Active Infrared Thermography applied to detection and characterization of non emergent defects on asphalt pavement

J. Dumoulin, L. Ibos, M. Marchetti, S. Ludwig, A. Mazioud

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Outline

UNIVERSITÉ PARIS XII VAL de MARNE

Centre d'Etudes et de Recherche en Thermique Energétique et Systèmes CERTES

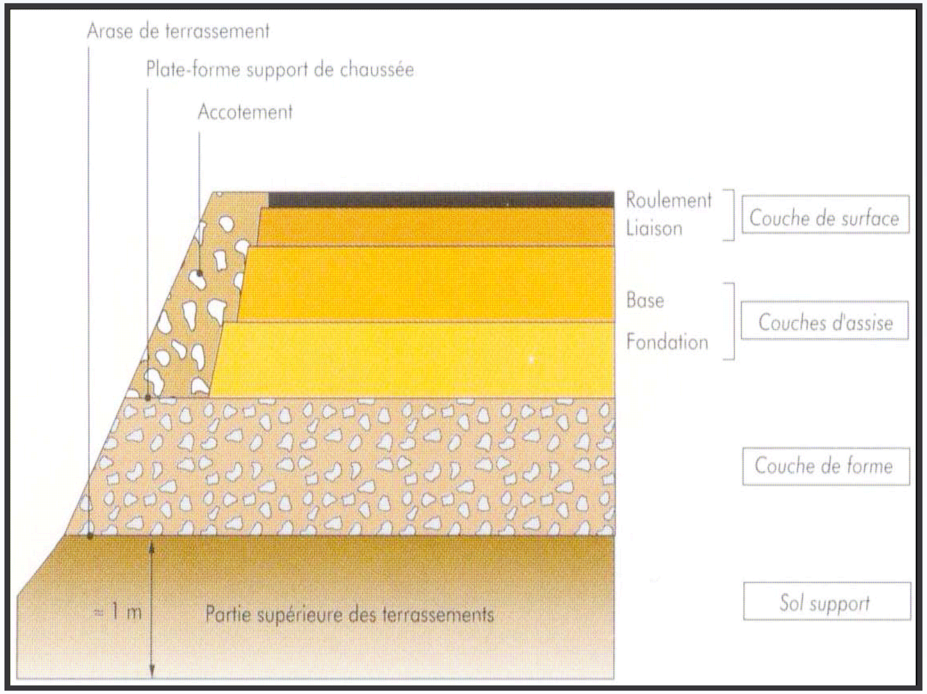
- Context – Problem position
- Experiments and numerical simulations
  - Pavement samples
  - Experimental set-up
  - Numerical simulations
- Thermal model used for defect depth characterization
- Results
- Conclusion and perspectives

Context – Problem position

Pavement carrots with sticking defect between layers

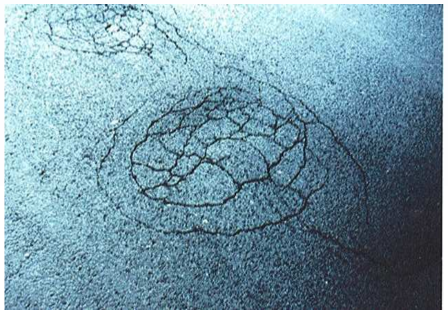
Mixed Structure

Thick asphaltic Structure



Schematic view of a pavement structure

(Extract from Technical guide SETRA-LCPC on pavement structure design)



Local pavement surface emergent cracking probably due to sticking defect

(extract from *Méthode d'essai LPC N°52 : French Catalogue for pavement surface distresses)*

Context – Problem position

The objective of this study was to

Main characteristics of pavement materials versus their thermal properties :

- Heterogeneous material
- High emissivity materials (ε => 0.96) in infrared spectral bandwidth 3 to 5 µm and 7.5 to 13 µm
- The mix of aggregate and bitumen binder drives to thermal diffusivity ranging between 10^{-6} to 10^{-7} $m^2.s^{-1}$

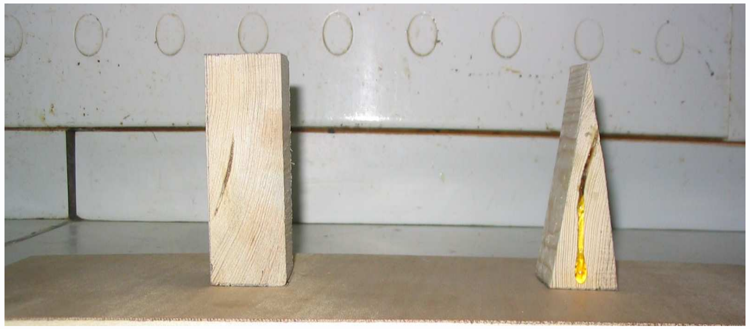
Main objectives of this study :

- Evaluating active infrared thermography using un-cooled camera on asphaltic pavement material
- Evaluate semi-infinite thermal heat transfer model applied to such pavement material for defect depth retrieval
- Addressing wearing course layer in order to complete step frequency radar performances for the first few centimeters (0 to 2 cm up to 4 cm)
- Evaluate to which extent the technique of Active infrared thermography could be applied to road pavements

