# Sudden winter disorders on pavements and behaviour of bituminous materials under frost/thaw conditions

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## ABSTRACT

Some recent winters as in 2009/2010 have given rise in France, but also in other European countries, to important disorders in the upper part of pavements. Those are mostly characterized by the onset of series of pot-holes, which have the particularity to appear suddenly and quasi simultaneously on long road distances. Thus several road and motorway sections, several tens of kilometres long, have been concerned during the same day, with the need sometimes for immediate closure to traffic. Beside, such significant disagreement to road users are accompanied by important costs of repair, not integrated into the scheduled program of maintenance.
Then such events have led the French Road administration to launch several studies in order to understand the phenomenon, to remedy to it and prevent future disorders of the same kind. On the one hand, these studies include detailed site analyses of the observed pathology and of the circumstances of disorders onset (pavement structures, traffic, climatic conditions, pavement sampling...).
On the other hand and on the basis of the site analyses, the RST and IFSTTAR have launched a laboratory testing program to study the behaviour under frost and thaw action of bituminous materials, which have preliminary been partially saturated with water. Some of these tests are closed in their principle to those performed to evaluate the frost/thaw behaviour of pavement unbound granular materials layers. The measurements show obvious parasite strain effects, due to the liquid/solid phase changes of the water contained into the porous space of the tested materials, which are believed to be at the origin of the disorders observed at the pavement surface. The article deals with the results obtained in lab and with the doors now opened to explain the phenomenon.

## 1. INTRODUCTION

Since winter 2002/2003, a peculiar mode of degradation of pavements has sometimes been observed in the northern and eastern parts of France and borderlands (south of England, Belgium, west of Germany…). This one occurs without specific early signs and in short time duration of about a few hours [1]. These degradations usually take the form of scabbing of the surface of the asphalt layer with formation of series of potholes and appear essentially in the wheel tracks. They may cause the closure in emergency of roads to traffic (figure 1). The extent of areas affected by such degradation events seems to coincide with that of areas undergoing in the same period similar climatic conditions, characterized by cold temperatures (below -10°C) preceded by periods of positive temperatures with rainfall episodes.

Due to the important consequences of the degradations in terms of traffic, safety and repair costs, the French Authorities asked the scientific community to analyze and understand the phenomenon in order to evaluate the vulnerability of the pavements not affected yet and to develop design or rehabilitation rules which allow avoid these disorders. Part of ongoing research is conducted within the frame of the IFSTTAR research program called CCLEAR dedicated to the study of the impact of climatic events on pavements.

*Figure 1: Series of potholes which appeared in a few hours*

Considering the sudden appearance and the large geographic extent of the events that lead in a few hours to the degradation of hundreds of kilometres of pavements, when cumulated, it proves that there exists a specific damage mechanism different from those usually encountered in pavement mechanics. In particular, the degradations do not arise from phenomena associated to mechanical or environmental fatigue or long-term stripping of binder that require several years to take place. However, it remains possible that the specific mechanism under consideration acts preferably on used pavements which have endured fatigue and therefore be an indicator of the structural soundness of already damaged pavements. Nonetheless, to confirm or not this assumption it is necessary to first specify the above-mentioned mechanism and to assess its “own strength”. Which are the mechanism parameters behind and what are the cause and effect relationships involved?

Is this sole mechanism able to cause the deteriorations observed or does it just deliver the final blow to a structure that was going to collapse?

In order to answer the questions above, a research program was launched to specify and analyze this mechanism. We present below a short overview of the works that were carried out and some of the results obtained.

## 2. SEARCH FOR THE TRIGGER MECHANISM: PRELIMINARY ANALYSIS

The degradations observed on the French road network have been widely investigated in particular through the gathering of the weather records prior to a critical event, the census of the damaged structures and the coring of pavements around the damaged zones.

These studies have shown that several common factors could be found when degradation occurs [2].

With regards to the weather conditions, the critical events occur after days during which the temperatures are alternatively positive and negative with the presence of precipitation. The event itself seems to be triggered by atmospheric temperatures reaching values around -10°C.

