Universidade do Minho

[CI-24]

Pais, J.C., Pereira, P.A.A., Sousa, J.B., Capitão, S.

“Evaluation of the load associated cracking in flexible pavements”

Sixth International Conference on the Bearing Capacity of Roads, Railways
and Airfields, Lisboa, Portugal, 2002, p. 585-594

Bearing Capacity of Roads, Railways and Airfields

A. Gomes Correia
Fernando E.F. Branco

VOLUME 1

Table of Contents

Introduction	XII
<i>A. Gomes Correia & Ivar Horvli</i>	
Preface	XIII
<i>Fernando E.F. Branco</i>	
Organization	XV
 <i>Bearing capacity policies, concepts, costs and condition surveys</i>	
A New Deflection Measuring System for Pavements in Spanish Airports Based on Laser Technology	3
<i>P.P. Carrasco, L. Martín</i>	
Monitoring Pavement Response during Spring Thaw Using Fiber-Optic Sensors	15
<i>G. Doré, G. Duplain</i>	
Evolution of French Airport Bearing Capacity Assessment	25
<i>J.-P. Guillon, J.-C. Deffieux</i>	
Inconsistencies in Rating the Effect of Aircraft Load and Reporting the Bearing Capacity of Pavements	33
<i>A. Loizos, C. Abacoumkin, G. Charonitis</i>	
Evaluation of Rigid Pavement Condition Using Falling Weight Deflectometer	43
<i>M.M. Pradhan</i>	
Non-Contact Deflection Measurement at High Speed	53
<i>S. Rasmussen, J.A. Krarup, G. Hildebrand</i>	
Application of Image Analysis to the Identification and Rating of Road Surface Distress	61
<i>C. Rasse, V. Leemans, M.-F. Destain, J.-C. Verbrugge</i>	
ROADDEX – Benchmarking Low Traffic Volume Road Condition Management in EU Northern Periphery Area	69
<i>T. Saarenketo, S. Bell, G. Berntsen, S. Sundberg, E. Vuontisjärvi</i>	
Pavement Condition Survey at a Motorway Section in Croatia: Maintenance and Rehabilitation Activities	79
<i>M. Srsen, I. Krsic</i>	

Validation of Pavement Condition Index – PCI: A Portuguese Case Study <i>J. Veloso, Fernando. E.F. Branco</i>	89
 <i>Analysis and modeling</i>	
A Simple Damage Approach to Modelling Fatigue in Bituminous Materials <i>Y.K. Choi, A.C. Collop, N.H. Thom</i>	103
Ultra-Thin Whitetoppings: A 2-D Finite Element Parametric Study <i>W. De Corte, D. De Leersnyder, E. De Winne</i>	113
A Mechanical Model for the Prediction of the Tire/Road Friction <i>M.-T. Do, F. Hammoum</i>	123
Material Models for Reinforced Unbound Aggregate <i>G. Eiksund, I. Hoff, G. Svanø, A. Watn, E.V. Cuelho, S.P. Perkins, B.R. Cristopher, C.W. Schwartz</i>	133
3-D FE Analysis of Test Road Structures – Comparison with Measurements <i>S. Erlingsson</i>	145
Dynamic Analysis of FWD Data for Pavement Evaluation <i>E. Fernando, W. Liu</i>	159
Limiting Equilibrium Methods in Bearing Capacity Analysis of Flexible Pavements Reinforced with Geosynthetics <i>T.C. Hopkins, M.E. Slepak, L. Sun</i>	169
Mechanistic Model for Road Design in Sweden <i>A. Huvstig</i>	181
Stress Paths in Flexible Pavements Subjected to Severe Climatic Conditions <i>J.-M. Konrad, S. Zhou</i>	191
Backcalculation of Thin Air – A Way to Cope with Slipping and Sliding Layer Interfaces <i>C.A. Lenngren</i>	203
Initial Rutting on Reconstructed Roads and How It Relates to FWD Testing II <i>C.A. Lenngren, R. Fredriksson</i>	213
Reinforcement of Flexible Pavements – Design of Finite Element Models <i>S. Neßlauer</i>	223
Prediction of Flexible Pavement Response Using Non-Linear Stress-Dependent Material Models <i>S.-W. Park, R.L. Lytton</i>	231