Road pavement sample with defects

Pavement sample rear side

Front side observed under thermal solicitation



Two defects in pine wood

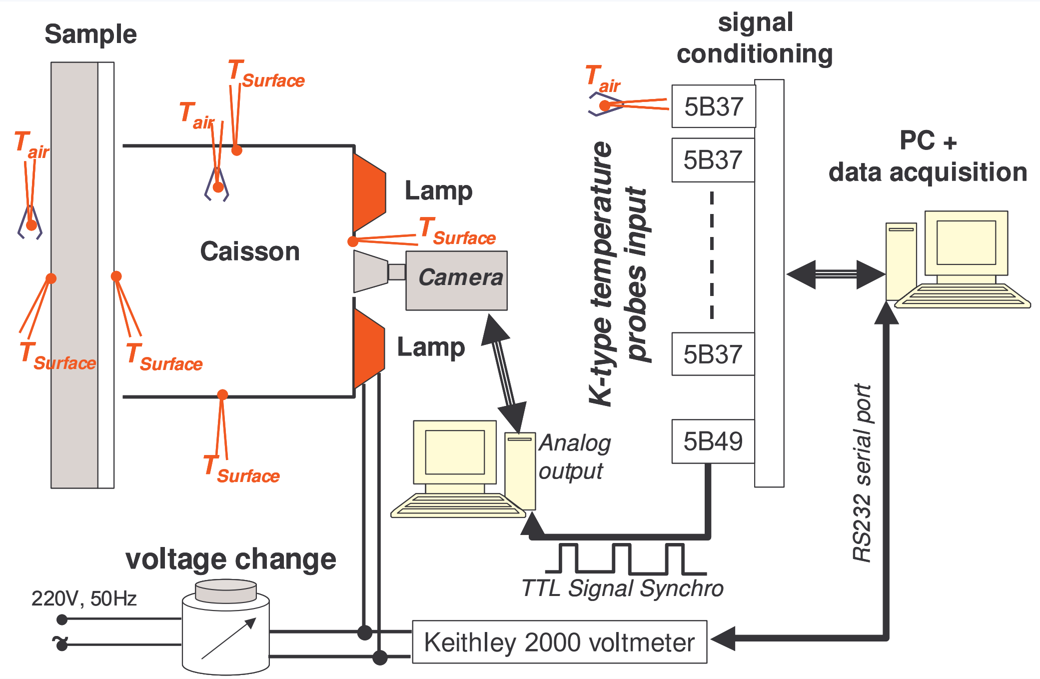
Defects characteristics

- •Depth from front surface : round -1.3 cm
- •Parallelepiped : square base 4 cm x 4 cm
- •Pyramid (wedge form): square base 4 cm x 4 cm
- •Pine wood or air

Sample characteristics :

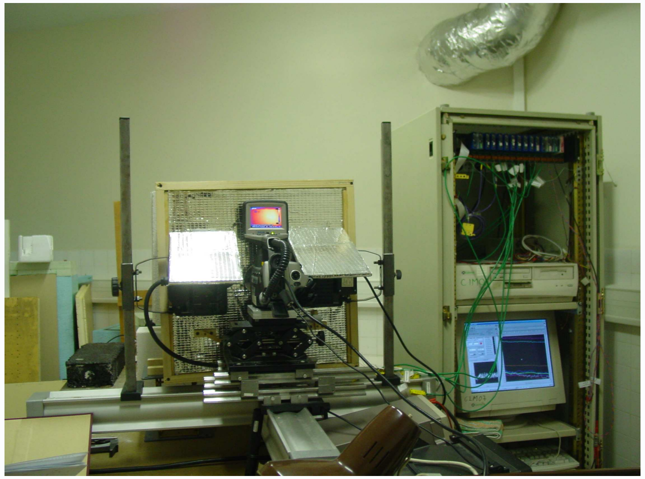
- • parallelepiped of 10 cm x 18 cm x 50 cm
- •Semi-granular bitumen concrete (BBSG)