Roads that went through maintenance consisting of the superimposition of old and new surface layers are often the worst affected roads. In this case, core drilled shows that the source of degradation is located at the old surface layers which are almost fully disintegrated (fig. 2). It also reveals the presence of water within the porosity of the asphalt surface layers.

Although for the reasons already mentioned, fatigue damage cannot be at the origin of the observed disorders (at least of their triggering), we wondered whether thermal cracking could be the triggering mechanism.

However, despite the negative temperatures reached before these sudden degradation episodes, it seems that their range of order is not low enough to yield failure by thermal cracking, given the type of bitumen used in France. This is attested by the current experience which shows that road networks are generally able to sustain temperatures not much lower than -10°C without problems. It is also confirmed in the laboratory by the restrained shrinkage cracking tests. These ones show that thanks to their property of relaxation, usual bituminous mixtures cooled down at a rate of a few degrees per hour and at zero deformation, do not crack for temperatures above -20°C.

Therefore this led us to believe that the cause of deterioration was rather due to a combined effect of negative temperature and presence of water in the porosity of the asphalt concrete. We then launched a test program in the laboratory to investigate this specific aspect of the behaviour of bituminous mixtures, not addressed yet in technical literature.

The first tests that we performed were inspired from the frost swelling tests developed in France and abroad to assess the risk of deformation of soil and granular materials under frost/thaw cycles [2], [3].

An overview of these tests and the results obtained are given below. These corroborate (but not completely demonstrate yet) the hypothesis that the aforementioned combined effect of water in the porosity of asphalt mixtures plus frost/thaw cycles is particularly detrimental to the durability of flexible pavements.

*Figure 2: Core drilled near a pothole*

*Disintegration of the old surface layers*

## 3. FROST/THAW TESTS ON BITUMINOUS MIXTURES IN THE LABORATORY

### 3.1 DESCRIPTION OF THE TEST

*Experimental set-up*

The experimental set-up used in our study was initially designed to freeze in one-dimensional condition, cylindrical samples of soil or untreated aggregate mixtures. Here we apply it to bituminous mixes. The device is composed of 6 cells in which samples can be tested simultaneously. The cells are immersed in a tank, filled with a refrigerated liquid at a temperature slightly above zero (1 to 2°C) (fig. 3). The frost/thaw cycles are applied at the surface of the samples which are in contact with a refrigerated metallic piston, controlled by a cryostat. It is also possible to immerse the bottom of the sample in a water bath at about 1 or 2°C for the study of suction effects due to capillarity and cryosuction during the freezing phases. However the tests presented herein are performed without water bath.