A380 Flexible Pavement Experimental Program <i>J. Petitjean, C. Fabre, J.M. Balay</i>	241
Effects of Moving Dynamic Tyre Loads on Tyre-Pavement Contact Stresses <i>W. Steyn, A.T. Visser</i>	253
Flexible Airport Pavement Evaluation for New Generation Aircraft using ILLI-PAVE-Based Concepts <i>M. Thompson, F. Gomez-Ramirez</i>	263
Evaluating of Overlay on Concrete Slab in Airport with 3D FEM <i>S. Wu, R. Yin</i>	275
 <i>Design and environmental effects</i>	
Development of Pavement Temperature Prediction Model for Asphalt Concrete Pavements <i>M.A.H. Abo-Hashema, F.M. Bayomy</i>	285
Effect of the Variability of Seasonal Moduli Adjustment Factors on the Mechanistic-Empirical Overlay Design <i>F.M. Bayomy, M.A.H. Abo-Hashema</i>	295
Critical Stresses for Thickness Design of Rigid Pavement Slabs Subjected to Multiple-Axle Heavy Aircraft Gear Loads <i>D.R. Brill, E.H. Guo, L. Ricalde</i>	305
Temperature Variation and Displacement Behavior of Model Asphalt Pavements During Repeated Plate-Loading Tests <i>E. Hirotsu, N. Yoshida, Masaru Nishi, H. Kanki</i>	315
Airfield Pavement Structural Analyses and Design in Sweden <i>C.A. Lenngren, H. Carlsson</i>	325
Impact of Heavy Vehicles on Pavement Responses <i>P.E. Sebaaly, R. Siddhartan, D.L. Huft, D. Bush</i>	335
Pavement Detriment Due to Runway Roughness <i>M.J.A. Stet, H.P.M. Thewessen</i>	345
New Experiences in Loading of Flexible Pavements <i>V. Vodopivec, V. Oštir, B. Lipoglavšek</i>	355
A New Approach to Pavement Design in Sweden: New Swedish Road Design Manual <i>T. Winnerholt</i>	365
Consideration of Climatic Conditions in Pavement Design <i>M. Wistuba, J. Litzka</i>	373

Pavement Design for the 3rd Runway at Stockholm-Arlanda Airport, Sweden H. Wolgé, L. Näslund	381
 <i>Construction, maintenance and rehabilitation</i>	
Characterisation of Dense-Graded Asphalt Cold Mixtures for Pavement Rehabilitation <i>F.A. Batista, M.L. Antunes</i>	391
Variation in Calculated Pavement Performance Due to Variation in Input Data <i>P. Ekdahl</i>	401
Could Adherence of a Road Surface be used to Identify the Areas where Maintenance is Needed? <i>M. Gothié</i>	411
Bearing Capacity of Flexible Road Structures Reinforced with Steel Fabrics <i>K. Gustafson, S. Said, L.G. Wiman</i>	423
Implementation of Nondestructive Structural Evaluation for Airport Asphalt Pavements <i>Y. Hachiya, Y. Tsubokawa, O. Takahashi</i>	433
Effects of New and Conventional Deicing Chemicals on Airfield Asphalt Concrete Pavement <i>Y. Hassan, A.O. Abd El Halim, A. El-Desouky, A. Mostafa, M. Farha</i>	443
Long-Term Monitoring of an Open Graded Drainage Layer Design for Airfields at the Prince George Airport, British Columbia, Canada <i>M.J. Hovan, R. Resaul</i>	453
Rockfill pavements on Soft Subsoil-Construction and Compaction <i>B. Johansson</i>	463
A Probabilistic Method for Estimating Pavement Performance Using Falling Weight Deflectometer Data <i>O. Melchor-Lucero, I. Abdallah, S. Nazarian, C. Ferregut</i>	475
Pavement Edge Drain Barriers in the Rehabilitation of Existing Roads (Experiments and Fields Results) <i>J.L. Paute</i>	487
Evaluation of Pavement Structure Reinforced with Steel Fabrics <i>S.F. Said, H. Zarghampour, S. Johansson, H. Hakim, H. Carlsson</i>	497
Network Level Analysis of Pavement Maintenance in Norway <i>E.K. Sund, T. Haugødegård</i>	505
QUASAR Structural Analysis of Asphalt Pavements <i>C.A.P.M. van Gurp, A.J. van Leest</i>	515

