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PREDICTION OF EXISTING REFLECTIVE CRACKING POTENTIAL OF FLEXIBLE PAVEMENTS

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Abstract

The overlay of a cracked pavement is subject to reflective cracking due the existing crack potential. In a cracked pavement, this cracking potential can be evaluated by means of crack activity due to traffic loads and temperature gradient.

Traffic loads cause vertical and horizontal activity between the two edges of the cracks. These activities are caused by rocking of blocks between the cracks as well as by the shape of the deflection basin, combined with the size of the blocks. The temperature gradient causes horizontal activity between the two edges of the cracks. The main goal of this work is the development of a model to predict the reflective cracking potential of flexible pavements.

In this work, the crack activity was measured with a Crack Activity Meter (CAM) on 14 test sections of Portuguese flexible pavements. The resulting crack activities were analyzed and the influence of pavement conditions was evaluated, which in turn lead to the development of a model to predict crack activity before overlay.

Reflective cracking potential is a function of overlay material properties, namely the overlay thickness and stiffness. Crack activity after overlay was predicted using a finite element model.

1. Introduction

Overlays are the most commonly used method for pavement rehabilitation. However, they often do not perform as desired due to existing cracks, which can quickly propagate through the new overlay. This type of cracking is commonly referred to as reflective cracking. It is a result of differential vertical and horizontal movements above the old crack tip. Such movements, also called crack activity, are caused by thermal stresses, traffic loads, or by a combination of these two mechanisms. Stress concentrations are induced in the new overlay by virtue of crack activity. Thus the existing crack pattern observed in the original pavement oftentimes quickly propagates up through the new overlay.

Pavement cracks that exist before overlay exhibit varying degrees of crack activity as a function of pavement properties, mainly pavement layer thicknesses and stiffness as well as applied load. After overlay, the existing cracks exhibit crack activity as a function of the crack activity before overlay, and of the overlay properties (thickness and stiffness).

The crack activity before overlay plays an important role in the mechanistic characterization of existing pavements, but when conducting an overlay design the crack activity after overlay is required to evaluate the pavement's resistance to reflective cracking in bituminous (asphalt) mixes.

2. Crack Movement

Crack edges are subject to relative movements mainly as a function of wheel load position and pavement properties. Irwin (1957) proposed a model that showed that crack movements occur through three modes: Mode 1 represents bending; Mode 2 represents shear; and Mode 3 represents tearing. This is illustrated in Figure 1 (Colombier, 1989).

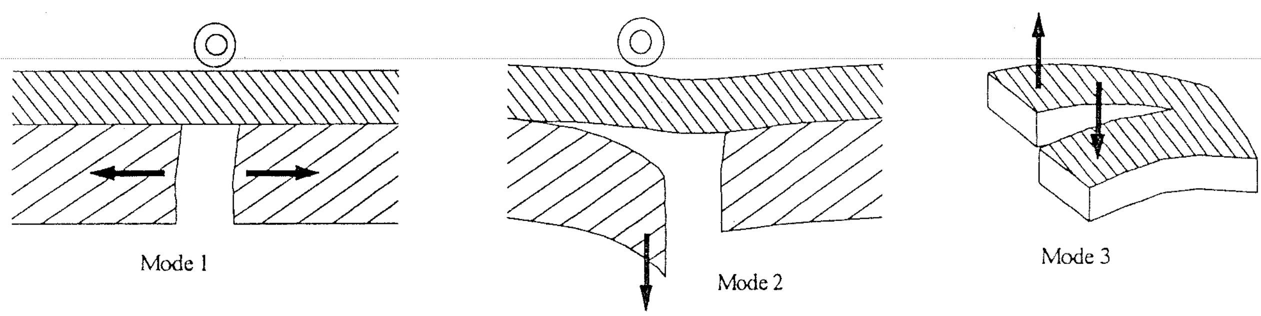

Figure 1. Crack Movements (Colombier, 1989)

Due traffic loads, these movements occur in pavement cracks depending on the position of a wheel load. The first mode is usually observed when a wheel load passes over a transverse or longitudinal crack. The second mode is observed when a wheel load approaches a transverse crack or when the load passes by the edge of a longitudinal crack. The third mode only appears in longitudinal cracks when the wheel load passes near the end of the crack. These modes are represented by Figure 2, as proposed by Pais (1999).