Experimental test bench



schematic description of laboratory test bench

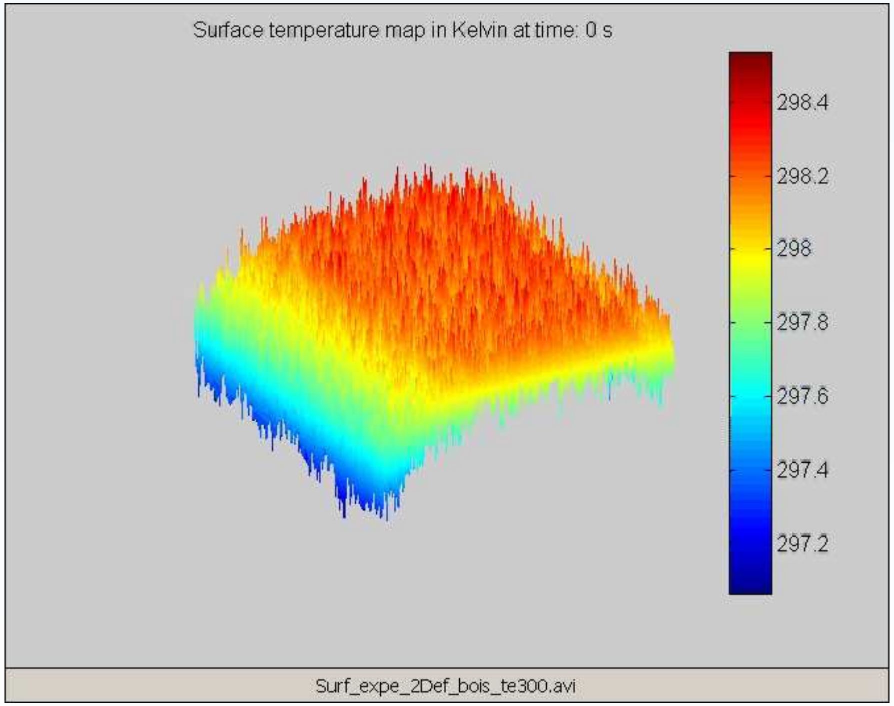
View of experimental test bench



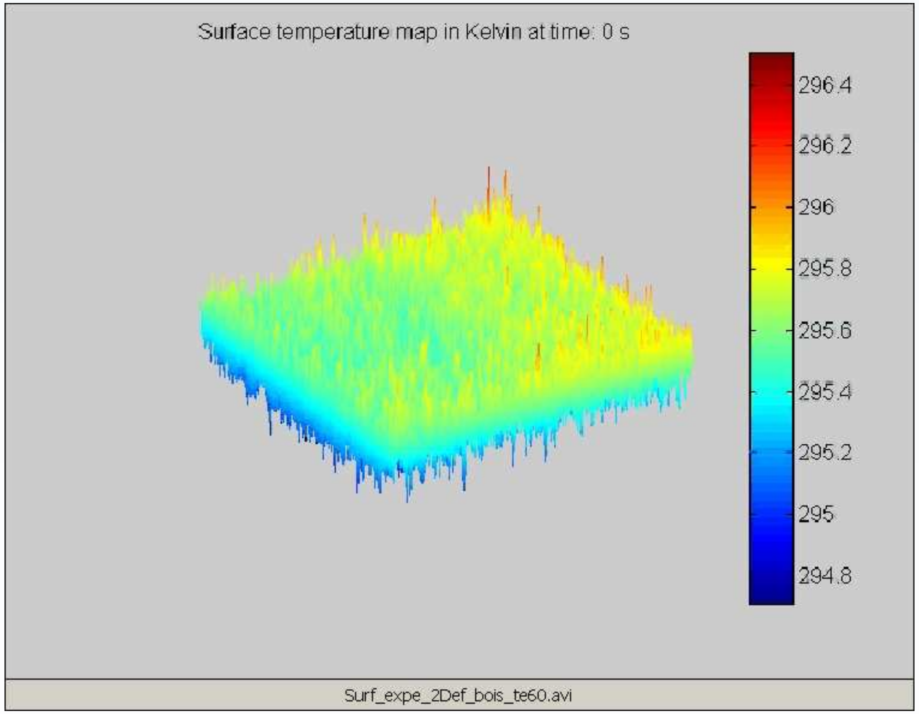
FLIR® S65 (LWIR)
un-cooled Infrared camera

Experimental surface temperature maps

Pine wood defects - Heat flux density round 3000 $W.m^{-2}$



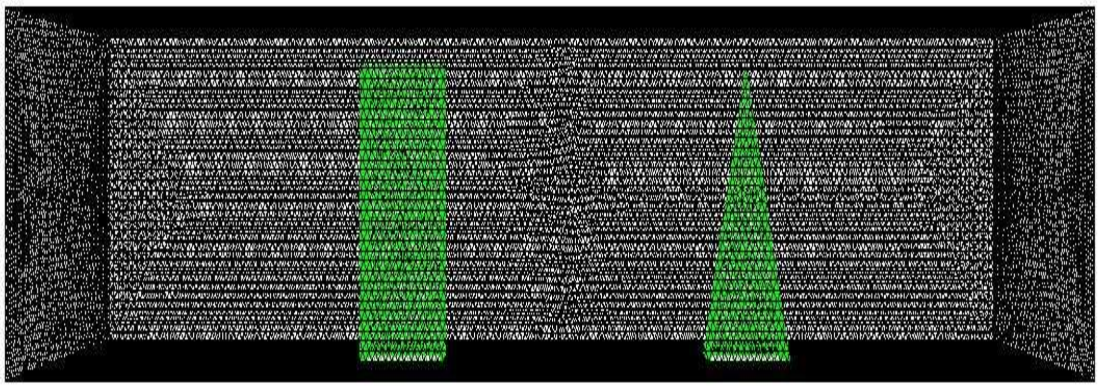
Square pulse duration τ = 300 s



Square pulse duration τ = 60 s

Numerical simulations

- Finite volume method for heat transfer were carried out using FLUENT™
- Geometry considered for simulation match the experimental sample containing two defects.
- Three-dimensional non-structured meshing based on tetrahedral cells was realized under GAMBIT™.
- Number of cells is 1892429



