figure 2. Crack movements of the longitudinal crack before pavement overlay.

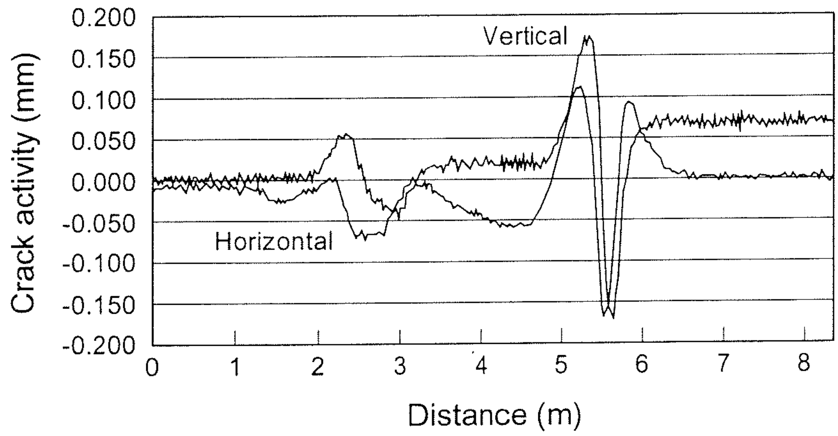

Figure 3. Crack movements of the transversal crack before pavement overlay.

Statistical calculations were made to correlate the measured crack activity with pavement and crack characteristics. To evaluate pavement characteristics, 11 FWD measurements were made in each cross section. The pavement layers stiffness was the average of the 11 measurements. For each pavement the considered stiffness was the bituminous layer stiffness and the thickness was the equivalent thickness for the bituminous layer stiffness according Equation 1. A thickness for the subgrade, defining a rigid layer, was considered.

$$\frac{E_1 h_1^3}{12(1-\nu_1^{\,2})} = \frac{E_2 h_2^3}{12(1-\nu_2^2)} \qquad (1)$$

The models to predict the crack activity before overlay as function of pavement characteristics are expressed by the Piecewise model with breakpoint. This model is a two tends linear regression with break point. Equation 2 shows the model to predict the horizontal crack activity before overlay for the transversal cracks.

$$AH = a_1 + b_1 * af + c_1 * h_t + d_1 * E_t \ , \ AH < AH_0 \qquad (2)$$
$$AH = a_2 + b_2 * af + c_2 * h_t + d_2 * E_t \ , \ AH \geq AH_0 \quad R^2 = 0.951$$

where AH is horizontal crack activity before overlay (e-6), af is the crack width (mm), h_t is pavement thickness (cm), E_t is pavement stiffness (MPa), and a_i, b_i, c_i, d_i are statistical coefficients. The vertical crack activity before overlay can be estimated using the Equation 3.

Table 1. Coefficients for Equation 2.

a_1	b_1	c_1	d_1	a_2	b_2	c_2	d_2	AH_0
-64.66	12.23	1.002	0.007651	-58.11	40.54	1.394	0.008957	123.9

$$AV = a_1 + b_1 * af + c_1 * h_t + d_1 * E_t \ , \ AV < AV_0 \qquad (3)$$
$$AV = a_2 + b_2 * af + c_2 * h_t + d_2 * E_t \ , \ AV \geq AV_0 \quad R^2 = 0.951$$

where AV is vertical crack activity before overlay (e-6).

Table 2. Coefficients for Equation 3.

a_1	b_1	c_1	d_1	a_2	b_2	c_2	d_2	AV_0
137.1	13.16	-1.528	0.006864	-1312	217.6	8.304	0.05128	174.4

Table 3. Coefficients for horizontal crack activity before overlay for longitudinal cracks.

a_1	b_1	c_1	d_1	a_2	b_2	c_2	d_2	AH_0
92.33	-1.703	-0.1844	-0.001347	55.93	-88.43	9.044	-0.09681	103.9

Table 4. Coefficients for vertical crack activity before overlay for longitudinal cracks.

a_1	b_1	c_1	d_1	a_2	b_2	c_2	d_2	AV_0
173.7	3.567	-0.6103	-0.01501	185.4	47.59	0.5914	-0.02649	115.6

Figure 4 shows a typical comparison between observed and predicted crack activities for the horizontal activity of transversal cracks.

