

Finite Element Method Applied To Thermal Nondestructive Characterization Of Delamination In The Dam Structure

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

Abstract

The dams advance, move back, crack and sometimes collapse under the pressure of million tons of water. In more of the water pressure, there are several phenomena being able to degrade^[1,2], even destroy dams which they are of technological origin, of natural origin, or of human origin.

At the time of a dam rupture, one observes downstream a flood catastrophic, preceded by the surge by a wave by more or less important immersion according to the type and nature by the rupture. These ruptures have a harmful, catastrophic effect for the environment. Consequently, the evaluation and the monitoring of the dams state prove very important, can avoid these catastrophes and protect, at best, the environment.

The ideal scenario of such evaluation is based on a nondestructive approach. The techniques used are varied: infra-red, ultrasounds, x-rays... These methods depend at the same time on the geometry of the structure to control, the nature of material and the necessary precision. The thermal nondestructive testing has the advantage of carrying out control without any contact with the structure to be checked and the results can be exploited immediately and without any preliminary treatment.

In this article, we will present a numerical three-dimensional response study of a dam structure, containing a delamination defects type, with a thermal excitation. In this work, we will study the influence of the thickness, the position and the orientation of the defects on the simulated thermographical image at the front face of the dam. The adopted method, in this work, is that of the finite elements.

Keywords: Finite elements, delamination, heat transfer, thermal nondestructive characterization, dam.

1. Introduction

For a few years, the roller-compacted concrete (RCC) has been used more and more for the construction of roads and dams. The low cost of this type of concrete, made of it an extremely interesting material. In spite of these advantages, research in the field of the roller-compacted concrete (RCC) is still very young and certain properties of this type of concrete, like the frost resistance and to the thaw for example, are still badly known. The presence of many vacuums of compaction pushed many users to be wondered about durability with freezing of these concretes^[2,3]. Indeed, it is possible that certain of these wrinkles of compaction are inter-connected, thus facilitating the saturation of material, and that they thus contribute to deteriorations likely to occur at the time of freezing.

This article is intended for the application of the thermal nondestructive testing method to the civil engineering works of the gravity dam type. It is a question of testing the capacities of this technique for the detection of vacuums of compaction aiming at determining the influence of various parameters such as the thickness, the position and the orientation of the

defects on the distribution of temperature which one can take on the surface. The resolution of this problem is carried out using commercial software based on the finite element method.

2. Description of the structure

In order to illustrate the use of the control method TND, we have the results of the non destructive testing of a monolith of gravity dam out of roller-compacted concrete (RCC), whose dimensions are indicated on figure 1. The defects have a parallelepipedic form a thickness e , a width d and a length l .

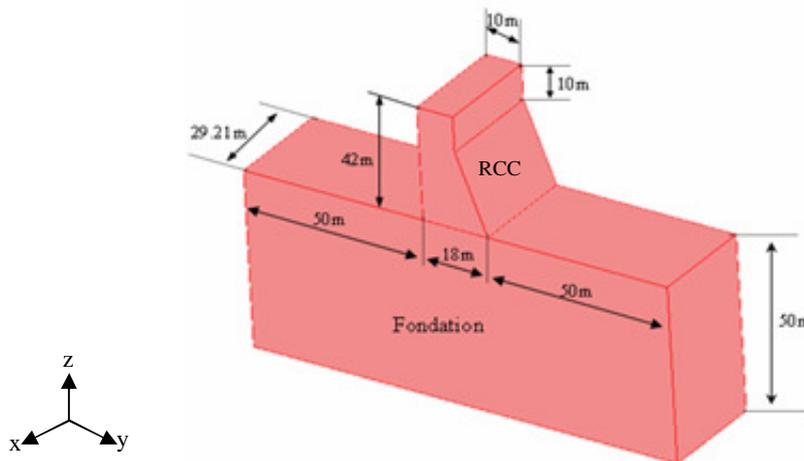


Figure 1 : Studied structure

3. Mathematical model

To solve the following thermal equation: $a\nabla^2 T = \frac{dT}{dt}$ (1), where the report $a = \frac{\lambda}{\rho c}$ is

called thermal diffusivity.

