Numerical method applied to the nondestructive characterization of the cracks in the roadways

A. ELBALLOUTI, S. BELATTAR, A. OBBADI. S. SAHNOUN

Laboratory of Electronics, Instrumentation and processing of the signal
Faculty of Sciences, 24000 El Jadida, Morocco
E-Mail: belattars@hotmail.com

Abstract

This article proposes numerical simulations for the thermal nondestructive characterization. It relates to the thermal nondestructive study of defects of cracks type in the roadways. The model used is a semi-rigid roadway containing cracks of various positions and sizes. The thermal behavior of the roadway, according to geometrical and thermophysical parameters of the defect, is analyzed. A constant density of heat flow is applied to the higher face of the wearing layer of the roadway, the face of lower part of the base layer being maintained at a constant temperature. The influence of the various geometrical parameters of the defect (size, thickness and position) is studied and the thermographical image of the face of entry is simulated then analyzed. The numerical method adopted for the resolution of this problem is that of the finite elements.

1. Introduction

The evaluation of the state of the roadways is an essential sector to identify the afflicted places, and for the planning and the assignment of the budgets of maintenance. The vehicular traffic worsens the cracks and propagates them towards surface, which leads to the deterioration of the external and fundamental layers [1]. For this reason, the first identification of the weak zones and cracks make it possible to departments of transport to develop remedies to attenuate the negative impacts and to lengthen the lifespan of the roadways. The ideal scenario in the evaluation of the defects is based on nondestructive approaches to prevent to obstruct the vehicular traffic. In this article, we will draw up a numerical study of the response of a semi-rigid roadway, containing defects of the cracks type, with a thermal wave and the influence of such defects on the thermographical image simulated on the road surface. Indeed, When a material is thermically requested, (e.g. reheating in a natural way by the sun), diffuse heat in material and the presence of a defect within the material (e.g. a crack) generally modify the heat flux through the structure taking into account the difference between the thermophysical parameters of material and those of the defect. It follows from there the appearance of a more or less hot zone on the surface compared to close material deprived of anomaly [2, 3]. To be able to detect the presence of an anomaly in the structure, the change which flow undergoes must be sufficient so that the contrast of temperature, between the healthy zones and the problematic ones, is significant and detectable thereafter.

2. Description of the model

We will represent the results of the non destructive testing of a structure of roadway semi-rigid (Figure1), having a length l_1=10000mm, a width l_2=4000mm and a height h=420mm. This structure (figure 2) [4] is composed of a single layer of low register treated with the hydraulic binders a height h_2=340mm, covered by a surfacing, a height h_1=80mm, (asphaltic concrete of connection and thin asphaltic concrete); the whole rests on a platform. Each time we will trace the change of temperature according to the axis A_1A_2 passing by the two points (0m, 2m, 0.42m) and (10m, 2m, 0.42m). In this structure (figure1), are inserted plane cracks which are represented in the form of layer of air of height h_f, a thickness e_f and a length l_f. On the whole, there are 5 cracks placed in an equidistant way. Their sizes and positions vary according to studied cases (Influence of the position of the cracks, the thickness or the height).

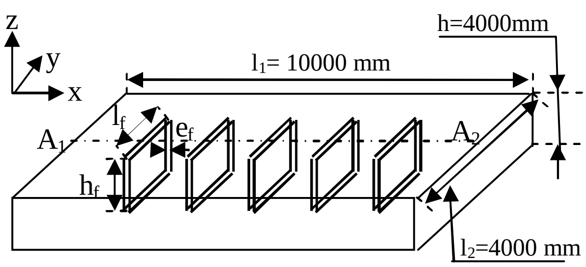


Figure1: *geometry in 3d of the studied structure*

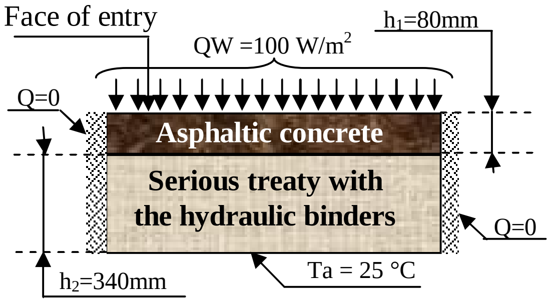


Figure 2: *Diagram of the structure used (out of cut)*

3. Mathematical model

To solve the following thermal equation:

$$a\nabla^2 T = \frac{dT}{dt} \qquad (1)$$

The report/ratio $a = \frac{l}{r\,c}$ is called thermal diffusivity. We call upon the numerical method of the finite elements [5, 6]. The analytical resolution is indeed impossible being given the geometry of the problem.

