4th Middle East NDT Conference and Exhibition, Kingdom of Bahrain, Dec 2007
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THREE-DIMENSIONAL THERMAL NONDESTRUCTIVE CARACTERISATION OF DEFECTS OF PIPE TYPE IN THE ROADWAY

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Abstract

The nondestructive testing of the roadways state is of paramount importance since it allows the detection of the anomaly within the roadway without disruption of circulation.
The present paper deals with the thermal nondestructive characterization of defect in the roadway. We expose a three-dimensional numerical study, presenting the response of a semi-rigid roadway structure, containing cylindrical defects of pipe type, using a thermal excitation. In this work, the influence of the size, the position and the thermophysical parameter of this type of defects on the temperature distribution to the entry face of a parallelepipedical roadway structure are studied. At the road surface a constant density flux is applied, the opposite face being supposed maintained at constant temperature and other surfaces are thermically isolated. The resolution of the problem is carried out by using numerical computation software based on the finite element method.

1. Introduction

The civil inspection of the engineering works is a necessary operation to maintain the level of the work service and to guarantee the safety of the users. It is an operation which must be periodically carried out in order to raise and analyze the totality of the defects in the whole of the work [1]. For that, the methods of non destructive testing are proving to be of a great utility since they allow the inspection without destruction of the structure nor deterioration of its uniform. The techniques of non destructive testing are varied: ultrasounds, thermography, x-rays, radiography... they depend at the same time on the nature of material, the necessary precision and the geometry to be controlled. In this work, we adopted a numerical method, based on thermal nondestructive control, to study the response, to a thermal excitation, of a portion of semi rigid roadway, containing cylindrical defects of pipe type. Indeed, when a material is thermically requested (heating in a natural way by the sun, for example), diffuse heat in material. The presence of defect modifies the heat diffusion process in the structure. It follows from there the appearance of regions of different temperature on the surface compared to close region deprived of anomaly. The simulated thermographical images make it possible to highlight variations in the temperature of the road surface. These variations characterize the presence of a defect in the structure.

2. Description of the model

The model used is a semi-rigid roadway (fig.1) having a length L=10000 mm, a width l=4000 mm and a thickness e=420mm. This structure is composed of a single layer of gravel, treated with the hydraulic binders, of height h_2=340 mm, covered by a layer of surface having a height h_1=80mm (asphaltic concrete); the whole rests on a platform. The structure contains cylindrical pipe (fig. 2 and 3) which can convey water or gas.

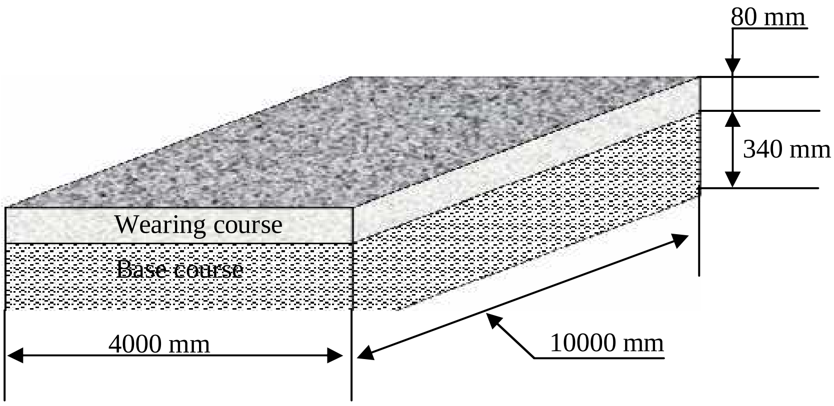

Figure 1 : roadway structure

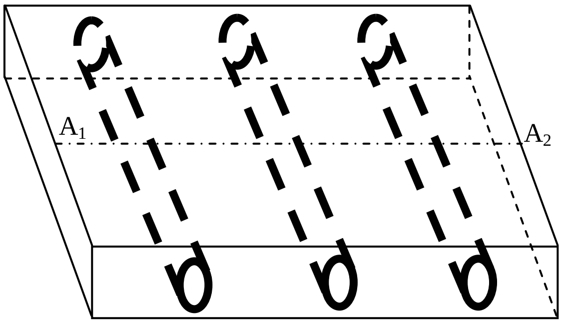

Figure 2: structure of the defects in the roadway

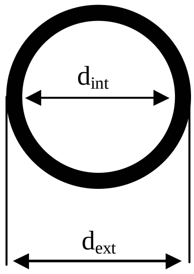

Figure 3: cross section of pipe

3. Mathematical model

To solve the following thermal equation:

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

the report $a = \frac{\lambda}{\rho c}$ is called thermal diffusivity.