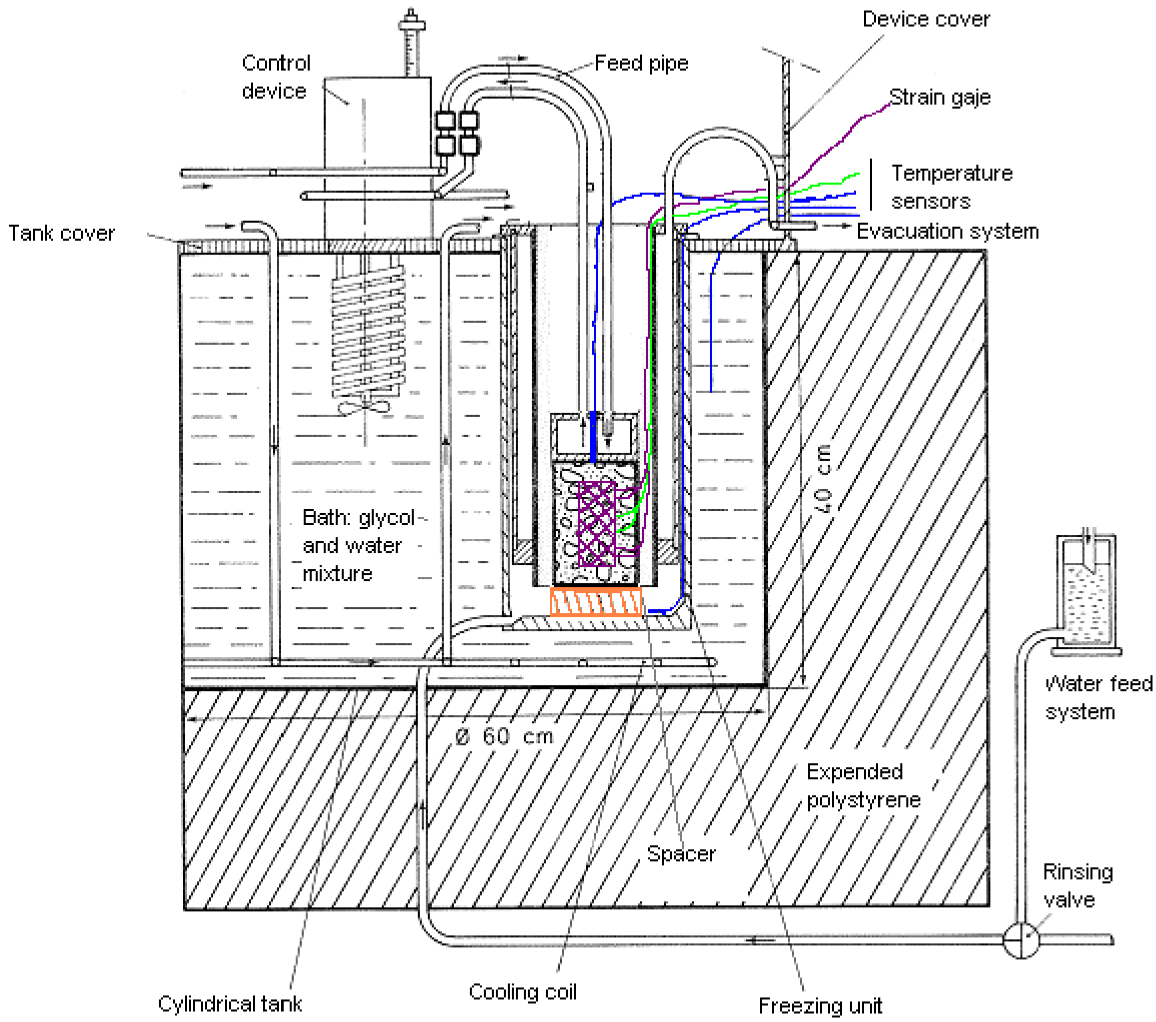


*Figure 3: Cross section of the experimental set-up showing one cell of the device used for testing the response of bituminous mixes to frost/thaw cycles*

### *Temperature measurements*

Preliminary tests were performed to appraise the temperature reached at the heart of samples when frost/thaw cycles are applied at the top surface. The purpose is to determine the amplitude of the thermal cycle and its duration to avoid surfusion inside the sample. The figure below shows the variation of temperature at different heights of the sample when cycles of 24 hours varying between +10°C and -10°C are applied at the top surface. The extreme values of temperature go from +6.5°C to -4.5°C at mid-height of the sample, from +5°C to -3°C at the bottom and from 0°C to 1.8°C at 20mm under the sample bottom surface (air temperature at this location). The variation of temperature measured by this sensor is very small showing the control of the temperature by the refrigerated liquid. The configuration of the experimental device thus generates non-homogeneous thermal gradients in the vertical direction, varying with time.