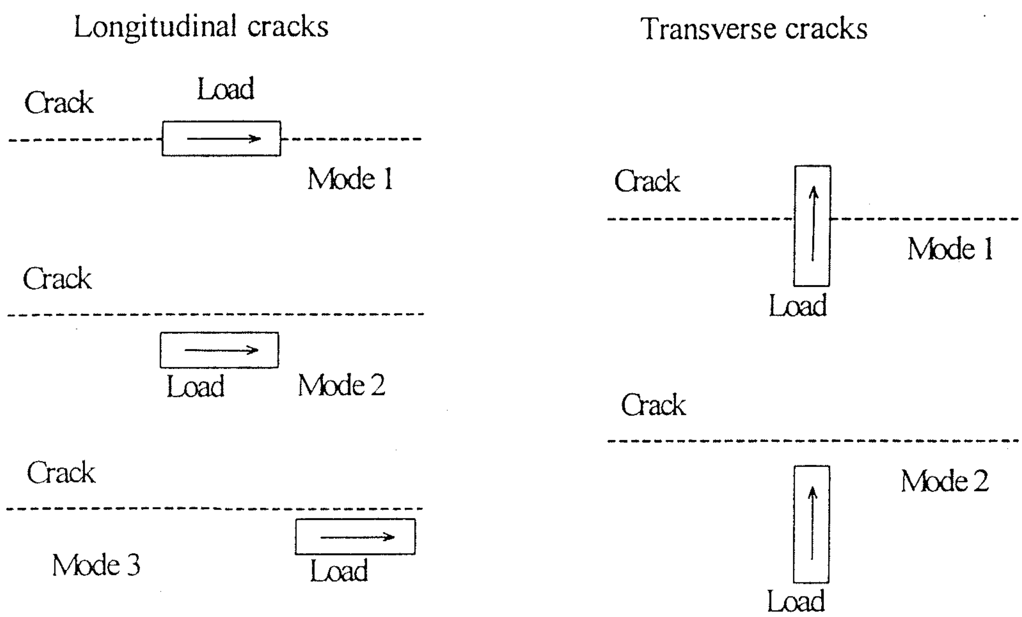

Figure 2. Crack Activity Modes as a Function of Location of Load (Pais, 1999)

From this analysis, it can be concluded that the most frequently observed modes of cracking in flexible pavements are Modes 1 and 2, representing the horizontal and vertical movements between the two edges of a crack. These movements are commonly called "crack activity", and they can be evaluated directly in an existing pavement using a crack activity meter (CAM).

3. Crack Activity

Crack activity in existing cracked pavements was first measured by Rust (1987) using a device called a Crack Activity Meter (CAM) which measures the relative movements between the edges of a crack.

The CAM is composed of two LVDTs (Linear Variable Differential Transformers), one placed vertically and the other placed horizontally, allowing the measurement of both differential movements. The CAM is installed on a support on one side of the crack. On the other side, the horizontal support is placed on the vertical support. Figure 3 shows a schematic representation of a CAM placed over a pavement crack.

The CAM can be used to measure the crack activity of both transverse and longitudinal cracks, as illustrated in Figure 4. In both cases, the CAM is placed over the crack and as close to the track where the wheel load passes by as possible. In each case, the wheel load should pass very close to the CAM to achieve the greatest crack movement, or activity.