View of the mesh realized

Boundary condition and thermal properties considered

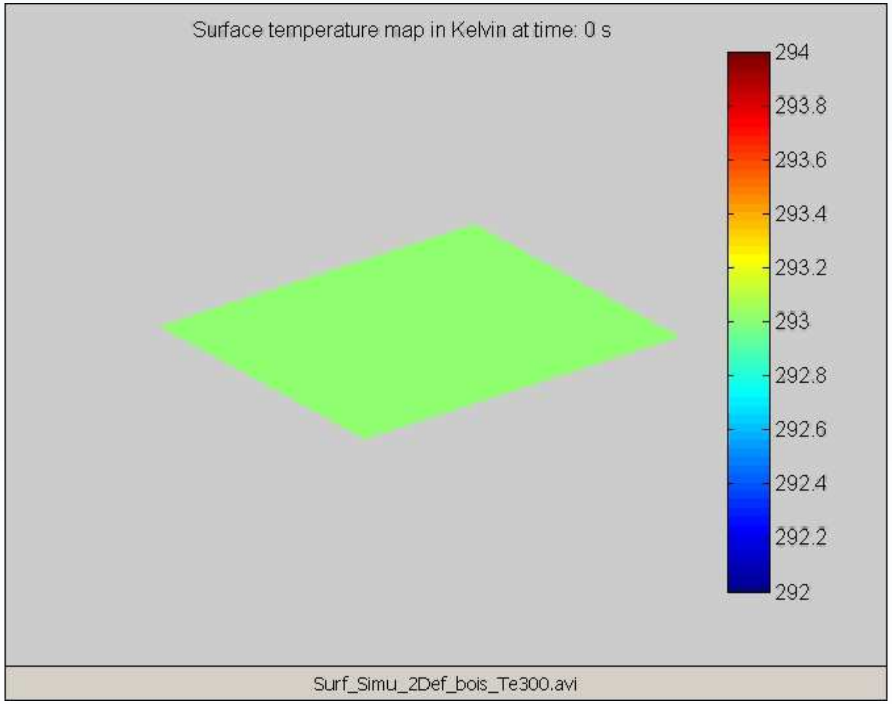
- Constant heat flux density of 2620 W.m-2 for square pulse of 30 s, 60 s, 120s, 300 s and 480 s were applied to the front face of the sample
- Ambient temperature was considered constant and equal to 293 K and to be the initial temperature of sample
- Sample was supposed homogeneous and insulated on its lateral faces
- Global heat exchange coefficient ***h*** of 10 $W.m^{-2}.K^{-1}$ was considered for the front and rear faces
- Temperature field inside sample was computed and surface temperature (equivalent to the viewed side) were extracted for each time step

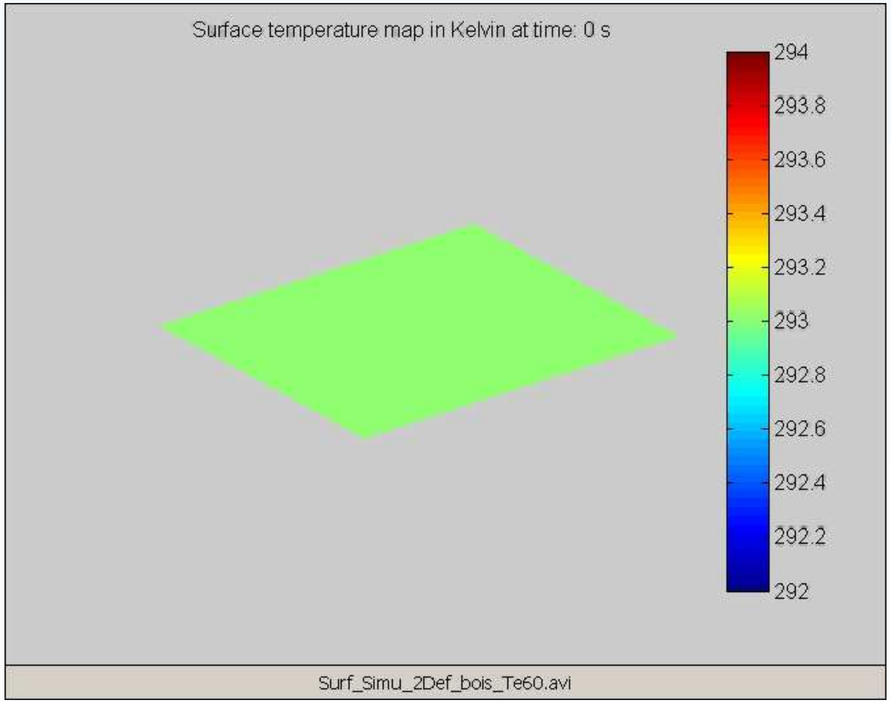
Thermophysical properties of materials used for numerical simulations

Material	λ ($W.m^{-1}.K^{-1}$)	ρ ($kg.m^{-3}$)	C_p ($J.kg^{-1}.K^{-1}$)
Bitumen concrete	1.41	2262	1255
Pine wood	0.15	600	1900
Air	0.0242	1.225	1006.43
Water	0.6	998.2	4182