Reflective cracking

- Laboratory Measurement of Crack Propagation in High Stiffness Asphalt Mixtures 529
A.C. Collop, N.H. Thom, A.J. Sewell
- Estimation of Relative Performance of Overlaid Asphalt Concretes against Reflection Cracking due to Shear and Bending Fracture Mode 539
K.W. Kim, S.J. Lee, Y.S. Doh, S.K. Rhee, T.S. Park
- Pavement Deterioration – Crack Initiation and Crack Propagation Models 549
W. Lars-Göran
- The Influence of Cracking on the Structural Properties of Asphalt Mixes 561
F.O. Martinez, S.M. Angelone
- Crack Element in the Non-Linear f.e.m. Program PA.R.M.A. for the Design of Reinforced Concrete Pavements 573
A. Montepara, F. Giuliani
- Evaluation of the Load Associated Cracking in Flexible Pavements 585
J.C. Pais, P.P.A. Pereira, J.M.B. Sousa, S. Capitão

Field Tests for layer moduli evaluation

- Efficient Backcalculation Algorithm of Time Domain for Large-Scale Pavement Systems using Ritz Vectors 597
Q. Dong, Y. Hachiya, O. Takahashi, Y. Tsubokawa, K. Matsui
- Method of Estimation of Bearing Capacity of Multi-Layer Pavements with Application of Quasi-Static Tests 607
M. Graczyk, T. Mechowski, J. Sudyka, M. Chomicki, J. Rafa
- Evaluation of the Influence of Asphalt Concrete Pavement Discontinuities on Falling Weight Deflectometer Measurements 617
S. Grenier, J.-M. Konrad
- In Situ Assessment of Stiffness of a Road Sand Embankment 629
W. Haegeman
- Repeatability, Reproducibility and Accuracy of GPR Measurements 637
V. Hopman, E. Beuving
- Backcalculation of Pavement Layer Moduli without Using D0-Deflection 647
J.W. Maina, T. Inoue, A. Kasahara, K. Matsui
- Falling Weight Deflectometer Configuration Standards for Airfield Testing 657
W. Marsey, N. Garg

Use of Backcalculated Falling Weight Deflectometer Modulus for Detecting Foundation Problems Caused by Rubblization of Concrete Pavements <i>Y. Mehta, B. Birgisson, B. Choubane</i>	667
Bearing Capacity of a Flexible Pavement During the Construction Phase <i>J.M.C. Neves, A. Gomes Correia</i>	677
Elastic Analysis of Thin Pavements and Subgrade Soil Based on Field and Laboratory Tests <i>W.P. Núñez, J.A. Ceratti, W.Y.Y. Gehling, J.A. Oliveira</i>	685
Validation of FWD Measurements in Connection with Outsourcing Contract <i>J.P. Pedersen, O. Noer, O. Olsen, D. Marquat, P. Offrell</i>	697
Multichannel Analysis of Seismic Waves for Layer Moduli Evaluation of Pavements <i>N. Ryden, P. Ulriksen, U. Ekdahl, C.B. Park, R.D. Miller</i>	705
Pavement Structural Evaluation: Production Level FWD Back-Analysis Using the Full Time History <i>G. Salt, D. Stevens, R. McLeod</i>	715
Using Seismic Investigation to Test the Interface between Two Pavement Layers <i>J.-M. Simonin</i>	721
Experimental and Theoretical Comparison of Dynamic Plate Testing Methods <i>N.H. Thom, P.R. Fleming</i>	731
In Situ Evaluation of Seasonal Variability of Subgrade Modulus Using DCP and FWD Tests <i>W. Uddin</i>	741
Standard and Recommended Practices for FWD based Evaluation and Reporting Strength of Airfield Pavement <i>J.P. Verbeek, M.J.A. Stet</i>	751
A Rapid Approach to Interpretation of SASW Results <i>H. Wu, S. Wang, I. Abdallah, S. Nazarian</i>	761
An Initiative Toward Mechanistic Construction Quality Control: Using Seismic Methods <i>D. Yuan, S. Nazarian</i>	771
<i>Author Index</i>	783

Evaluation of the Load Associated Cracking in Flexible Pavements

J.C. Pais & P.P.A. Pereira

University of Minho, Department of Civil Engineering, 4800-058 Guimarães, Portugal