We call upon the numerical method of finite elements [2, 3]. 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 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, 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 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 front face, continuous and extended of density Q=100 W/m2. 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 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 [4] containing:

- asphaltic concrete wearing layer characterized by K = 1.5 W/m.K (thermal conductivity), ρ = 2400 Kg/m^3 (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 at 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;
- to highlight the influence of the geometrical parameters of defects (size and position), we chose cylindrical PVC pipes characterized by λ = 0.18 W/m.K (thermal conductivity) ρ = 1380 kg/m^3 (density) and C = 1000 J/kg.K (specific heat).
- to illustrate the influence of the thermophysical defects factor, we considered a cast iron pipe characterized by λ = 56 W/m.K (thermal conductivity) ρ = 6800 kg/m^3 (density) and C = 450 J/kg.K (specific heat) and another out of PVC.
- the pipes supposed to be traversed by water characterized by λ = 0.589 W/m.K (thermal conductivity) ρ = 999.054 kg/m^3 (density) and C = 4180 J/kg.K (specific heat).

The results of simulation are given thereafter in the form of thermal images representing the distribution of the apparent surface 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 one.

4.1. Influence position of the defects

In this part, we considered a portion of roadway containing 3 pipes (fig. 4), out of PVC, of internal diameter d_{int} = 200 mm and of external diameter d_{ext} = 220 mm, located at 190mm, 140mm and 80mm of the road surface.

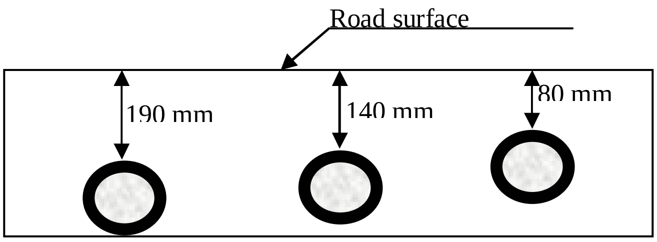

Figure 4 : defects position

The results of simulations are given on figure 5 and 6 below. Figure 5 represents the thermographical image simulated on the road surface. The hot tasks reflect the presence of the defects of the pipe type contained in the roadway, one can notice that to the closer defect to the surface, corresponds a great intensity of the thermal task and its detection is easy. Figure 6 represents the change of the temperature according to the line A_1A_2 which passes by the points: {0,2,0.42} and {10,2,0.42}. This figure can be exploited in order to define the required resolution of nondestructive testing equipment to use.

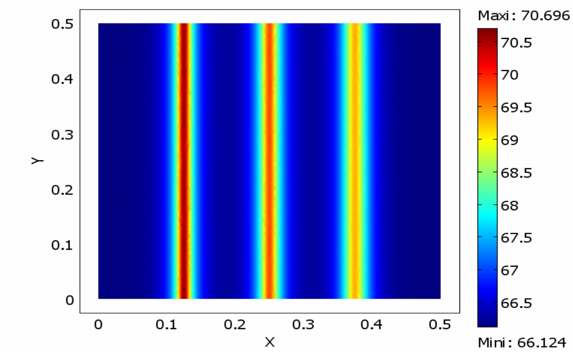

Figure 5: Effect of the position on the thermographical image of surface

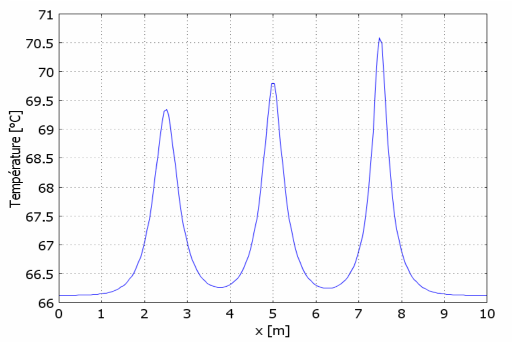

Figure 6: Distribution of the temperature along line A_1A_2

4.2. Influence of defect diameter

In this part, we considered the same structure of roadway, containing 3 pipes, located at 90mm of surface, and having respectively as external diameter d_{ext} = 240mm, 280mm and 320mm and like internal diameter d_{int} = 220mm, 260mm and 300mm. Figure 8 represents the thermographical image simulated on the road surface, and figure 9 represents the change of the temperature according to line A_1A_2.

Figure 7 represents the remarkable effect of the pipe diameter on the thermographical image simulated on the road surface. In the presence of the defects (pipe), the heat flow is propagated mainly beside the obstacle, from where the rise in the temperature at the location of defect, this rise is increasingly important when the diameter is larger. Figure 8 confirms what one deduced according to figure 7.