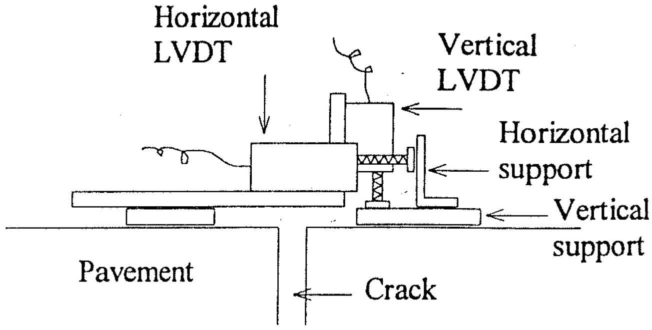

Figure 3. Crack Activity Meter (CAM)

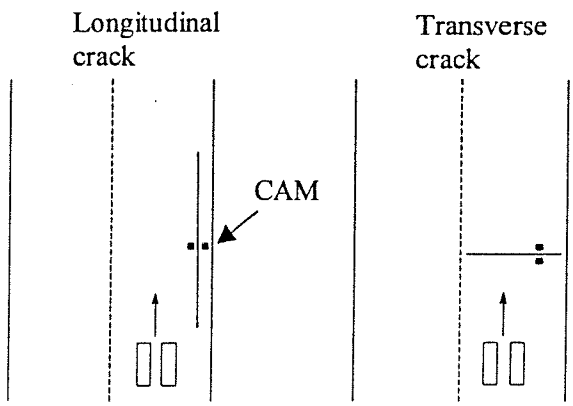

Figure 4. Position of the CAM for Measuring Longitudinal and Transverse Cracks

3.1 Crack Activity Before Overlay

The evaluation of crack activity before overlay was made on 14 cracked cross sections, each of which were 500m long, in the Portuguese road network. Only flexible pavements were studied.

In all 14 cross-sections, layer thicknesses and stiffnesses were measured by coring. The results are presented in Table 1, where all asphalt-bound layers were combined into a single layer called "bituminous" and all granular layers, including the subgrade, were combined as a single layer called "granular". This combining of adjacent layers was carried out in order to define representative pavement structures having only two effective layers, allowing for the characterization of pavements using four parameters (the thicknesses and stiffness of each structural layer).

From the array of cross-sections presented, transverse cracks in 14 cross-sections and longitudinal cracks in 9 cross-sections were measured and analyzed. Typical crack activity for a longitudinal crack is shown in Figure 5. Figure 6 shows typical crack activity for a transverse crack. Positive values for horizontal crack movements indicate opening or widening of a crack, while negative values represent closing or narrowing of a crack. In these figures, the distance represents the load track movement.

Table 1. Pavement Structural Cross-Sections

Cross-Section (#)	Bituminous Thickness (m)	Granular Thickness (m)	Bituminous Stiffness (@ 20°C) (MPa)	Granular Stiffness (MPa)
1	0.20	2.46	1400	100
2	0.20	2.08	1200	180
3	0.17	2.55	2600	140
4	0.18	2.65	3400	160
5	0.29	2.81	1100	140
6	0.21	2.52	2000	130
7	0.32	2.89	1800	140
8	0.18	2.27	1200	160
9	0.22	2.91	3000	80
10	0.30	2.67	3000	120
11	0.32	3.31	4100	60
12	0.18	2.18	1800	120
13	0.29	2.72	1700	180
14	0.15	2.38	4900	80