J.M.B. Sousa

Consulpav, Taguspark, Edificio Tecnologia I, n.26, 2780 Oeiras, Portugal

S. Capitão

*Department of Civil Engineering of the Superior Institute of Coimbra, Quinta da Nora,
Apartado 10057, 3031-601 Coimbra, Portugal*

ABSTRACT: The overlay of a cracked pavement is subject to reflective cracking due to the existing crack potential. In a cracked pavement, this cracking potential, due to traffic loads and temperature gradient, can be evaluated by means of crack activity. 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 evaluation of the crack activity before and after an overlay and its evolution during pavement life. This work was done monitoring 50 cracks in two trial section of an in service pavement. Models for crack activity before and after overlay were developed, based on finite elements, and applied in this case.

KEYWORDS: Crack activity before overlay, crack activity after overlay, finite elements, crack activity meter, falling weight deflectometer

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 thickness and stiffness for an 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 ACTIVITY

Crack edges are subject to relative movements mainly as a function of wheel load position and pavement properties. These movements can be represented by a combination of a bending, a shearing and a tearing. The tearing only appear in special situations mainly when the applied load is close to the end of the crack. So, only the first two opening modes should be considered in flexible pavement evaluation.

Due to traffic loads, the 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. Figure 1 represents these modes, as proposed by 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" (Rust, 1987), and they can be evaluated directly in an existing pavement using any type of high precision measurement device, usually with a crack activity meter (CAM) or two sensors of a falling weight deflectometer (FWD).

The use of a FWD only allows the measurement of one direction crack activity while with the CAM, which is composed by two transducers, the vertical and horizontal crack movements can be evaluated. When the FWD is used only the vertical movements are measured.

The measurement with the CAM requires the use of a track, which passes very slowly near the CAM that is glued to the pavement (between the two edges of the crack). This is a slow process and very dangerous for the CAM integrity, as observed in Figure 2.

In the case of a FWD, the load plate is placed close to the crack and two geophones are manually placed between the two edges of the crack. This procedure presented in Figure 3, used to measure the crack activity after overlay, is very quick and any danger for the used material occurs.

Figure 1. Crack activity modes as a function of location of load (Pais, 1999).

3 CRACK ACTIVITY BEFORE PAVEMENT OVERLAY

The evaluation of crack activity before overlay was made on 50 cracks of two cross sections (CS1 and CS2), each of which were 100 m long, in the flexible pavements of a Portuguese road. The measurements were made in four different times during two years (May 98, Sep 98, Mar 99 and Jun 99).

Figure 2. Measurement of the crack activity before overlay with the CAM device and truck.

Figure 3. Measurement of the crack activity after overlay with the FWD.

Table 1. Characterization of cross-sections.

Cross-section (CS)	Time	Stiffness (MPa)		
		Bituminous (20°C)	Granular	Subgrade
1	May 98	5400	500	80
2		3100	400	70
1	Sep 98	3100	375	60
2		2250	190	75
1	Mar 99	2800	310	60
2		2100	150	65
1	Jun 99	2500	350	70
2		1500	210	70
		Thickness (m)		
		Bituminous	Granular	
1		0.20	0.60	
2		0.20	0.64

Figure 4. Typical crack activity influence line for longitudinal cracks measured with the CAM.

In all two cross-sections, layer thickness was measured by coring and layer stiffness was measured by back-calculation from FWD data.

The results are presented in Table 1, where all asphalt-bound layers were combined into a single layer called “bituminous” and all granular layers, excluding 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 three effective layers, allowing for the characterization of pavements using five parameters (two thicknesses and three stiffnesses).

3.1 Measured Crack Activity in Pavement

Typical crack activity influence line for a longitudinal crack is shown in Figure 4. Figure 5 shows typical crack activity influence line for a transverse crack. Positive values for horizontal crack

Figure 5. Typical crack activity influence line for transverse cracks measured with the CAM.

Figure 6. Vertical crack activity before overlay in all cracks.

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.

From crack activity influence line, both for longitudinal and transverse cracks, the crack activity is obtained, which represent the maximum amplitude of crack activity. For transverse cracks, only the ascendent part of the influence line was considered to define the crack activity.

In Figure 6 the vertical crack activity before overlay is presented for all 50 cracks. The first 30 cracks correspond to the CS1 and the other 20 cracks correspond to the CS2. Longitudinal cracks are the crack number: 3, 5, 6, 9, 11, 12, 16, 18, 20, 22, 24, 27, 34, 36, 47 and 48. Figure 7 shows the horizontal crack activity before overlay.