The method consists in using an approximation by finite elements of the unknown functions T to discretize the variational form of the equation (1) and to transform it into system of algebraic equations of the form:

$$[\mathrm{A}]T = F \qquad (2)$$

With :

A square matrix of dimension [N_h, N_h]

F a vector of N_h components

T the vector of the temperatures to be calculated

We start by building the variational form of the equation (1). We carry out a spacial discretization which consists in calculating the elementary integrals by using the finite element and a temporal discretization.

There are many specialized software which makes it possible to implement the method of resolution of problems by finite elements in a more or less simple and convivial way. They take care in particular of the grid of the studied object, of the automatic numbering of the elements and the nodes, of the calculation of a solution then of the chart of the results.

In this study, we used a commercial software based on the finite element method and which makes it possible to calculate the evolution of temperature at any moment and in any point of material. The material is considered isotropic.

The calculation of the thermal response is made in the case of a portion of roadway subjected to a step of flow on the surface, on the face front, continuous and extended of density Q=100 W/m^2. The back face being maintained at a constant temperature T_a = 25°C and the others faces are insulated (Q=0). It is supposed that the thermal excitation is applied in a uniform way to considered surface. The initial temperature is of T_0=25 °C.

4. Results of simulations

In order to illustrate the theoretical considerations quoted previously, we have the computation result of the thermal response in the case of a portion of roadway containing:

- Asphaltic a concrete wearing layer characterized by K = 1.5 W/m.K (thermal conductivity), ρ = 2400 Kg/m3 (density) and C = 907 J/Kg.K (specific heat).
- A base layer in treaty gravel characterized by K=0.95 W/m.K (thermal conductivity), ρ=2350 Kg/m^3 (density) and C = 886 J/Kg.K (specific heat).

Thanks to the equation of heat, knowing the thermal characteristics of the roadway, and by using a commercial numerical computation software founded on the finite element method, it is possible to determine the distribution of temperature in any point of the structure, the assumption design retained are as follows:

- The temperature in bottom of structure (base of the platform) is constant;
- There is not discontinuity between the various layers of materials;
- The defects of the crack types are represented as blades of air characterized by: K=0.0272 W/m.K (thermal conductivity), ρ=1.057 Kg/m^3 (density) and C=717.8 J/Kg.K (specific heat) [6].

The results of simulation are given thereafter in the form of thermal images representing the distribution of the apparent temperature, in degree Celsius (°C), on the upper surface of the roadway. The scale of temperature chosen to describe the variation in the temperature on the surface is a scale of color which associates the temperatures of surface highest (potentially problematic zones) the red color and the temperatures lowest (zones a priori healthy) the blue color.

4.1. Description of the grid:

We present the whole wall in order to emphasize the density of the grid around the defect (Figure 3). We chose a grid made up of triangular elements. Its density is increased when one is around the defect (Figure 3). Figure 4 shows the grid according to the (x.y) plan.