Numerical Simulation Results

Heat flux density 2620 $W.m^{-2}$





Square pulse duration $\tau = 300$ s

Square pulse duration $\tau = 60$ s

Heat transfer model used with active infrared approach

Hypothesis :

- One dimensional heat transfer
- Semi-infinite body
- Neglecting natural convection

Heat transfer system

$$\begin{cases} \dfrac{\partial^2 \theta}{\partial z^2} = \dfrac{1}{a}\dfrac{\partial \theta}{\partial t} \; with \; \theta = T(x,t) - T_0 \\ Boundary \;\; condition: \; t \le 0 : \theta(z,t) = 0, \; t > 0 \; and \;\; z = 0 : -\lambda \dfrac{\partial \theta}{\partial z} = \varphi_0(t) \end{cases}$$

Square heat flux density pulse $\quad \varphi_0(t) = q_0 \; if \; t \le \tau \; and \; \varphi_0(t) = 0 \;\; if \; t > \tau$

Surface Temperature evolution

$$\begin{cases} if \;\; t < \tau : \theta(0,t) = \dfrac{2q_0\sqrt{t}}{b\sqrt{\pi}} \\ \text{if } t \ge \tau : \theta(0,t) = \dfrac{2q_0}{b\sqrt{\pi}}\left(\sqrt{t} - \sqrt{t-\tau}\right) \end{cases}$$

Characterization of defects : Depth retrieval

Based on effusivity approach proposed by Balageas using solution for square pulse . Depth of the defect can be determined using the relation :

$$z_{def} = \sqrt{a}\sqrt{t_{min}}\left(b_{n,min}\right)^{0.95}$$

Where :

a is the thermal diffusivity, b the thermal effusivity, t_{min} the time when the effusivity curve is minimum, z_{def} the depth of the defect in material and $b_{n,min}$ the normalized minimum effusivity

Thermal effusivity relation for a Square heat flux density pulse

$$\begin{cases} if\ t < \tau \ \ \mathrm{b}(t) = \dfrac{2q_0\sqrt{t}}{\Delta T(t)\sqrt{\pi}} \\ \text{if } t \geq \tau \ \mathrm{b}(t) = \dfrac{2q_0}{\Delta T(t)\sqrt{\pi}}\left(\sqrt{t}-\sqrt{t-\tau}\right) \end{cases}$$

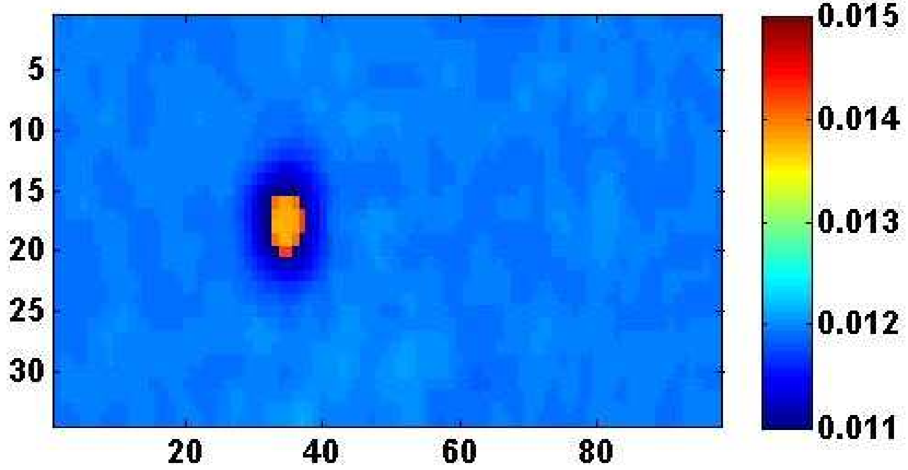
Normalized thermal effusivity expression

$$b_n = \frac{b}{b_{BBSG}}$$

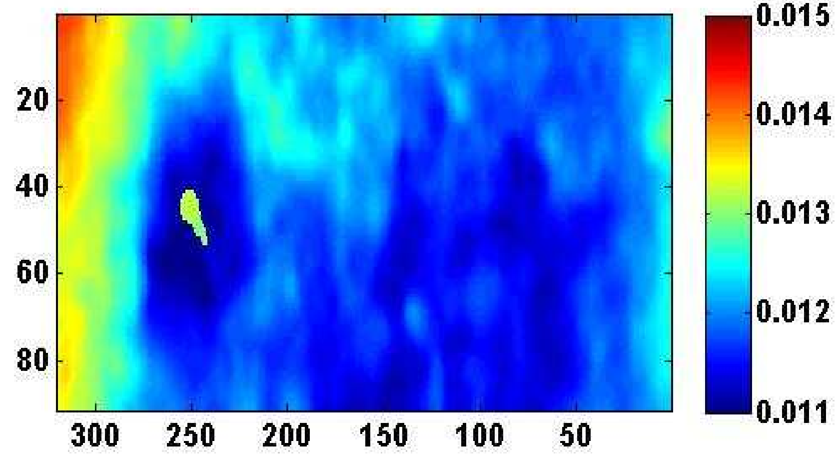
$$with\ b_{BBSG} = \sqrt{\lambda\rho C}$$

Results :
Defect depth map (pine wood)