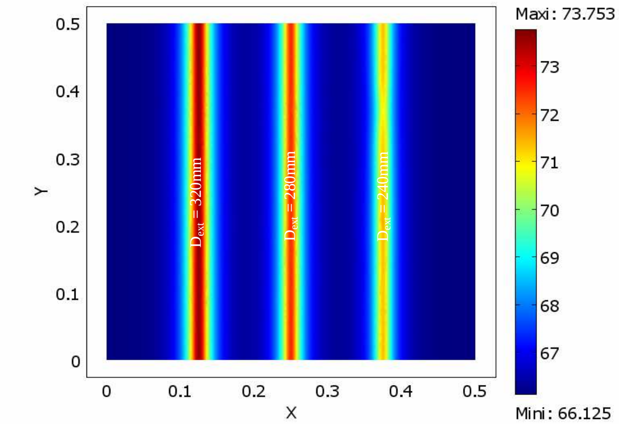

Figure 7: Effect of the diameter of the defect on the thermographical image of surface

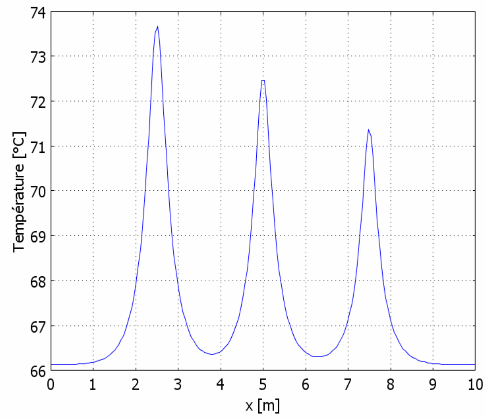

Figure 8 : Distribution of the temperature along line A_1A_2

4.3. Influence thermophysical parameter of the pipe

The underground pipes can be built starting from several materials: PVC, Lead, Cast iron... To highlight the influence of the thermophysical properties of materials constituting these pipes, on the thermographical image on the road surface, we considered the same portion of roadway, but this time, with two pipes of the same internal diameter d_{int} = 220mm, even external diameter d_{ext} = 240mm and at 110mm of the road surface. One of these pipes is out of cast iron and the other out of PVC. The results of simulations are represented on figure 9 and 10 below:

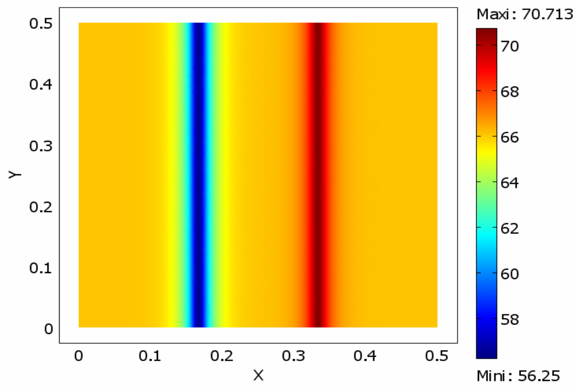

Figure 9: Effect of the thermophysical parameters on the thermographical image of surface

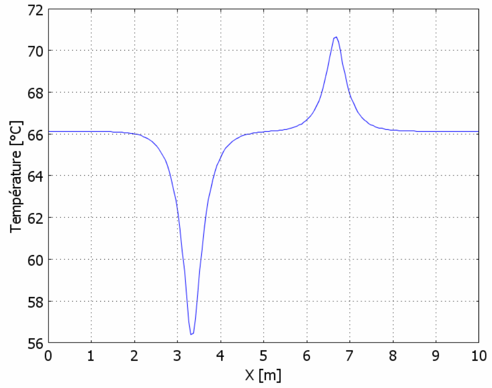

Figure 10: Distribution of the temperature along line A_1A_2

Figure 9 shows the pipes nature influence on the thermographical image, indeed, when the material constituting pipes is a thermal conductor (case of the cast iron), the heat flow is propagated while converging towards the defect from where a reduction in the temperature of surface at the location of pipes. When the defect material is heat insulator, the heat flow is propagated by avoiding the defect, from where a rise in the temperature of surface at the location pipes.

5. Conclusion

The numerical analysis brings important information in connection with thermal nondestructive testing. The results presented in this article show the possibility of checking underground pipes by interpreting the distribution of the temperature on the road surface, in condition to have the adequate material of non destructive testing. Such defects can be easily detected and analyzed whenever they are close of the entry face, when they have relatively large diameters or when the difference between their thermophysical properties and those of the healthy structure is important. This method can be also exploited to check the state of the pipes inside the roadway.

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