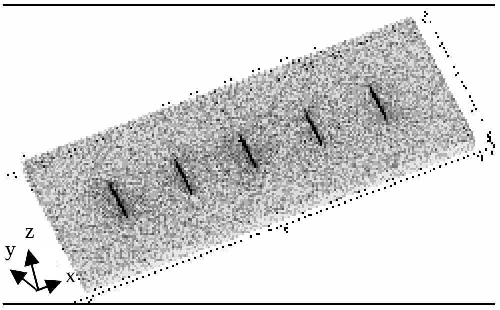


Figure 3: *Diagram of the grid according to space (x,y,z)*

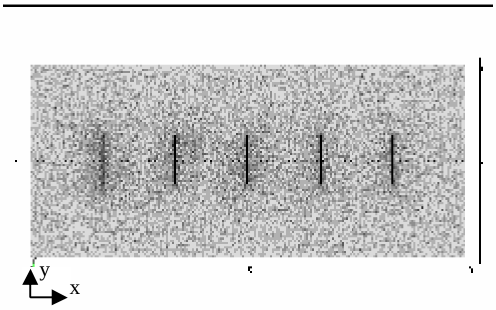


Figure 4: *Diagram of the grid according to the x.y plan*

4.2. Effect of the thickness of the defect

In this case, we introduced 5 cracks having successively thicknesses (e_f) of 4mm, 7mm, 8mm, 9mm and 10mm, with a constant position of 40mm from the face of entry, the width of each one of these cracks (l_f) is of 1000mm and the height (h_f) is of 200mm. After resolution of the problem, we represented the distribution of the temperature to the face of entry (figure 4) and the change of the temperature along axis A_1A_2 (figure 5).

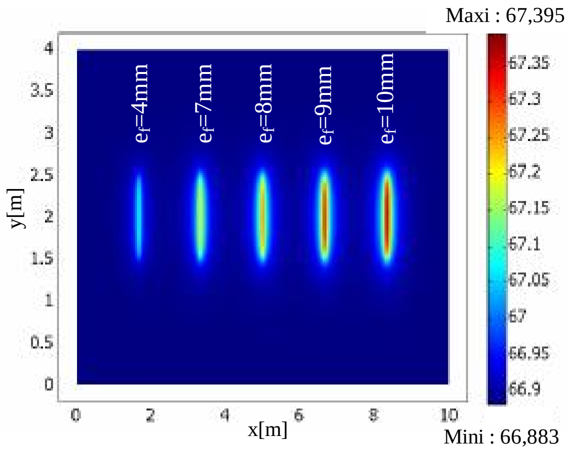


Figure 5: *Effect the thickness of the defect on the thermographical image (temperature in °C) of the face of entry*

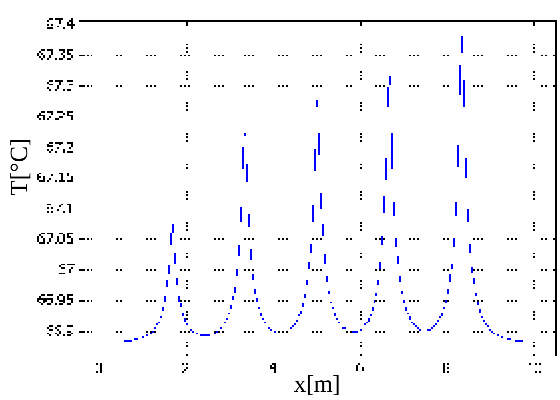
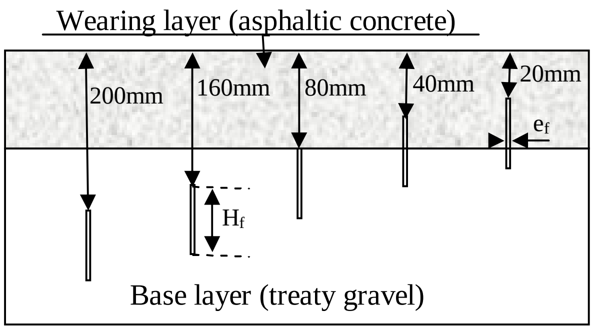


Figure 6 : *Evolution of the temperature along axis A_1A_2.*
A_1A_2 :{(0m,2m,0.42m) ; (10m,2m,0.42m)}

Figure 5 shows the distribution of the temperature on the face of entry; it is noted that the temperature passes by tops reflecting the presence of defects. According to figure 6, the lowest temperature is of 66,88°C; the tops pass respectively by 67,39°C ; 67,32°C ; 67,27°C ; 67,22°C and 67,07°C. The difference between the maximum value and the minimal value of temperature is 0.51°C. Figure 6 makes it possible to appreciate the relative importance of thickness of a defect of the type fissures compared to the neighbour defect, because more the thickness of the defect is large, more the value of the top of the associated temperature with this defect is raised and conversely.