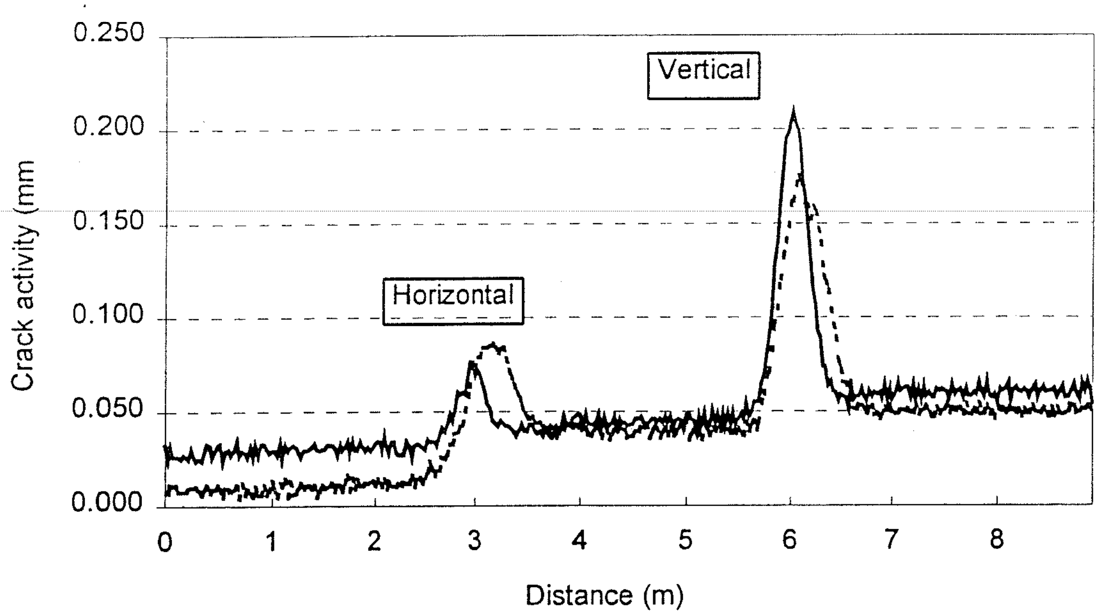

Figure 5. Crack Movement of a Longitudinal Crack Before Overlay

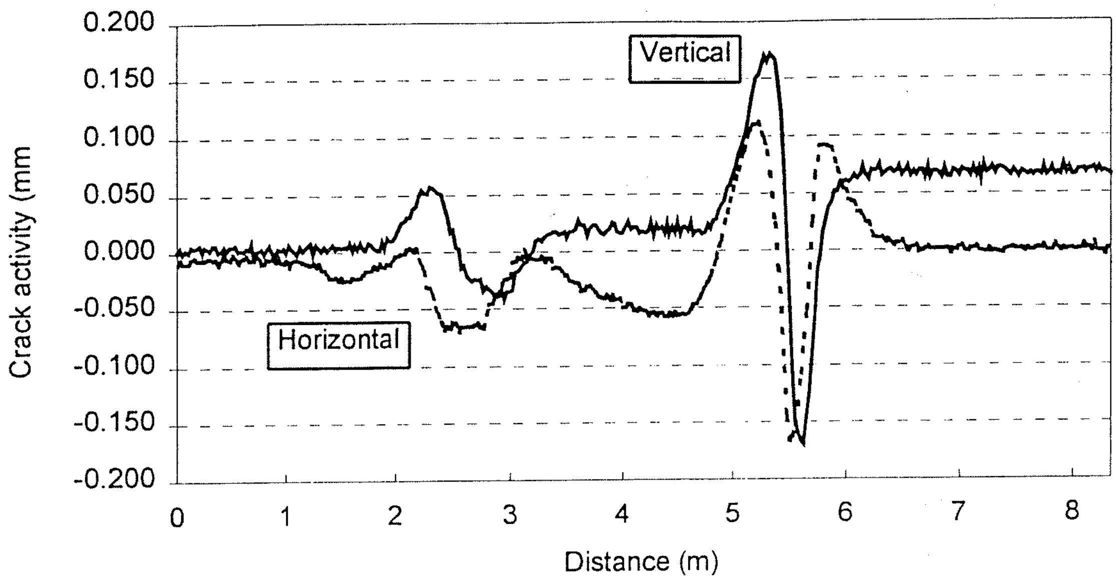

Figure 6. Crack Movement of a Transverse Crack Before Overlay.

From the cross-sections shown, transverse cracks in 14 cross-sections and longitudinal cracks in 9 cross-sections were analyzed. Table 2 shows the greatest crack activity measured in each cross-section.