Using numerical simulation



Using Experimental data

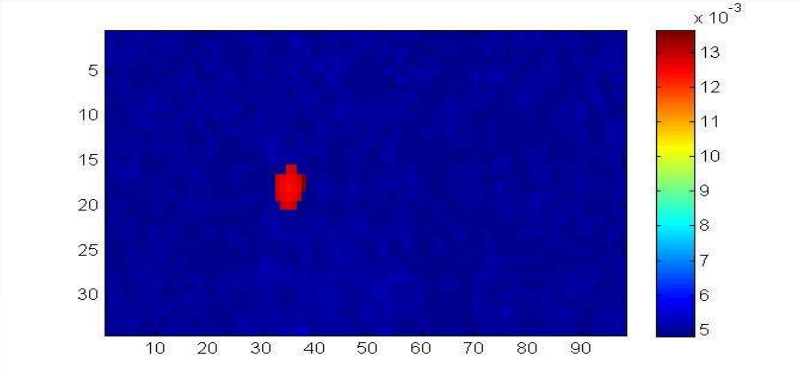


Depth obtained for the parallelepiped is in the range of 1.2 to 1.4 cm for numerical data, compared to 1.1 to 1.3 cm for measurement data.

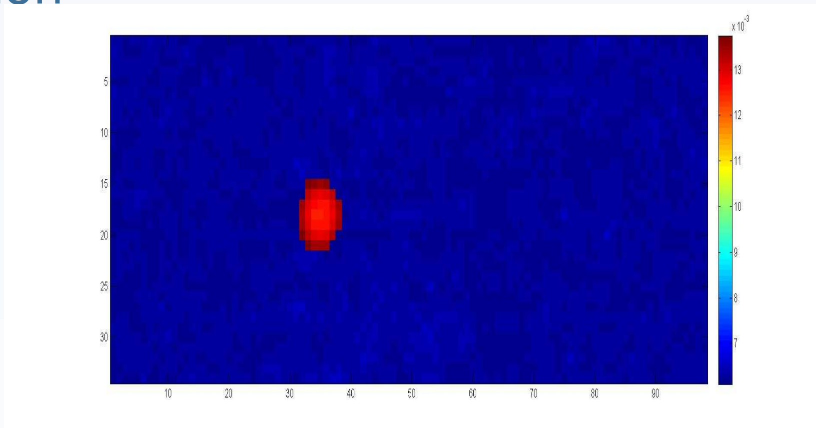
Heat pulse duration 300 s

Results :
Defect depth map (pine wood)

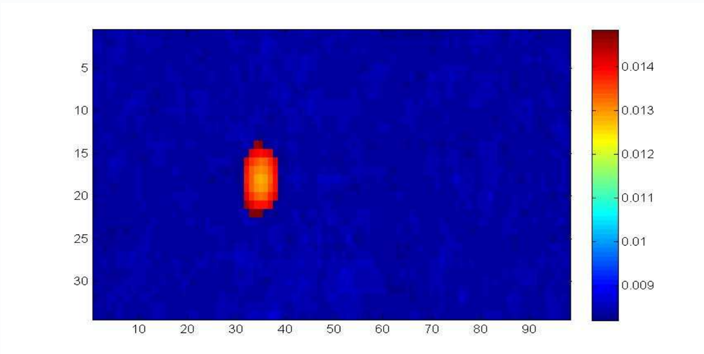
Depth retrieval using numerical simulation for different heat pulse duration