4.3. Effect of the position of the defect

To highlight the influence of the position of the cracks by report to the face of entry, we placed in the structure 5 cracks, at thickness e_f=7mm, width l_f=1000mm, and height h_f=200mm, successively at 20mm, 40mm, 80mm, 160mm and 200mm of the surface of entry. In figure 8, the distribution of the temperature at the face of entry is represented and the evolution of the temperature along axis A_1A_2 in figure 9.



ef = 7mm ; Hf = 200mm

Figure 7: *Geometry of the structure studied (out of cut)*

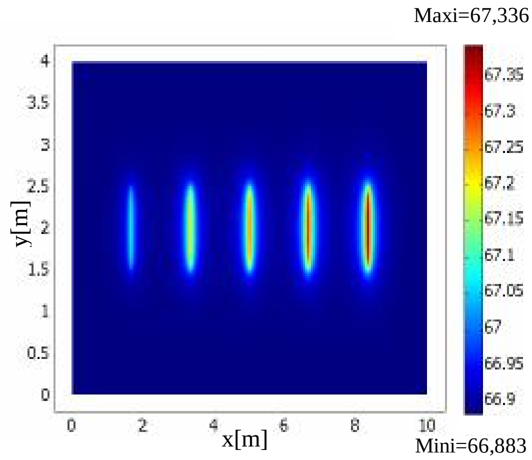


Figure 8: *Effect of the position of the defect on the distribution of the temperature (in °C) at the face of entry*

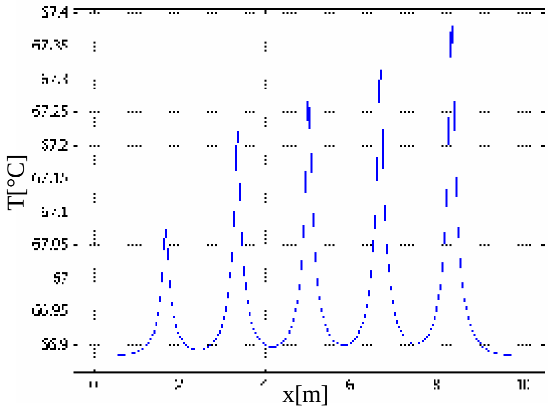


Figure 9: *Evolution of the temperature along axis A_1A_2*

Figure 8, represents the distribution of the temperature on the road surface. The effect of the position of the defects on the thermographical image simulated with the face of entry is remarkable. Indeed, more the defect is far from the face of entry, more the maximum of temperature associated to the defect becomes weak. Thus, the values of temperature to these maximum are: 67,33°C ; 67,23°C ; 67,20°C ; 67,15°C and 67,07°C. The lowest temperature on the surface being of 66,88°C. Let us consider the crack which is at 200mm from surface, the peak of temperature which represents it is of 67,07°C, the difference with the lowest temperature of surface is of 0.18°C, it is a low value which requires a more sensitive detection equipment. Such considerations must be taken into account in the choice of the material of measurement, in particular the resolution of the thermographical camera used.

4.4. Effect the height of the defect

In this last part, we studied the influence the height h_f of the defect of the cracks type on the distribution of the temperature on the road surface, indeed, we considered 5 cracks having the same width l_f=1000mm, the same thickness e_f=7mm, located at the same position by report to the surface (at 40mm from the surface); and having respective heights h_f, of 50mm, 100mm, 150mm, 200mm and 250mm. the simulated thermographical image of the face of entry is represented by figure 10 and that of the evolution of the temperature along axis A_1A_2 by figure 11.

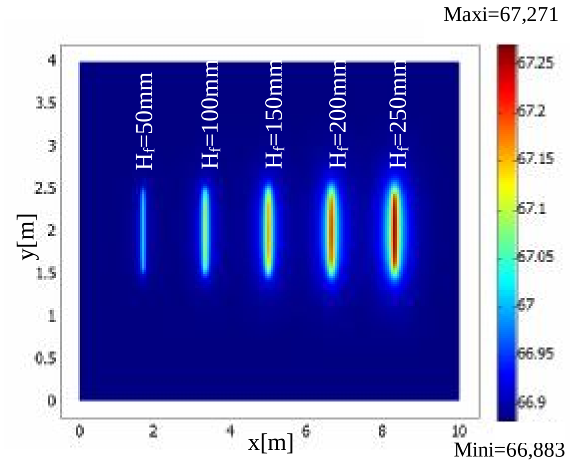


Figure 10: *Effect the height of the defect on the distribution of the temperature (in °C) to the face of entry*