Table 2. Measured Crack Activity Before Overlay

	Longitudinal Cracks			Transverse Cracks		
Cross-Section (#)	Horizontal Activity (10^{-6}m)	Vertical Activity (10^{-6}m)	Tempe-rature (°C)	Horizontal Activity (10^{-6}m)	Vertical Activity (10^{-6}m)	Tempe-rature (°C)
1	100	60	11			
2	100	90	15	100	20	15
3	95	100	14	80	150	14
4	70	15	14	40	40	14
5	115	180	20	100	100	20
6	205	200	16	350	250	16
7	55	35	7			
8	50	25	17	50	80	17
9	70	35	15	60	140	15
10	80	100	8	125	250	8
11	230	360	16	30	10	16
12	155	105	10			
13	240	360	10			
14	170	130	11			

Statistical calculations were made to correlate the measured crack activity with actual as-measured pavement and crack characteristics. The models to predict crack activity before overlay as function of pavement characteristics are expressed by the "Piecewise Model" with breakpoint (Act_0). This model is a two tends linear regression with breakpoint. Equation 1 shows the model used to predict the crack activity before overlay:

$$Act = a_1 + b_1 * af + c_1 * h_t + d_1 * E_t \quad , Act < Act_0$$
$$Act = a_2 + b_2 * af + c_2 * h_t + d_2 * E_t \quad , Act \geq Act_0 \tag{1}$$

where Act is crack activity before overlay (10^{-6}m), 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 as given in Table 3.

Table 3. Coefficients for Crack Activity Before Overlay

Crack Type	Activity type	a_1 a_2	b_1 b_2	c_1 c_2	d_1 d_2	Act_0
Transverse	Horizontal	56.21 -88.19	5.30 -0.43	0.259 2.160	-0.00404 0.0163	123.9
Transverse	Vertical	232.5 -1204.3	1.043 105.4	-1.634 6.904	0.000206 0.10918	128.2
Longitudinal	Horizontal	211.7 2804.1	2.883 480.6	-1.339 -22.37	-0.00481 -0.3272	91.8
Longitudinal	Vertical	-14.43 17042	13.03 850.9	0.482 -147.2	-0.00783 -0.72201	107.3

3.2 Crack Activity After Overlay

Overlay design methods that takes reflective cracking into account must recognize that crack displacements are responsible the propagation of existing cracks through the overlay, in other words the crack activity after overlay.

Crack activity measured in the pavement before the overlay is different from crack activity after overlay, since this will depend on the overlay thickness material stiffness. Crack activity after overlay can be estimated using a finite element analysis knowing the existing pavement and overlay material properties.

The finite element model used to estimate crack activity after overlay consists of a layer with Hg thickness representing the granular layer, a layer with Hb thickness representing the cracked bituminous layer, and a layer with $Href$ thickness representing the pavement overlay, as shown in Figure 7.

The crack in the bituminous layer is shown by the shaded elements in Figure 7. The crack is modeled as a "void" with a negligible modulus of 1 MPa in the finite element model.