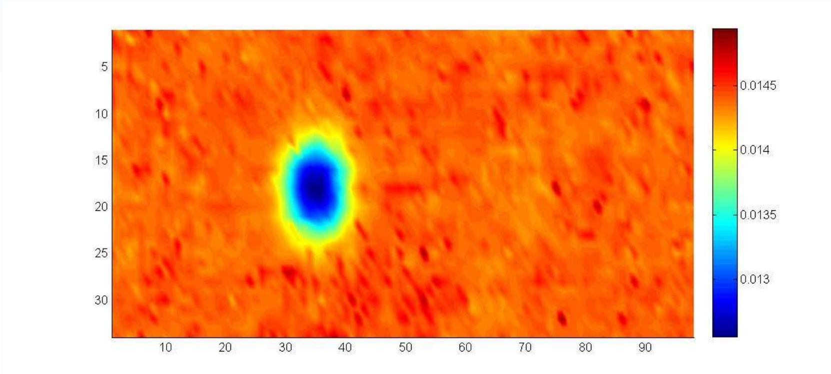
Heat pulse duration of 30 s



Heat pulse duration of 60 s



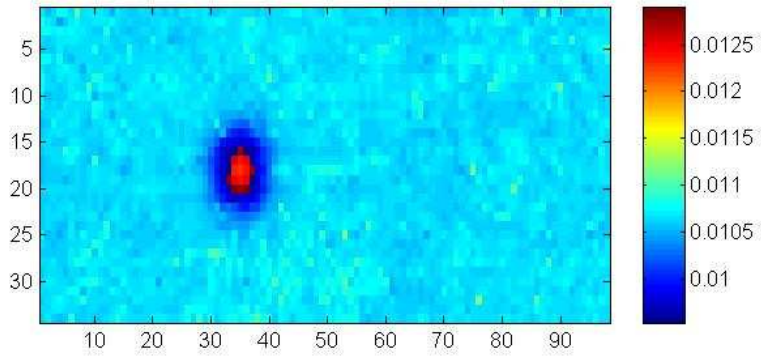
Heat pulse duration of 120 s



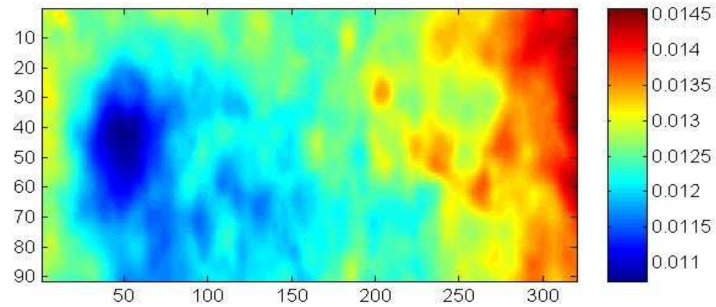
Heat pulse duration of 480 s

Results :
Defect depth map (air)

Using numerical simulation



Using experimental data



Depth obtained for the parallelepiped is in the range of 1.0 to 1.3 cm for numerical data, compared to 1.1 to 1.2 cm for measurement data.

Heat pulse duration 300 s

Results :
Defect depth map (air)

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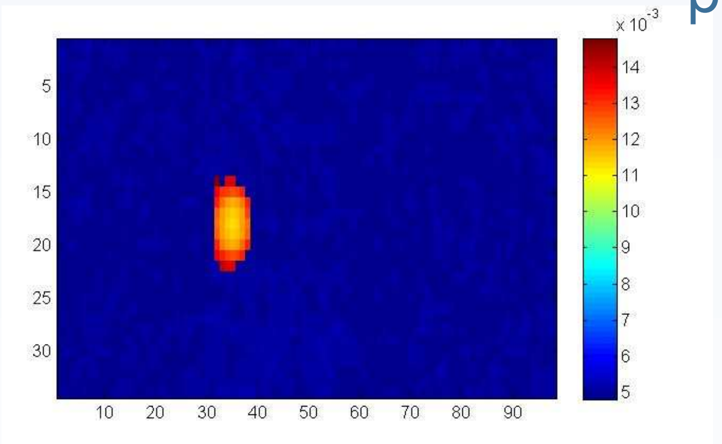
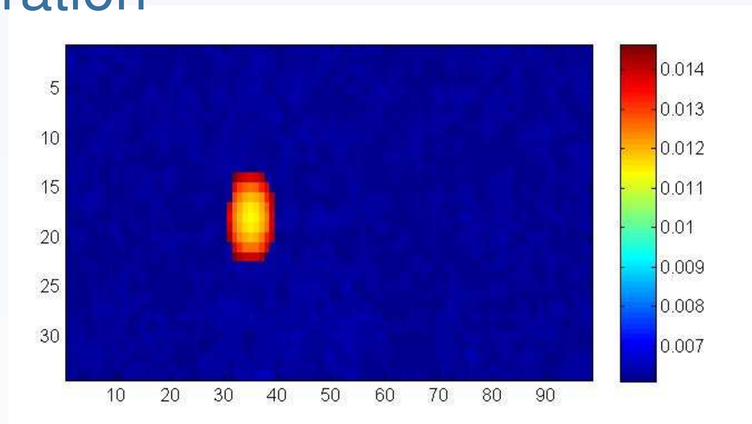
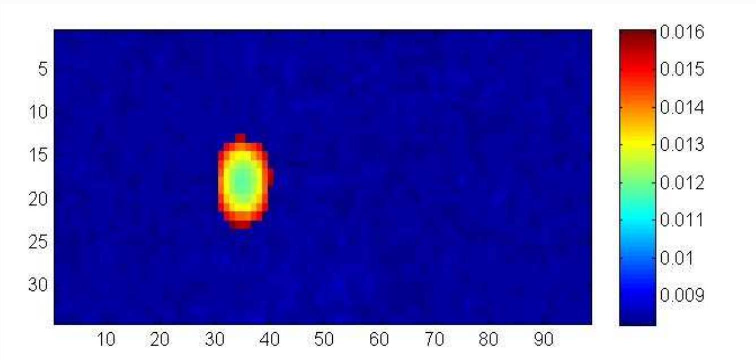
Depth retrieval using numerical simulation for different heat pulse duration