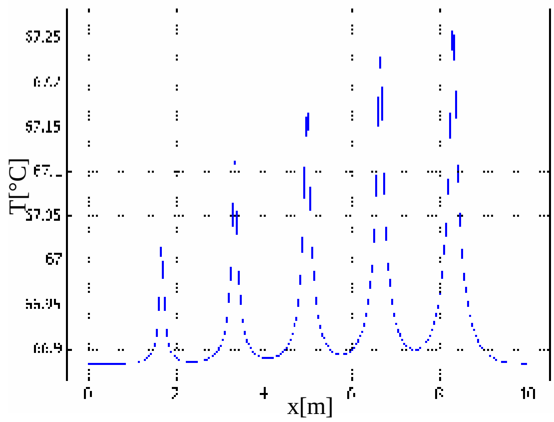


Figure 11: *Evolution of the temperature along axis A_1A_2*

Figure 11 shows the evolution of the temperature along axis A_1A_2, thus, the extremum of the temperature pass by: 67,27°C ; 67,23°C ; 67,21°C 67,16°C and 67,11°C. In the same way, the influence of height of the defects on the thermographical image of the face of entry is remarkable. The value of the tops of temperature associated to the defect becomes increasingly low if the height of the defect decreases and the variations between the temperatures, maximum and minimal, is essential in the choice of the measuring apparatus.

5. Conclusion

In this work, we studied a structure of roadway semi-rigid containing defects of plane cracks type. We analyzed the influence of various parameters of these cracks, on the temperatures of surface road, namely the thickness, the position and the height. This study enabled us to validate other work which was carried out previously [6, 7] concerning the thermal non destructive testing in concrete structures. Thus, one can confirm that in certain cases, thermography can be conclusive in the field of the detection of the defects of the cracks type in the concrete, in particular in the roadways; but if dimensions of such defects are relatively low or are very far from the face of entry, detection by thermography can be difficult to see impossible because the influence of the defect on the profile of temperature on the surface will be unimportant in this case, nevertheless, the use of the thermal methods in the non destructive testing remains of great importance owing to the fact that the measurment of the data is fast and the thermographical images can be exploited in real time.

6. References

[1] Tarek A. Monem, Amr A. O. and Maghoub, H.: "Asphalt Crack Detection Using Thermography" University of Central Florida-Center for Advanced Transportation Systems Simulation. Inframation 2005 Proceeding, ITC 108 A 2005-06-01.

[2] Rahzi, J. and Naar, S., " Aptitude de la thermographie infrarouge à détecter les fissures et les nids d'abeille dans le béton", 12ème colloque sur la progression de la recherche québécoise sur les ouvrages d'art, Québec (Canada), 13p. (10-11 mai 2005).

[3] Lesniak, J. R., Basile D. J. , and Zickel, M. J. : "Coating tolerant thermography for the detection of cracks in structures Stress" Photonic Inco. 3002 Progress Rd. Madison WI 53716, April 1997.

[4] Delphine, L.: "Modélisation de la remontée de fissure en fatigue dans les structures routières par endommagement et microfissuration" (thèse présentée pour obtenir le grade de Docteur d'Université) Université de LIMOGES, Faculté des sciences. (Soutenue le 06-03-2002).

[5] Obbadi, A. and Belattar, S. : " Méthode des éléments finis apliquée au contrôle thermique non destructif (CTND) tridimensionnel en génie civil" Revue marocaine du génie civil 1er trimestre 2004, p16-21, volume1, N°105

[6] Obbadi, A. and Belattar, S. : "Characterization of delamination by a thermal method of non destructive testing" Proc. Vth International Workshop, Advances in Signal Processing for Non Destructive Evaluation Of materials Quebec city, (Canada), 2-4 Aug 2005, X. Maldague ed., E du CAO (2006) Volume 6, ISBN 2-9809199-0-X, p 203 – 208.

[7] Obbadi, A. and Belattar, S.: "Tree dimentional non destructive thermal control of a delamination of a wall by the surface temperature analysis" 3rd WORKSHOP "NDT in PROGRESS" International Meeting of NDT Experts October 10-12, 2005 Prague, Czech Republic, p 235–245.

[8] Hu, C. W. , shin, J. K. C. , Deplak, R. and Tann D B, Detection of air blisters and crack propagation in FRP strengthened concrete elements using infrared thermography. Iframation 2002, ITC 035A, 2002-08-01