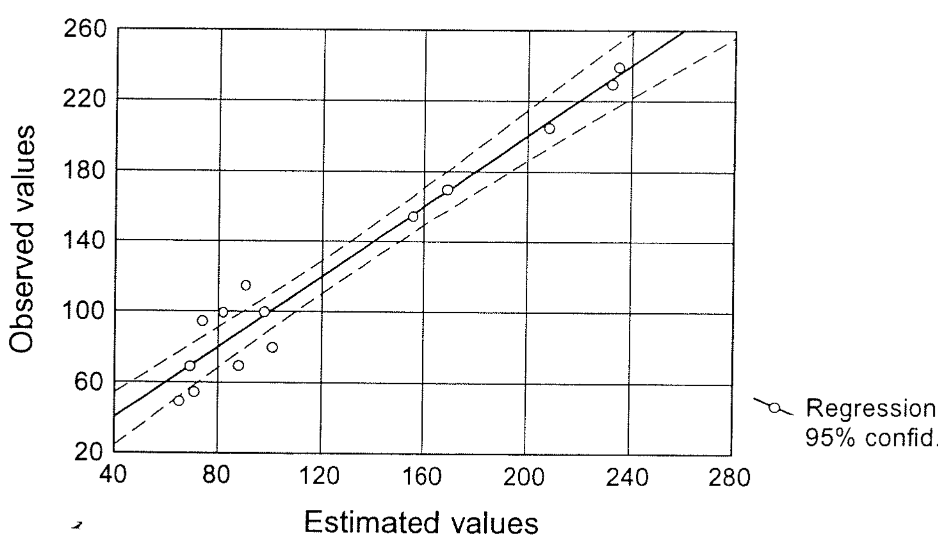

Figure 4. Estimated values versus observed values for horizontal activity of transversal cracks.

Estimation of crack activity after overlay

The crack activity measured in the pavement before the overlay is different from the crack activity after overlay since it depends on the overlay thickness and material stiffness. The crack activity after overlay can be estimated using a finite element analysis and knowing the old pavement properties such as the one shown in Figure 5.