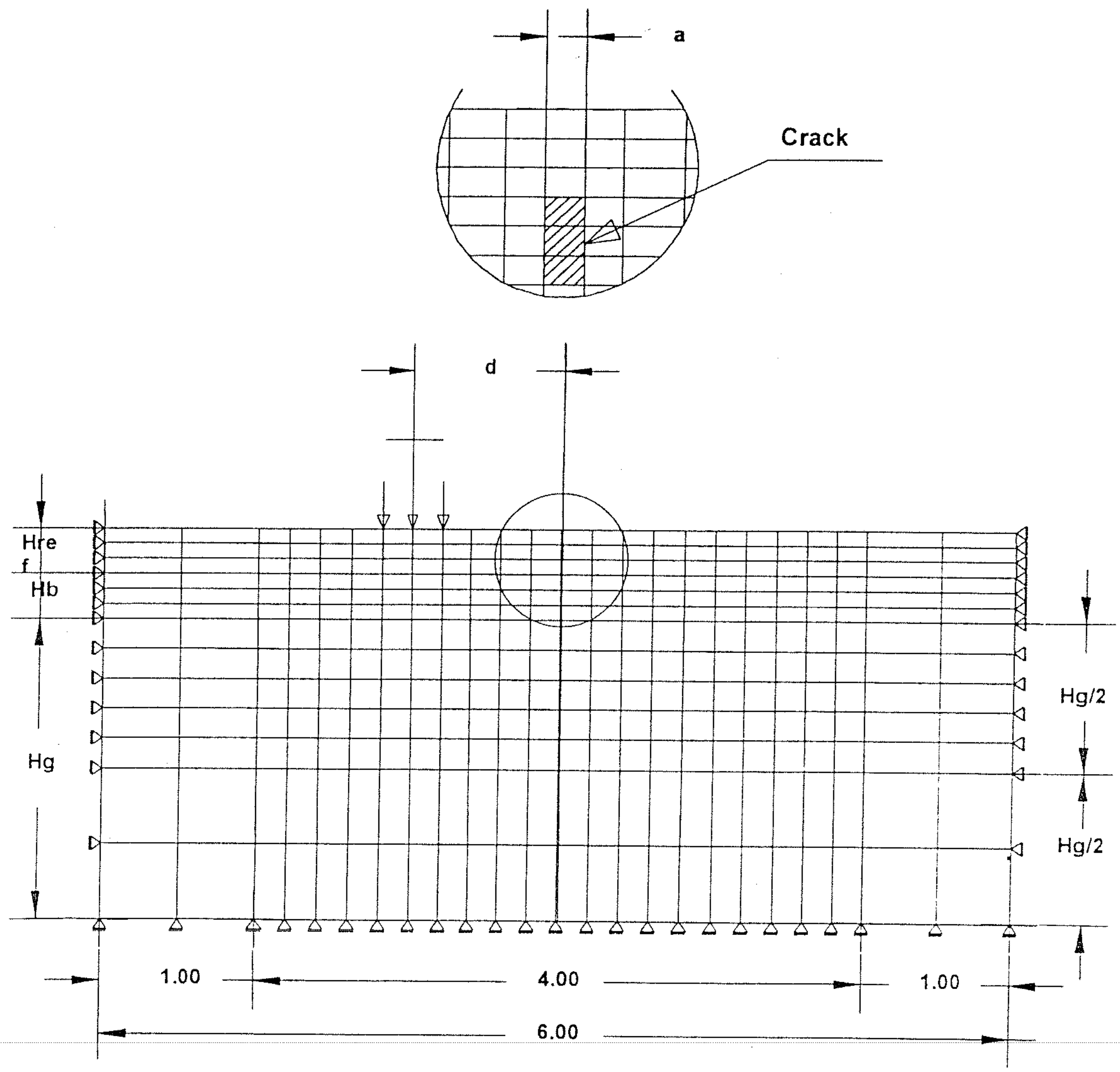

Figure 7. Finite Element Model for Estimation of Crack Activity After Overlay

Based on experience, the crack width applied in the model must be approximately three times those measured in the actual pavement in order to account for the disintegrated edges of the cracks of the real pavement section.

The model presented was used to study the influence of overlay thickness and stiffness on the crack activity after overlay. The influence of the crack width was also studied.

The main results given by the application of this model to the cross-sections used in this study are presented in Figure 8, where the influence of overlay thickness on crack activity after overlay is presented for a 5000 MPa overlay stiffness, or modulus. As an example, this is only shown for cross-section #2, the cross-section that shows the highest ratio between the horizontal and vertical crack activity after overlay.