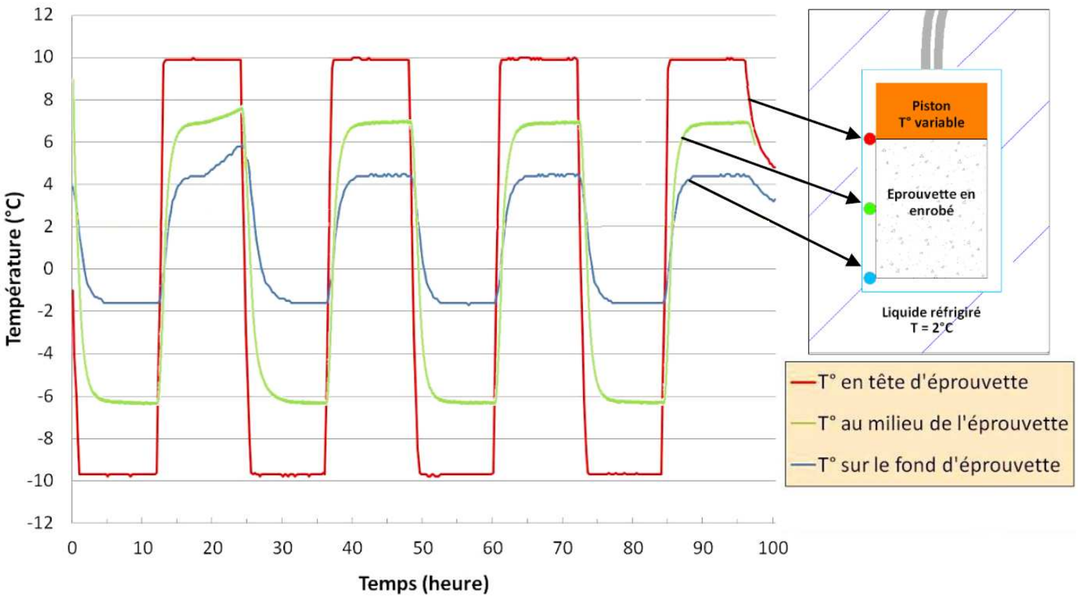


*Figure 4: Temperature measurement at different heights of a sample during a test*

Indeed the measurements performed in the horizontal directions of any section show only small differences of temperature between the edge and the heart of the specimen. In the following, the temperature measured on the outer lateral surface of the sample is taken as reference.

### *Strain measurement*

Strain gauges (of length 30 mm) are positioned on the outer lateral surface of the sample, either in the vertical direction parallel to the frost propagation direction or in horizontal planes. These gauges are sensitive to temperature variations, thus measurements need to be corrected for removing this bias. We accomplish this by subtracting the response of a similar gauge subjected to the same thermal conditions and stuck on a silicate rod which strain is (quasi) independent upon temperature. Some measurements of contraction/extension carried out on a stainless steel sample of known thermal coefficient, showed a good agreement between the theoretical and measured values of this coefficient assessing the accuracy of our corrective procedure.

Further in this paper, we present only the radial strains measured by gauges positioned perpendicular to the propagation direction of the freezing front. Indeed these gauges are better suited than the axial ones to isolate “sharp” events that occur at the freezing front. Whereas the axial gauges average over their height the phenomena observed. Nonetheless, the analysis of both signals recorded in the radial and axial directions allows us to evaluate the three-dimensional behaviour of the material. Actually, the similarities found between the two signals at any time of a test and for all the tests performed (under free strain conditions) attest that the response of the material is quasi-isotropic whatever the circumstances.

### *Samples*

The results presented below are relative to a medium coarse asphalt mix obtained with a continuous distribution of the grain size (0/10mm) and straight bitumen with grade 35/50. The sample porosity is of the order of 10%. Part of the tests is performed on dry samples.

The other samples are partially saturated by immersion using a vacuum pump. The degree of saturation increases with the negative pressure applied. The following results correspond to a degree of saturation equal to 72%.

### 3.2 TEST RESULTS OBTAINED FOR DRY SAMPLES

Figure 5 shows the typical response of a dry sample of asphalt concrete. During a cycle, the deformation of the asphalt concrete (red curve) varies almost proportionally with its temperature (blue curve) showing that the asphalt concrete mostly verifies the usual law of thermal deformation.