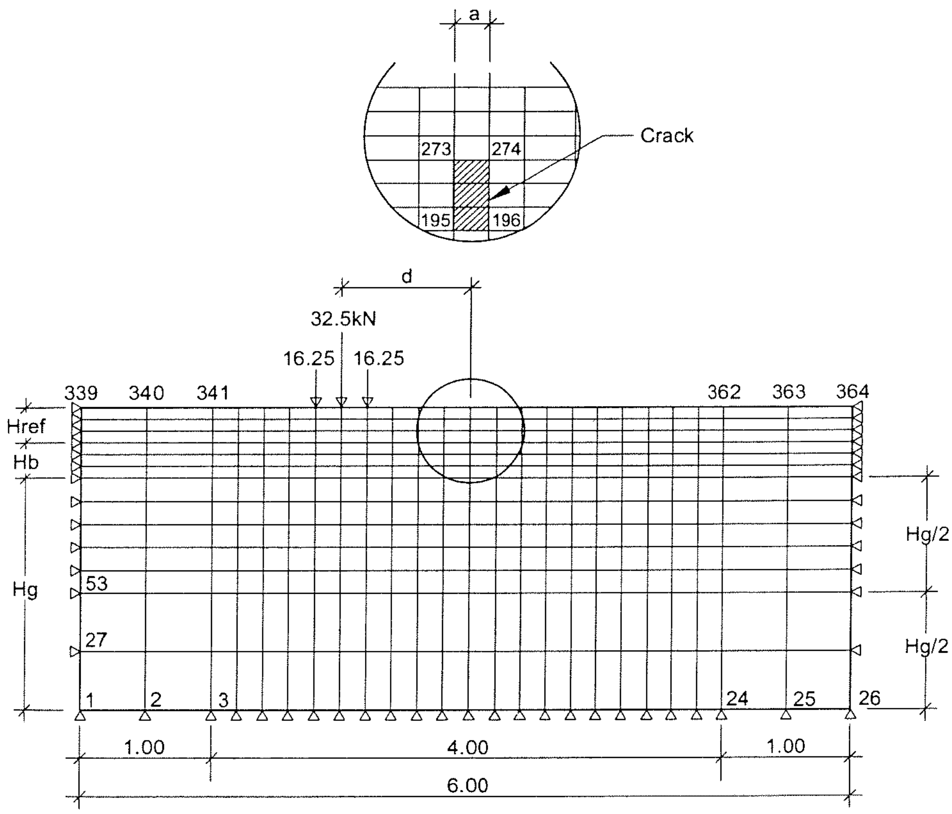

Figure 5. Finite element model for estimation of crack activity after overlay.

The influence of the overlay thickness in the crack activity after overlay, for 5000 MPa overlay stiffness, is presented in Figure 6.

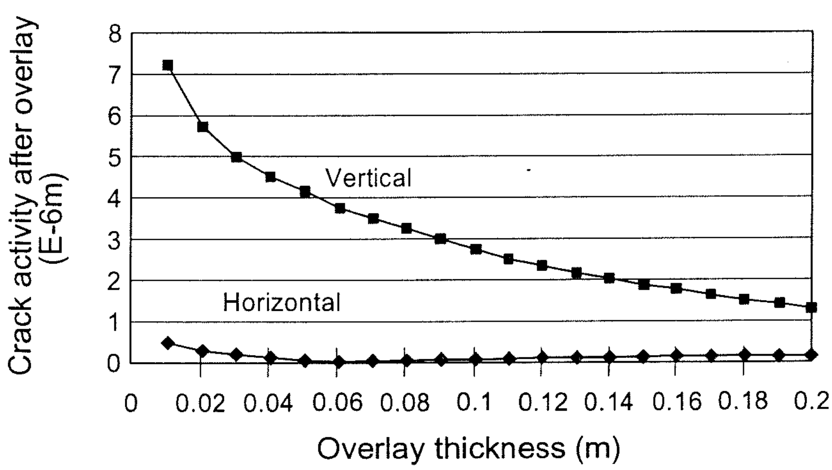

Figure 6. Crack activity after pavement overlay as function of overlay thickness.

Two important conclusions can be taken from the finite element analysis:

1. After overlay the horizontal crack activity is almost null.
2. The vertical activity is highly reduced and follows a logarithmic law.

The crack activity after overlay can be correlated with the crack activity before overlay with the following relationship:

$$AV = (a * \ln(h_r) + b * \ln(E_r) + c * \ln(af) + d) * (e * AV^-) + f \qquad (4)$$

where AV is vertical crack activity after overlay (e-6), AV^- is vertical crack activity before overlay (e-6). af is the crack width (mm), h_r is overlay thickness (cm), E_t is overlay stiffness (MPa). and a. b, c, d, e, f are statistical coefficients.

Table 5. Coefficients for Equation 4 for transversal cracks before e after Break Point (BP).

BP	a	b	c	d	e	f	R^2
Before	-1.2926	-6.3182	0.05945	52.9983	0.01427	-0.2477	0.8519
After	-0.3345	-1.1717	-0.01169	9.9659	0.05149	-3.7264	0.9649

Table 6. Coefficients for Equation 4 for longitudinal cracks before e after Break Point (BP).