We call upon the numerical method of the finite elements^[4,5]. 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:

$$[A]T = F \quad (2)$$

With:

A square matrix of dimension $[Nh, Nh]$

F a vector of Nh components

T the vector of the temperatures to be calculated

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

There are many specialized software which make 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, the automatic numbering of the elements and the nodes, the calculation of a solution then of the chart of the results.

In this study, we used 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 calculation of the thermal answer is made in the case of a gravity dam with defect subjected to a level of flow on the surface, continuous and extended from intensity $Q=50$ W/m². The faces in contact with water are supposed to be maintained at a constant temperature $T = 25^\circ\text{C}$, the others faces are insulated ($Q=0$). It is supposed that the request is

applied in a uniform way to surfaces considered (figure 2). The initial temperature is of $T_0=25\text{ }^\circ\text{C}$, near to the ambient temperature.

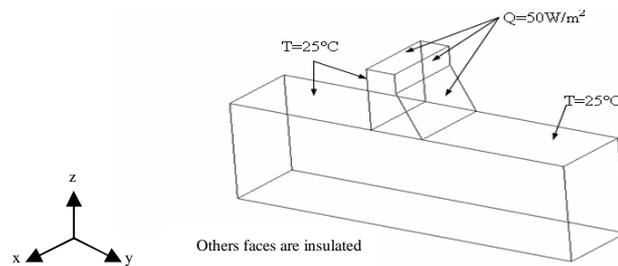


Figure 2 : Boundary conditions

4. Results of simulations

In order to illustrate the above mentioned theoretical considerations, we have the computation results of the thermal response in the case of an isotropic roller-compacted concrete (RCC).

In this study RCC concrete is characterized by $K_d = 9,27\text{W/m.k}$ (thermal conductivity), $\rho_d = 2400\text{kg/m}^3$ (density) and $C_d = 0,9673\text{J/kg.k}$ (specific heat)^[1]. The foundation is characterized by $K_f = 8,374\text{W/m.k}$ (thermal conductivity), $\rho_f = 2400\text{kg/m}^3$ (density) and $C_f = 0,9672\text{J/kg.k}$ (specific heat)^[1]. After resolution of the posed problem, it is possible to trace the distribution in temperature on the totality or a part of the structure, as well as the temporal evolution of the temperature in a given point. Defects are considered of delamination type, characterized by $K = 0.0272\text{ W/m.K}$ (thermal conductivity), $\rho = 1,057\text{kg/m}^3$ (density) and $C = 717,8\text{J/kg.K}$ (specific heat).

4.1. Influence of the defect position

In this part, we inserted a defect of a parallelepipedic form (Figures 3 and 4), a length $l = 6\text{m}$, a width $d = 6\text{m}$ and a thickness $e = 0.2\text{m}$ at a distance h respectively of 0.5m, 1.5m, 2.5m, 3m and 3.75m compared to the front face.