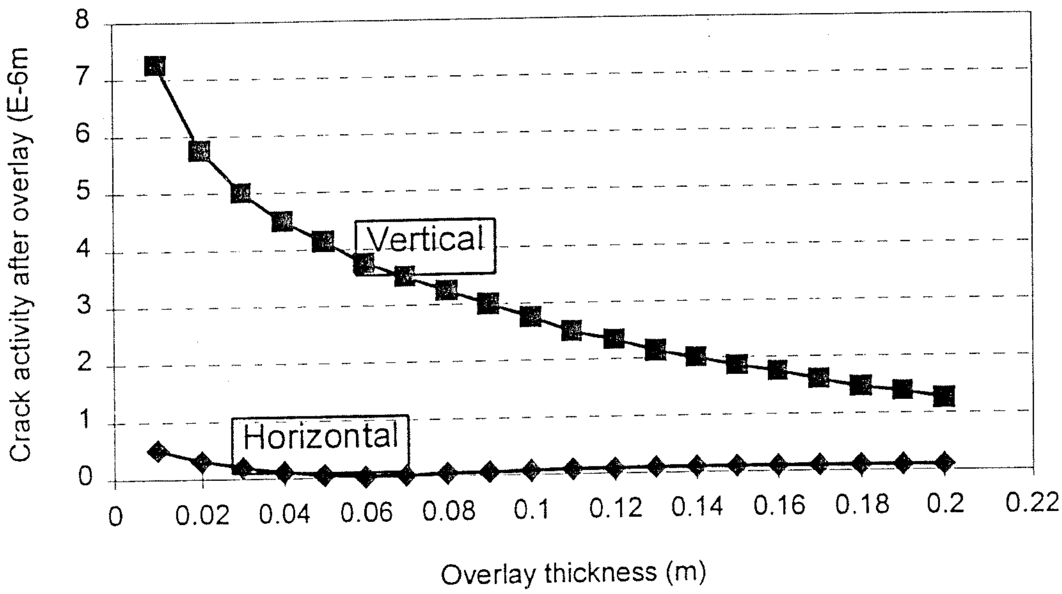

Figure 8. Crack Activity After Pavement Overlay as a Function of Overlay Thickness

From this finite element analysis two important conclusions can be made:

1. After overlay, the horizontal crack activity is of minor importance compared to the vertical crack activity. In all finite element simulations studied, the horizontal crack activity after overlay can only attain a level half as great as the vertical crack activity.

2. After overlay, the vertical activity is highly reduced and follows a logarithmic law as a function of overlay thickness.

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

$$AV = (a * \ln(h_r) + b * \ln(E_r) + c * \ln(af) + d) * (e * AV^-) + f \qquad (2)$$

where AV is vertical crack activity after overlay (10^{-6}m), AV^- is vertical crack activity before overlay (10^{-6}m), 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. The application of the model proposed by Equation 2, for the cross-sections used in this study, has lead to the statistical coefficients shown in Table 4.

Table 4. Coefficients for Equation 2

Crack Type	Break Point	*a*	*b*	*c*	*d*	*e*	*f*	R^2
Tranverse	Before	-0.694	-2.588	0.2911	22.694	0.642	-3.595	0.8519
	After	-2.662	-7.496	2.4637	67.578	0.452	-19.98	0.9649
Longitudinal	Before	-0.974	-2.668	0.3924	22.394	0.439	-1.293	0.4999
	After	-0.951	-3.148	0.5609	25.975	1.155	-1.992	0.9271

4. Conclusions

To evaluate the reflective cracking potential of flexible pavement overlays, the crack activity under wheel loads must be measured. The crack activity before overlay can be used to estimate the crack activity after overlay. The various kinds of crack activity before overlay are well correlated with the same kinds of crack activity after overlay.

After overlay, the horizontal crack activity at the bottom of overlay material is of minor importance compared to the vertical crack activity. The horizontal crack activity cannot reach 50% of the vertical crack activity after overlay. The vertical crack activity is highly reduced with the overlay thickness and follows a logarithmic law. Crack activities are influenced by the overlay properties, namely the overlay thickness and stiffness.

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5. References

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