BP	a	b	c	d	e	f	R^2
Before	-0.1355	-0.4771	0.03726	3.8086	0.1302	0.7464	0.4999
After	-0.1546	-0.6083	0.1236	4.7448	0.1289	5.4194	0.9271

REFLECTIVE CRACKING

Test apparatus

Laboratory simulation of reflective cracking phenomena was made using RCD to fit in CS 7200 shear testing machine, applying the displacement pattern measured in the road with the CAM. Figure 7 shows a schematic representation of the crack zone that is simulated by the RCD. The RCD is represented in Figure 8.

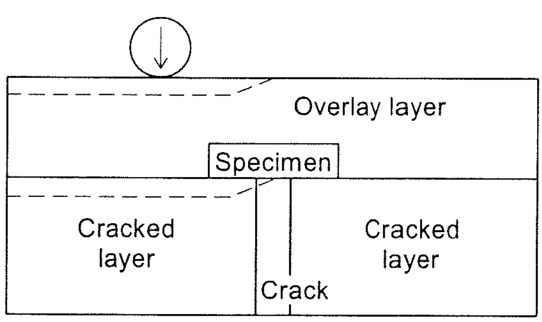

Figure 7. Schematic representation of the crack zone

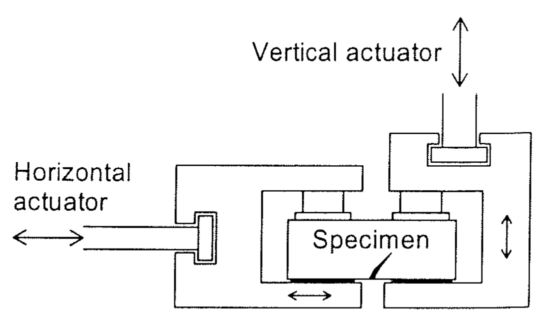

Figure 8. Schematic representation of the Reflective Cracking Device.

Finite element simulation

In order to understand the reflective cracking behaviour, a finite element model, simulating the RCD and the specimen, was used (Figure 9). With this model, the state of stresses for cylindrical specimens with 5 and 6 cm thickness by 15 cm diameter were analyzed.

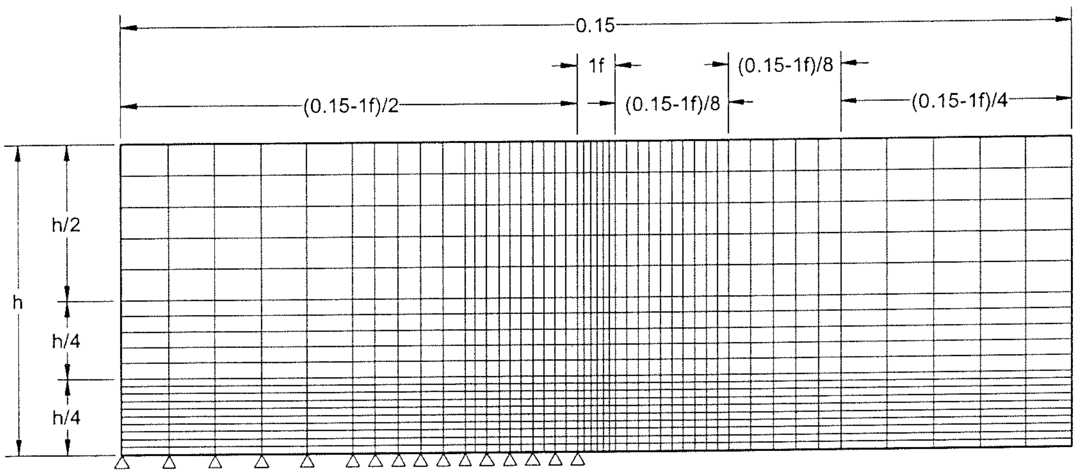

Figure 9. Finite element model to simulate RCD.

Finite element results in terms of overlay thickness and crack activity after overlay are presented in Figure 10 where 5 crack activities were studied. The crack activities used in RCD and presented in Figure 10 were 4, 8, 16, 32 and 64 times higher than those estimated for a cracked pavement.