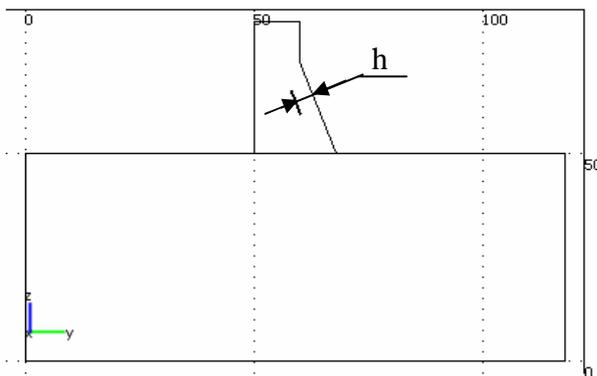


Figure 3 : Defect position

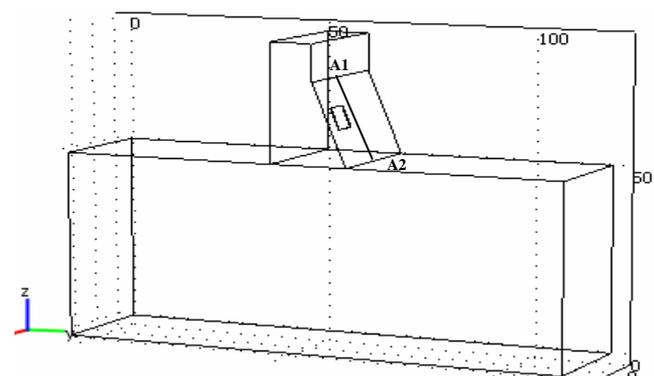


Figure 4: Presentation of the line A_1A_2 position

Figures 5, 6, 7, 8 and 9 represent the simulated thermographical images on the surface for the various considered positions and figure 10 represent evolution of the temperature according to line A_1A_2 passing by the points $A_1(14.6, 0, 82)$ and $A_2(14.6, 68, 50)$ (Figure 4). The effect of the defect position on the temperature distribution at the surface is remarkable; indeed, for defects of the same dimensions, more one moves away from surface, more the tasks of the temperature associated to the defect becomes weak and the limit of detectability of such defects will depend on the resolution of the equipment used in control.

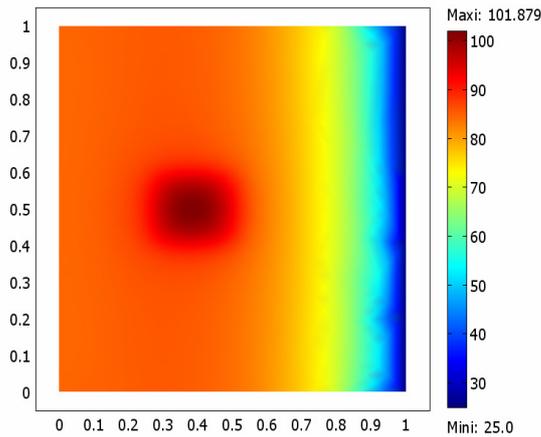


Figure 5 : thermographical image at the face
(h = 0,5m)

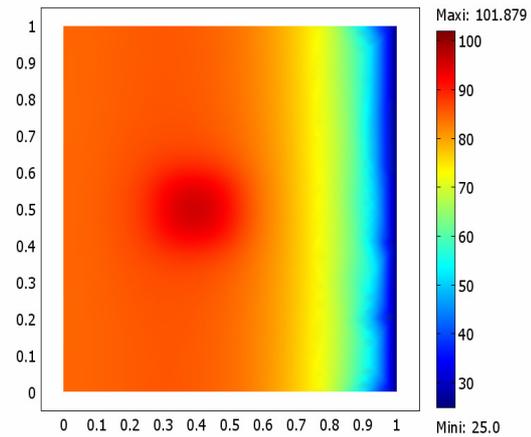


Figure 6 : thermographical image at the face
(h = 1,5m)

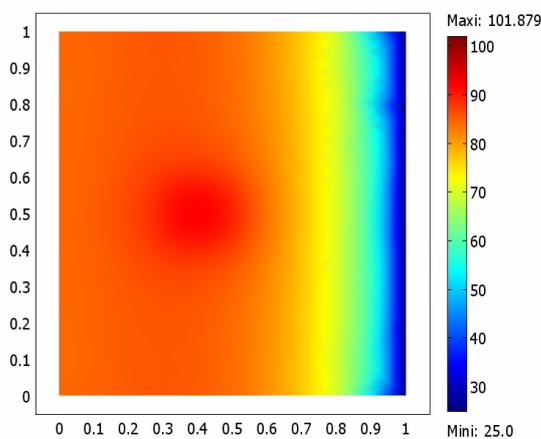


Figure 7 : thermographical image at the face
(h = 2,5m)

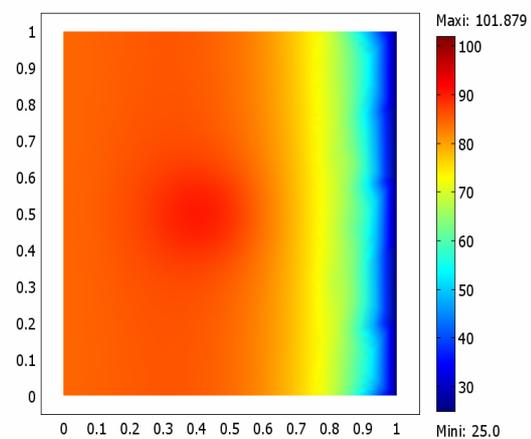


Figure 8 : thermographical image at the face
(h = 3,5m)