Figure 7. Horizontal crack activity before overlay in all cracks.

Figure 8. 3D finite element mesh used to calculate the crack activity before overlay.

No expressive differences were found between the crack activity measured on longitudinal and transverse cracks. So, the crack activity was jointed in only one group that include both longitudinal and transverse cracks.

The analysis of the results of vertical and horizontal crack activity before overlay shows that some differences can be found during the winter and summer months. These differences were more effective on CS2, during the winter the cracks showed the highest crack activity.

3.2 Estimated Crack Activity

Finite elements, in a 3D representation, as presented in Figure 8, were used to develop a model to estimate the crack activity before overlay. The pavement was modeled as a 3 layers pavement, with a bituminous cracked layer, a granular layer and a subgrade layer. A longitudinal crack is

Figure 9. Comparison between measured and predicted vertical crack activity before overlay.

also represented in a model with 4.70 m * 2.4 m (due to symmetrical pavement configuration) * pavement thickness. If the pavement has more than 3 layers, a usual situation in flexible pavements, layers of identical materials must be included in one layer.

Using the 3D finite element model, the vertical crack activity before overlay was calculated to fit in a statistical model and the Equation 1 was obtained.

$$Act = 11.773 \log(Tbet) - 21.388 \log(Tgra) - 52.893 \log(Mbet) - 94.619 \log(Mgra) - 16.418 \log(Msub) + 1181.66 \quad R^2 = 0.95 \quad (1)$$

where Act = vertical crack activity before overlay (10–6 m), Tbet = bituminous cracked layer thickness (m), Tgra = granular layer thickness (m), Mbet = bituminous cracked layer modulus (MPa), Mgra = granular layer modulus (MPa) and Msub = subgrade modulus (MPa).

It has been demonstrated by Pais et al. (2000) that the most important component of the crack activity is the vertical displacement. This is so because after an overlay the horizontal displacements are reduced to extremely small values. Because the crack activity before overlay was developed only for the vertical crack activity.

The application of the model developed to predict the vertical crack activity before overlay was made to the crack activity measurements in Mar 99 and Sep 99 for both cross-sections. The results are presented in Figure 9 where the horizontal lines represented the estimated values given by the statistical model. It can be concluded that on the average the model represents well the in situ measurements.

4 CRACK ACTIVITY AFTER PAVEMENT OVERLAY

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

Figure 10. Vertical 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 crack activity after overlay measured in the pavement requires access to the top of the cracked layer. This can be accomplished in two ways. In the first way a piece of wood with the overlay thickness is placed over the crack and the bituminous mixture is placed around it just prior to overlay compaction. After the pavement cools down the wood can be taken off providing access to the existing crack. In the other way a double aluminium foil sheet is to be placed on the crack and the overlay is placed. After the pavement cools down the overlay is cored until the existing pavement at a location given by accurate measurements. This situation can be found in Figure 3.

4.1 Measured Crack Activity in Pavement

For the measurement of the crack activity after overlay the FWD device was used which give only the amplitude of the activity after overlay. No influence line was obtained for this type of measurements. Once the FWD was used to measure the crack activity after overlay only the crack activity in one direction was measured. As demonstrated by Pais et al. (2000), the vertical crack activity after overlay should be measured instead of the horizontal. The results of the crack activity after overlay are presented in Figure 10.

The crack after overlay was measured in Aug 2000 on CS2 (cracks 30–40) and May 2001 on CS1 (cracks 1–20). The cracks 41–50 were eliminated because the pavements fails before overlay and it was rebuild. The crack activity after overlay on cracks 21–30 was not yet measured. The overlay thickness on existing cracks range from 7.5 to 13 cm as presented in Table 2.

Table 2. Overlay thickness for each crack.

Crack	Overlay thickness (cm)	Crack	Overlay thickness (cm)	Crack	Overlay thickness (cm)	Crack	Overlay thickness (cm)
1	8	8	11	15	13	33	12.5
2	7	9	11	16	13	34	13
3	7	10	11	17	13	35	13
4	10	11	11	18	12	36	11
5	10	12	13	20	12	37	11
6	11	13	11	31	12.5	38	10.5
7	11	14	13	32	12.5	40	11.5

Figure 11. 3D finite element mesh used to calculate the crack activity after overlay.