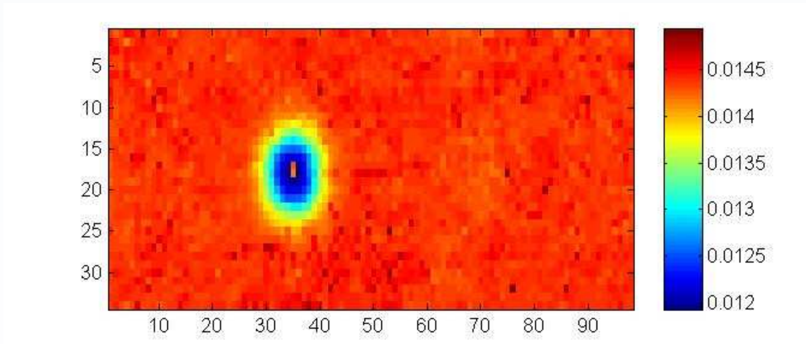
Heat pulse duration of 30 s



Heat pulse duration of 60 s



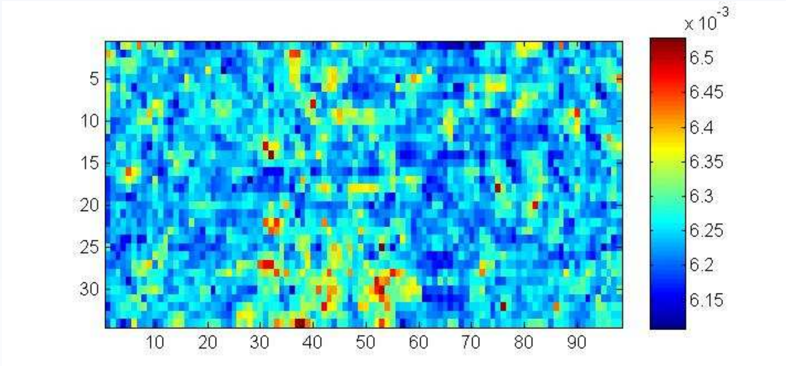
Heat pulse duration of 120 s



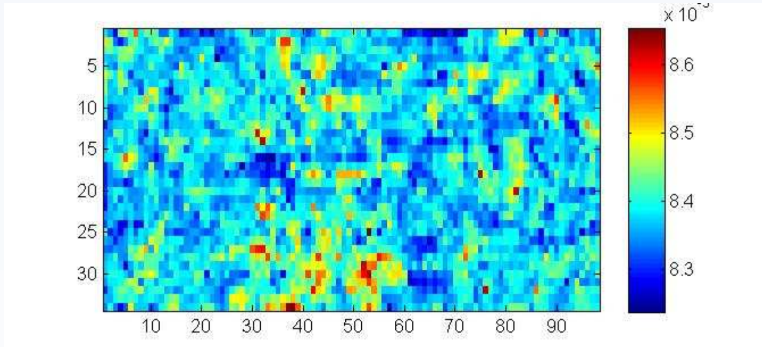
Heat pulse duration of 480 s

Results : Defect depth map (water)

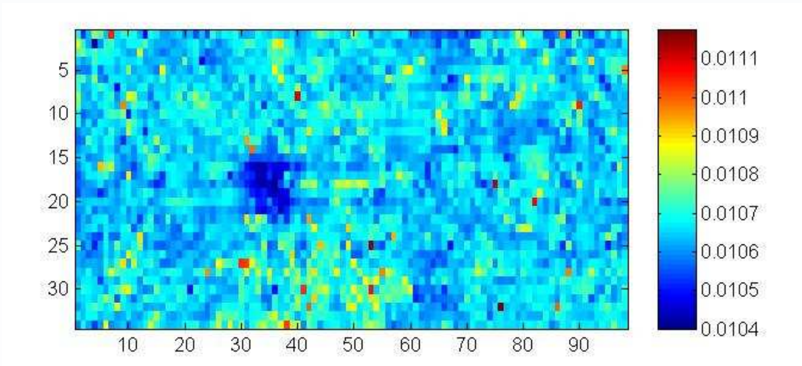
Depth retrieval using numerical simulation for different heat pulse duration



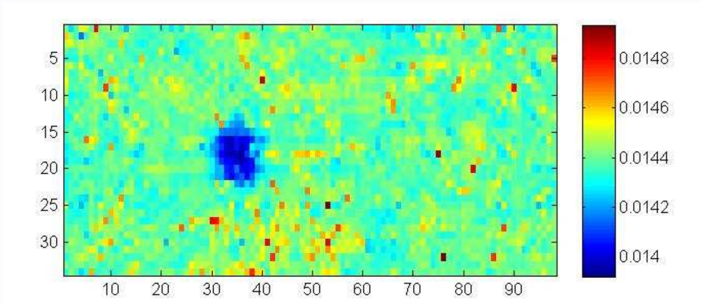
Heat pulse duration of 60 s



Heat pulse duration of 120 s



Heat pulse duration of 300 s



Heat pulse duration of 480 s

Conclusion

- The active infrared thermography could be applied to detect road pavements defects.
- The step heating method was efficient to identify the presence of defects within this particular structure of road material.
- Experimental map defect shape and signature intensity are affected by non uniform natural convection developed on the pavement sample surface but also by un-cooled infrared camera performances.
- Without any information on the location of the pyramid-shape defect, its detection remains difficult and not established with such approach.
- Numerical simulation is an helpful complementary tool to identify optimal heat pulse duration for different nature of defect and for testing depth retrieval model.

Perspectives

- Develop other analysis approach to localise and characterize narrow shape defect.

- Evaluate measurement performance influence of cooled and un-cooled infrared camera for defect detection.

- Develop numerical simulation for non homogeneous material.

- Develop and evaluate defect depth retrieval approach based on 2D and 3D heat transfer model.