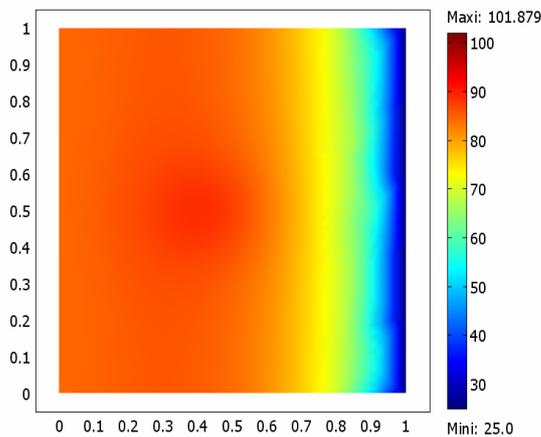


Figure 9 : thermographical image at the face
(h = 3,5m)

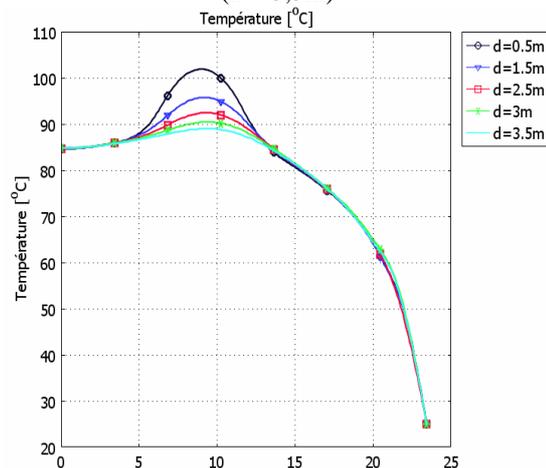


Figure 10 : distribution of the temperature along
axis A1A2.

4.2. Influence of the defect thickness

To illustrate the influence defect thickness, we inserted in the structure defects parallel with the front face of the dam and having respectively like thickness e : 5cm, 30cm, and 50cm. The distance between the defect and such a face is $h = 1$ m.

Figures 11, 12 and 13 represent distribution profile of the temperature on the dam surface in question, they show hotter thermal tasks on the level of the problematic region. The intensity of these tasks decreases with the thickness.

Figure 14 represents the evolution of the temperature according to the A_1A_2 axis. It highlights the thickness influence of the defect on the temperature distribution at surface, thus, the smaller the thickness is, the more the intensity of the temperature peak reflecting the defect is low.

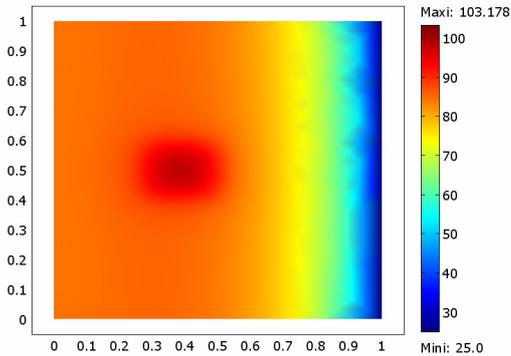


Figure 11: thermographical image at the face (e = 5cm)

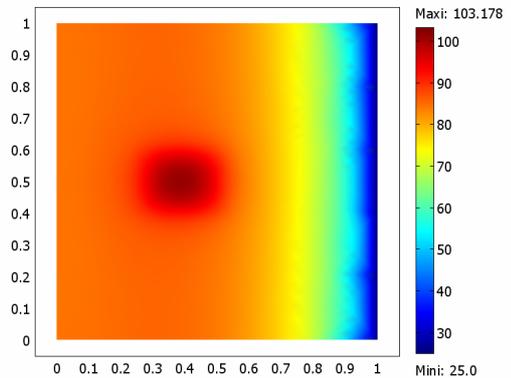


Figure 12: thermographical image at the face (e = 30cm)