It can be concluded that the increase of crack activity after an overlay increase the stress level in the specimen and the increase of specimen thickness decrease the stress level in the specimen.

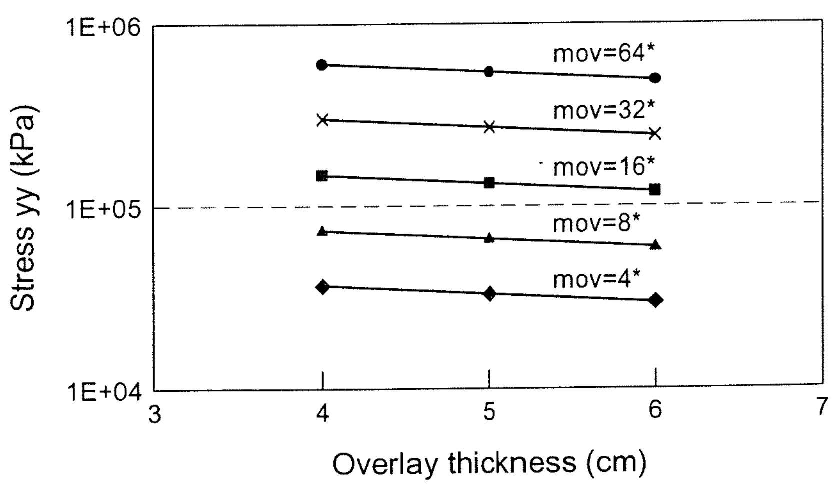

Figure 10. Influence of overlay thickness and crack activity level on specimen stress level.

EXPERIMENT DESIGN

The laboratory simulation of reflective cracking was made on bituminous mixtures produced in laboratory. The bituminous mixture used in this study was a dense graded bituminous mixture with a maximum aggregate size of 25 mm manufactured according the Portuguese standards and used in binder layers. The bitumen used to produce the bituminous mixture was a conventional 50/70-penetration grade.

For these tests the crack width of the reflective cracking was set to 6 mm, corresponding to three times the crack width measured in pavement. The test frequency was 10 Hz and the test temperature was 20 °C.

To simulate the reflective cracking through overlays, the crack activity after overlay, calculated using the finite element model, was applied to the specimen by the shear machine through the RCD. Because this crack activity is very low, test would take several days. Therefore a test program was undertaken at higher crack activity levels involving the use of a fatigue law to extrapolate the results to the desired crack activity (Pais et al, 1998).

TEST RESULTS

To evaluate reflection cracking through overlays Sousa et al (1996) suggested that, an equivalent stiffness in the crack zone could be used to define the fatigue life for this problem. This equivalent stiffness is defined as the average stiffness in specimen volume above the crack and is defined as follows:

$$S = \frac{F/L.H}{\delta/w} \qquad (5)$$

where S = equivalent stiffness in crack zone; F = measured force; δ = applied displacement; L = crack length (i.e. specimen length); H = specimen height and w = crack width.

The AASHTO TP8-94 standard test defines the fatigue life for flexural beam specimens when the specimen stiffness is reduced to 50% of the initial stiffness. For this study, the fatigue life was defined as the number of load cycles to reach 50% of the initial equivalent stiffness in crack zone.

A reflective cracking fatigue model can be established using a linear regression between logarithm of fatigue life, *log* N, and the logarithm of displacement, log Δ, defined as follows:

$$N = a\left(\frac{1}{\Delta}\right)^{b} \qquad (6)$$

where N is the fatigue life; Δ is the crack activity after overlay and a, b are experimentally determined coefficients.

Using the equivalent stiffness in the crack zone to analyze the reflective cracking, two types of stiffness evolution were found during the test. The most usual stiffness evolution found in these tests was the logarithmic law (Figure 11) but in some tests a exponential law (Figure 12) was found.