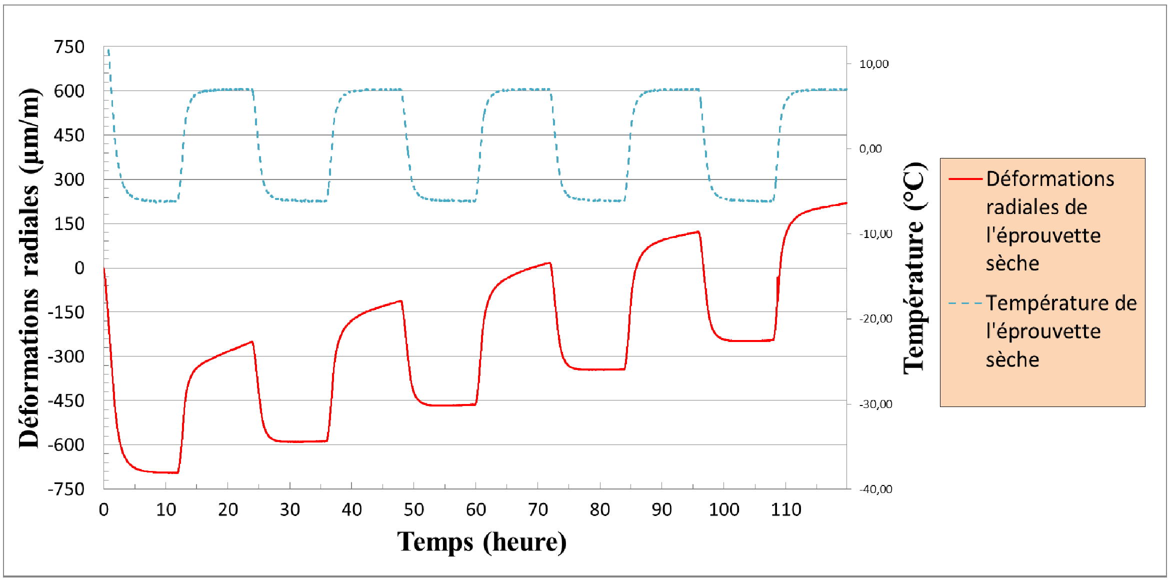


*Figure 5: Radial strain measured during frost/thaw cycles applied to a dry sample of asphalt concrete (Convention: extension is in the upward direction on the graph)*

We also notice under these free strain test conditions (except for the own weight of the piston and the sample) a remaining creep component in extension after each cycle, which in turn leads to a progressive swelling of the sample by cumulative effect. However this phenomenon is considered of secondary importance for our purpose and its explanation is not addressed here.

Then, it is possible to compute the average radial thermal coefficient, $\alpha = \Delta\varepsilon_r / \Delta T$ , between the two plateau temperatures of a same cycle. We obtain a value of the order of $30.10^{-6}$/°C which is in accordance with values found in literature.

### 3.3 RESULTS FOR AN ASPHALT CONCRETE WITH A WATER SATURATION OF 72%

Figure 6 shows the behaviour of a water-saturated asphalt concrete at a saturation of 72%. In this case the response of the material is way more complex than that of the dry sample. In particular, we notice peaks of deformation (either in the upward or downward directions) each time the measure of temperature goes through zero at the location of the radial gauge.