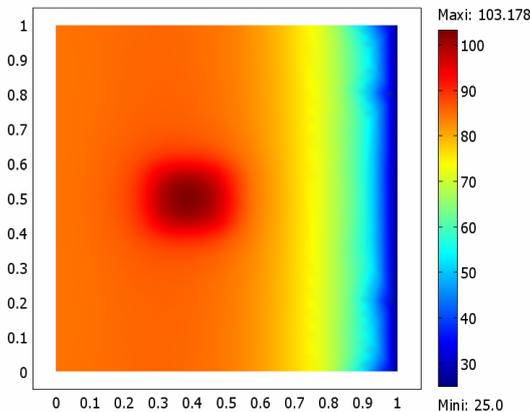


Figure 13: thermographical image at the face (h = 50cm)

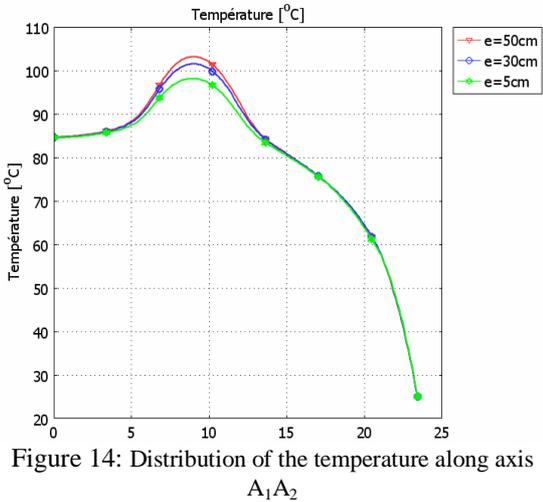


Figure 14: Distribution of the temperature along axis A_1A_2

4.3. Influence of the defect direction

To highlight the influence of the defect direction by report to the front face, we placed the defect in parallel, with 45° and finally perpendicularly with the front face as showed in figure 15.

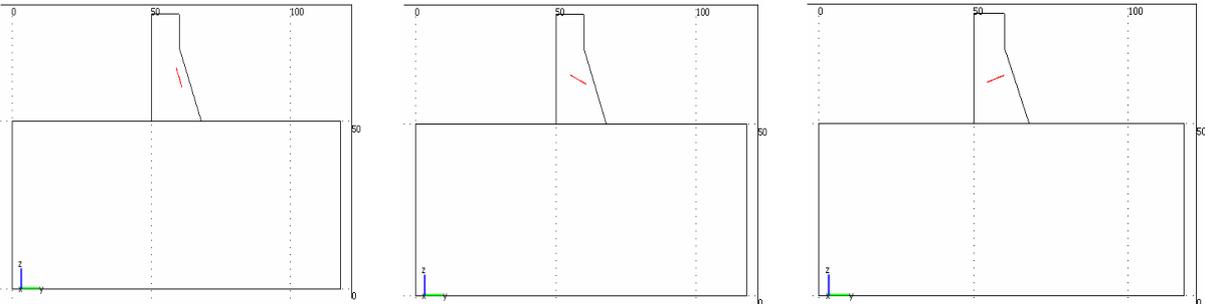


Figure 15 : Presentation of the defect directions

Figures 16, 17 and 18 represent the simulated thermographical images of the face in question for the three directions adopted of the defect. Figure 19 illustrates the evolution of the temperature according to line A_1A_2 . One can note that contrast representing the defect is

higher when the defect is in a parallel position with the face, however, when the defect in the structure is perpendicular; its detection proves to be very difficult. Indeed, when surface is excited by a heat flow, the presence of a defect having a low thermal conductivity deviates the heat flow. In our case, when the defect is parallel to surface, such a deviation is considerable, which generates a hotter thermal task on the surface. However, when the defect is perpendicular to surface, this deviation is weak; in this case, the defect does not have an important effect on the thermographical image simulated on the surface.

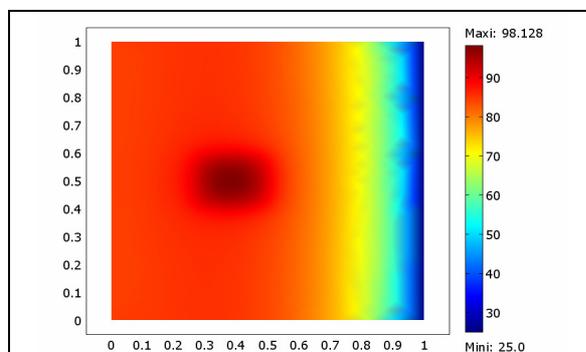


Figure 16 : thermographical image at the face (0°)