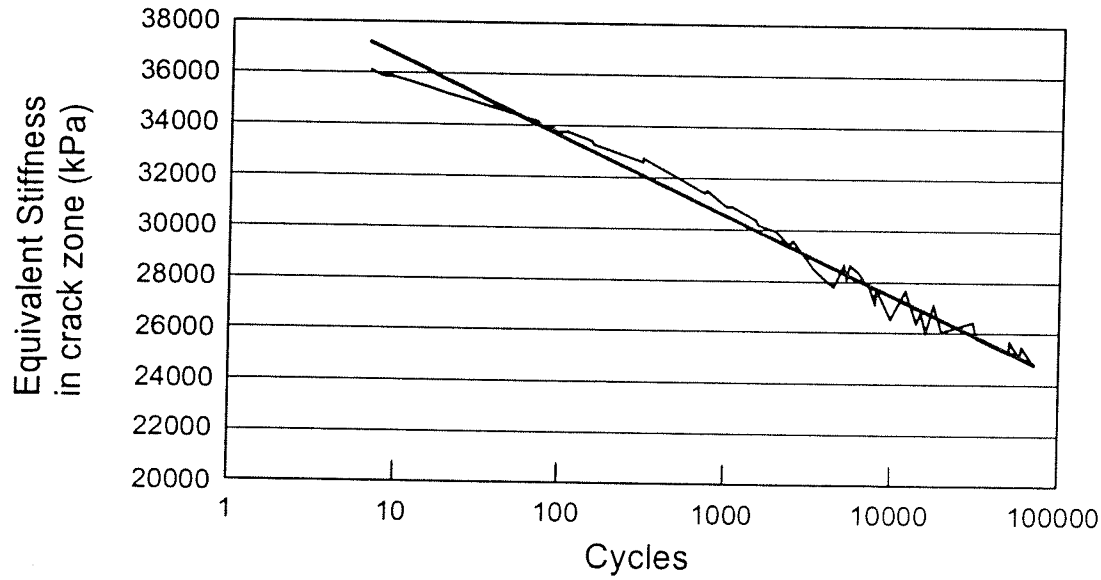

Figure 11. Logarithmic evolution of equivalent stiffness in crack zone.

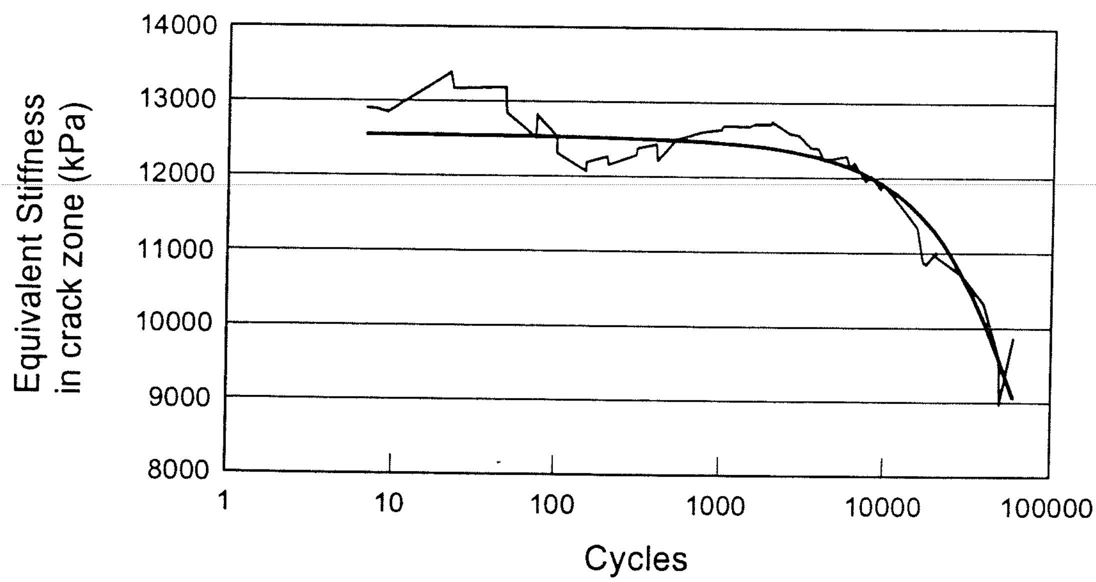

Figure 12. Exponential evolution of equivalent stiffness in crack zone.