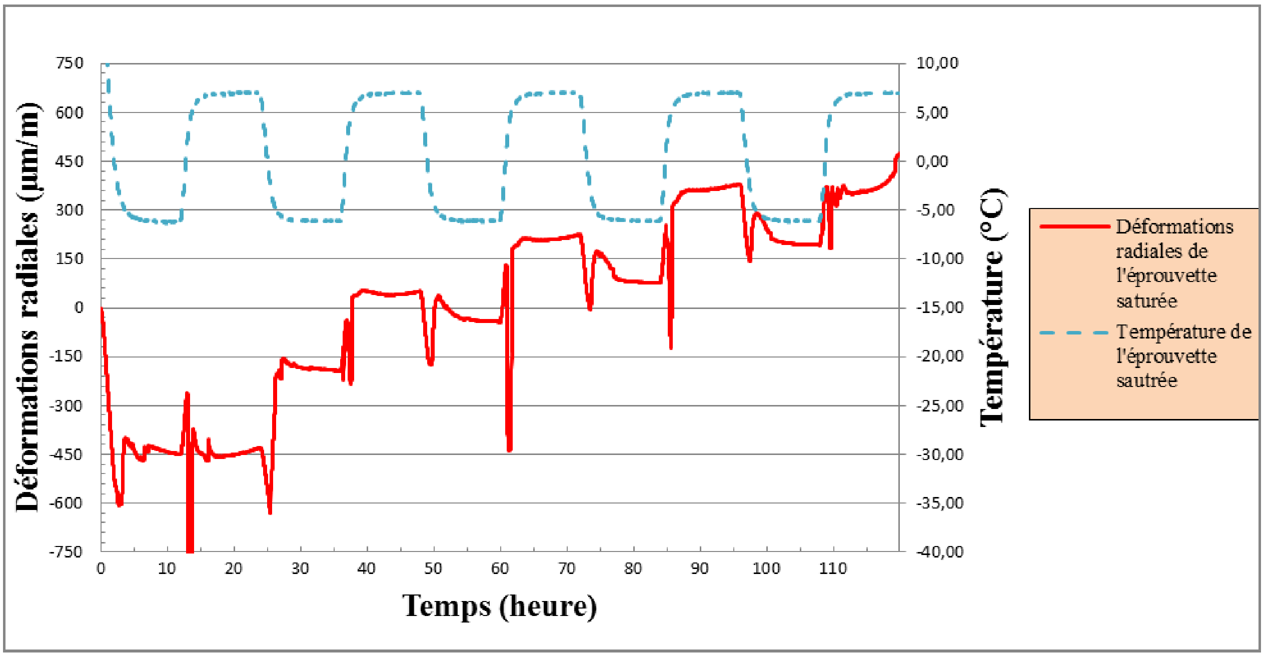


*Figure 6: Radial strain measured for sample E8 during frost/thaw cycles*

A zoom in of a time period of 17h is represented in Figure 7. This representation makes easier the visualization and interpretation, at the scale of a single frost/thaw cycle, of the history of the local deformation of the material near the instrumented section. Between 0 and 1h30, the temperature decreases but remains positive and the material undergoes thermal contraction as for the dry sample.

Between 1h30 and 3h, the temperature becomes negative and the freezing front goes through the location of the gauge in the downward direction. The material undergoes a relative extension of about 200 micro strain. This is definitely due to the dilatation of the volume of water saturating the porosity of the asphalt concrete during the phase change from liquid to solid (for recall the volume expansion of liquid water to ice is 9%).