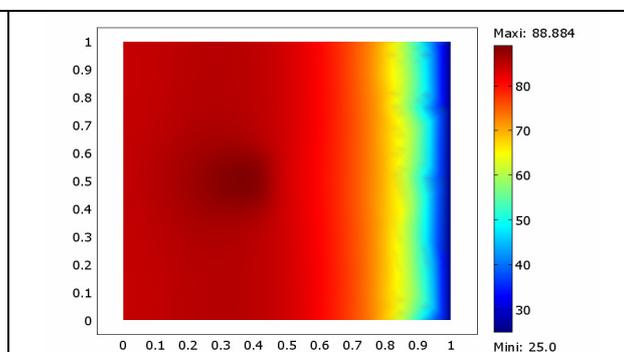


Figure 17: thermographical image at the face (45°)

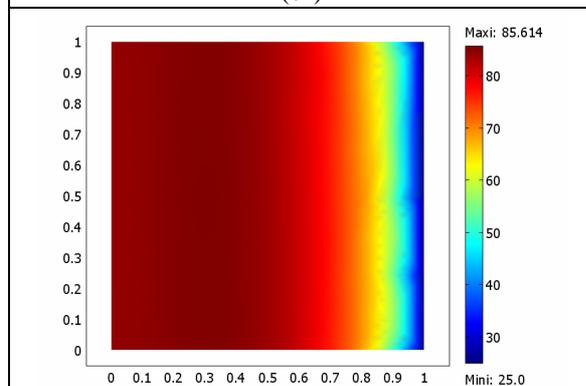


Figure 18 : thermographical image at the face (90°)

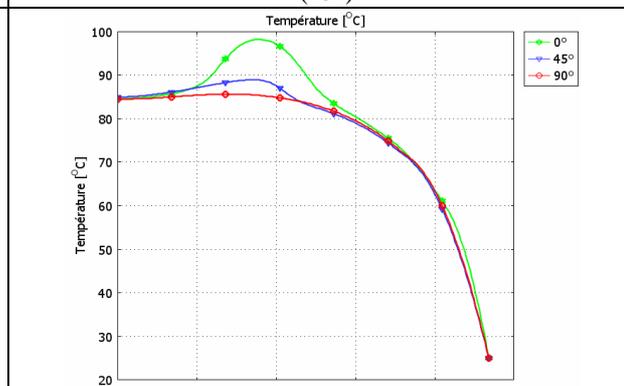


Figure 19 : Distribution of the temperature along axis A_1A_2

5. Conclusion

In this work, we studied the influence of the geometrical parameters of a defect contained in a structure of gravity dam on the temperature distribution at the surface. We can note that the difference in temperature between the healthy and that problematic region is strongly related to the position, the thickness and the direction of the defect. Indeed, this difference in temperature proves to be important if defect is close to surface, if it has a great thickness or if it is parallel with the face. We can also notice the difficulty even impossibility of detecting defects whose direction is perpendicular to the face. This study can be used like a tool of assistance for the thermal nondestructive testing of the gravity dam structure in RCC, this control which can be very useful in the prevention against the risk of damage RCC concretes.

Reference

- [1] HongWei Xie, YaoLong Chen "Determination of the type and thickness for impervious layer in RCC dam" *Advances in Engineering Software* 36, p.561–566, 2005. <http://www.elsevier.com/locate/advensoft>
- [2] J. P. BOURNAZEL "Comportement thermomécanique des bétons compacts au rouleau sous l'effet d'automaturation: approche thermodynamique" *Materials and Structures*, 28, 318-323, 1995.

- [3] A. ELAGRAVE, J. MARCHAND, M. PIGEON “Résistance au gel-dégel du béton compacté au rouleau pour les barrages a base de liant Rolac” *Materials and Structures*, 27, p.26-32, 1994.
- [4] A; Elballouti, S. Belattar : “Numerical method applied to the non-destructive characterization of the cracks in the roadways” *Physical & Chemical News* 35 (May 2007) 43-47
- [5] Obbadi, A. and Belattar, S. : Vth International Workshop, *Advances in Signal Processing for Non Destructive Evaluation Of materials*, 6 (2006) 203 – 208 (Canada, Quebec).