The reflective cracking fatigue life as function of crack activity and specimen thickness for longitudinal cracks is shown in Figure 13 where one can conclude that the increase of crack activity decreases the fatigue life and the increase of specimen thickness increases the fatigue life.

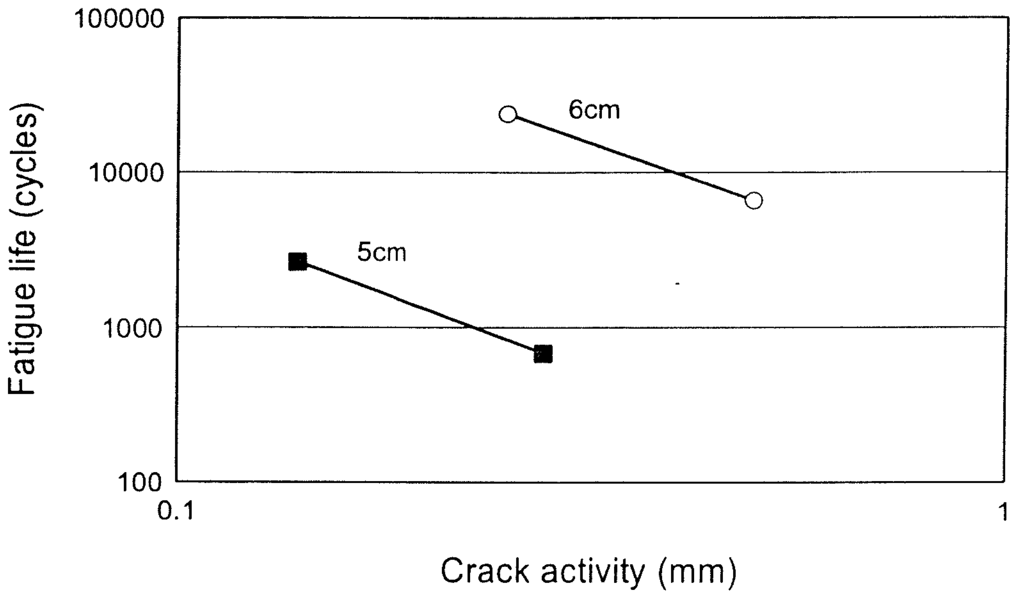

Figure 13. Fatigue life laws for longitudinal cracks.

Those two thicknesses and three crack activities can be used to extrapolate the reflective cracking fatigue life for other thicknesses and crack activities. However, further conditions need to be evaluated to demonstrate the validity of these assumptions.

CONCLUSIONS

To evaluate the reflective cracking potential, the crack activity must be measured. This crack activity before overlay can be used to estimate the crack activity after overlay. Both crack activities can be well correlated with old pavement and overlay characteristics.

After overlay, the horizontal crack activity in the bottom of new layers is almost null and the vertical activity is highly reduced with the overlay thickness and follows a logarithmic law. These crack activities are influenced by the overlay properties, namely the overlay thickness and material stiffness.

The laboratory study with the reflective cracking device showed that the stiffness behaviour during test follows either an exponential law or a logarithmic law.

The reflective cracking fatigue life is influenced mainly by the crack activity after overlay and overlay thickness. The increase of crack activity decreases the fatigue life and the increase of specimen thickness, representing the overlay thickness, increase the fatigue life.

This approach appears to open promising avenues and further research should be made in this area.

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