4.2 Estimated Crack Activity

Finite elements were also used to develop a model to estimate the crack activity after overlay. The pavement was modeled as a 4 layers pavement, based on the mesh used to model the crack activity before overlay as shown in Figure 11.

Using the 3D finite element model, the vertical crack activity after overlay was calculated to fit in a statistical model and the Equation 2 was obtained.

$$\text{Vertical activity after overlay (10}^{-6}\text{ m)} = a * [\text{Overlay thickness (m)}]^b \quad (2)$$

Where:

$$a = \prod_{i=1}^6 [a_{1i} * \ln(X_i) + a_{2i}] \quad (3)$$

$$b = \prod_{i=1}^6 [b_{1i} * \ln(X_i) + b_{2i}] \quad (4)$$

and a_{ij} and b_{ij} coefficients are given by the Table 3.

This statistical model was developed based on crack activity after overlay representing the situation of an overlaid pavement. The application of this model give the crack activity that is applied to an overlay during its life. The crack activity after overlay measured in pavement was made changing the pavement near the crack, i.e. producing a hole in the overlay layer until the existing pavement. That hole reduces the overlay stiffness near the crack and thus the crack activity after overlay will be decreased. So, the crack activity after overlay measured in pavement cannot be compared with the one predicted with finite element results, which was calculated for a pavement without that hole.

Table 3. Statistical coefficients for vertical crack activity after overlay model, $R^2 = 0.98$.

i	X_i	a_{1i}	a_{2i}	b_{1i}	b_{2i}
1	Cracked thickness (m)	$-2.487\text{E}-02$	$-3.542\text{E}-01$	$4.590\text{E}-03$	$3.790\text{E}-01$
2	Granular thickness (m)	$1.448\text{E}-02$	$-3.244\text{E}-01$	$8.765\text{E}-03$	$-1.167\text{E}+00$
3	Overlay modulus (MPa)	$3.441\text{E}-01$	$1.952\text{E}+00$	$5.794\text{E}-02$	$1.173\text{E}+00$
4	Cracked modulus (MPa)	$-2.640\text{E}-01$	$8.469\text{E}+00$	$9.997\text{E}-02$	$7.102\text{E}-01$
5	Granular modulus (MPa)	$3.025\text{E}-01$	$3.328\text{E}+00$	$-8.531\text{E}-02$	$1.287\text{E}+00$
6	Subgrade modulus (MPa)	$-2.284\text{E}-01$	$5.208\text{E}+00$	$-7.745\text{E}-03$	$8.043\text{E}-01$

The crack activity after overlay was compared with results of a finite elements model where an hole was defined to represent the situation produced for that measurements. That comparison shows that the crack activity after overlay measured in pavement can be predicted, with a sufficient accurate, by a numerical analysis.

5 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 measured using a CAM device or with two sensors of a FWD device. In this paper both devices were used.

The measurements with the FWD are very easy but only allow measuring the crack activity in one direction. In this case the vertical activity should be considered once the one that have more magnitude after overlay.

In this work, the crack activity of longitudinal and transverse cracks was measured but no expressive differences were found between these two types of cracks.

The analysis of the results of vertical and horizontal crack activity before overlay shows that some differences can be found during the winter and summer months.

The statistical models based on finite element results, both for pavement with and without overlay, follows the values measured in pavement with good accurate.

ACKNOWLEDGEMENT

The authors acknowledge and are thankful for the support provided by the National Road Administration for the facilities for crack activity measurements.

REFERENCES

- Pais, J.C. 1999. Reflective Cracking in Flexible Pavement Overlay Design (in Portuguese). Ph.D. Thesis, University of Minho, Portugal.
- Pais, Jorge C., Sousa, Jorge B., George B. Way & Stubstad, Richard N. 2000. "An Overlay Design Method for Reflective Cracking", Asphalt Rubber 2000 Conference, Vilamoura.
- Pais, Jorge C. & Pereira, Paulo A.A. 2000. "Prediction of Existing Reflective Cracking Potential of Flexible Pavements", Fourth International RILEM Conference and Exhibition on Reflective Cracking in Pavements, Ottawa.
- Rust, F.C. 1987. Load associated crack movement and aspects of the rehabilitation of reflection cracking in cemented pavements. University of Pretoria, South Africa.