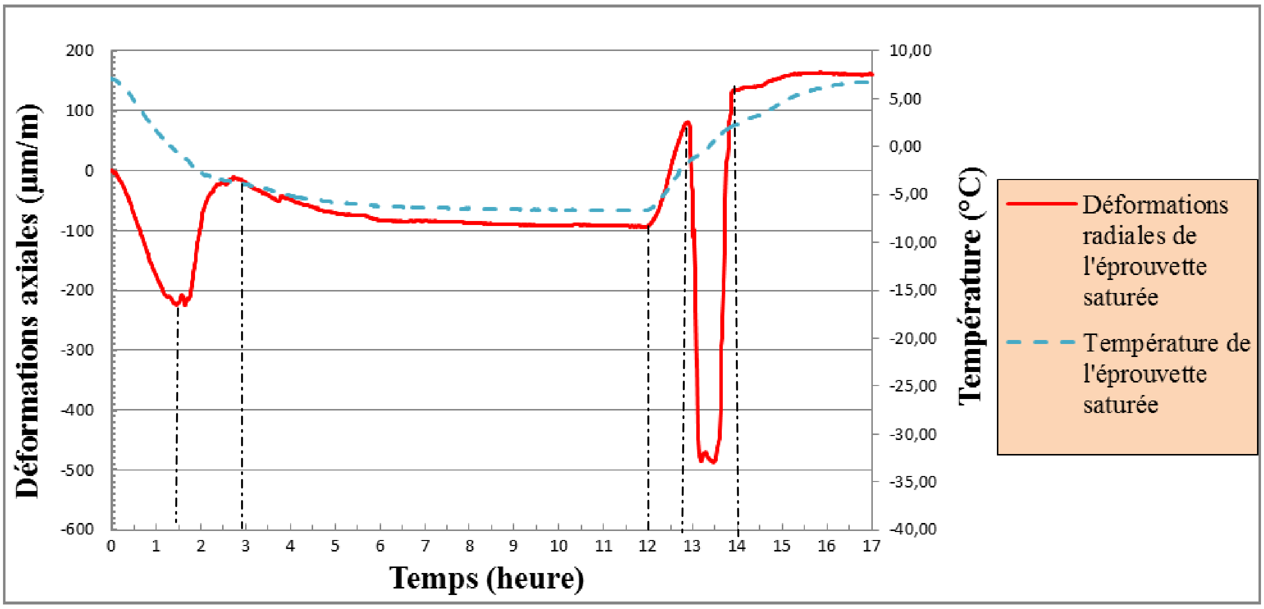


*Figure 7: Zoom in of the radial strain measured on the sample during a frost/thaw cycle*

*detailing the different phases of behaviour of the material*

Between 3 and 12h, the material contracts as the temperature decreases. The water within the pore volume is largely or totally frozen; the grains, the binder and the ice contract according to the classical thermo-mechanical process.

After 12h, the freezing front goes up to the top surface of the sample. The material and the ice start warming up in the domain of negative temperatures; as expected an expansion is observed.
The freezing front goes through the vicinity of the gauge in the time interval between 13 and 14h. The material then undergoes a large phase of contraction (600 micro strain) followed by a phase of expansion of similar amplitude. These fluctuations are probably due to the inverse transformation of the water present in the pore volume from solid to liquid, which is associated with a decrease of volume. The fact of having alternatively contraction and expansion may result from a negative pressure effect (as compared to the atmospheric pressure) of the newly melt water, followed by a balancing of the air/liquid water pressures. Finally, the last portion of the curve (14-17h) at positive temperatures reflects the thermal dilatation expected when a material is warming up.

Therefore these tests demonstrate the significant effects that partial saturation of asphalt concretes with water might play on their behaviour when subjected to frost/thaw episodes.

## 4 WHAT CONSEQUENCES FOR THE PAVEMENT?

What might be the consequences of the phenomena highlighted in the previous section on pavements?
Despite spectacular, the tests performed here can neither fully answer this question yet, nor totally confirm the origin of the road degradations that we are looking for.

To be able to conclude, several other aspects have to be examined. First, we need to characterize the behaviour of asphalt concrete in terms of “stress” (“dual” variables of free strains, considered in the preceding) when subjected to the same environmental and saturation in water conditions as previously. In particular, the question is whether the presence of ice in the porosity is likely to annihilate the relaxation capabilities of the material and to generate, under restrained deformation, high stress levels that could lead to cracking of the material or damaging of interfaces.

Another point is the accurate determination of the stress and strain distributions likely to appear in heterogeneous multilayer structures (e.g. materials with different porosity and saturation in water) due to these phenomena. Is there a risk for instance that a “bimetal” effect develops between a layer of dry material contracting when cooling down and a saturated layer expanding because of frost effect? This would be particularly detrimental to interfaces.

A Ph.D. thesis is now planed to address these questions from the experimental and the modelling point of view.

A better understanding of the phenomena involved would help:

- Locate and identify road portions at risk (e.g. detection (using radar?) of pavements likely to store water).

- Determine preventive solutions suited to a given portion at risk (pavement reshaping, use of different resurfacing materials, improvement of the water drainage inside and outside the pavement…).
- Adapt, if needed, the design and maintenance rules for pavements by specifying for example the technical recommendations on the choice of either the superimposition of new layers or the substitution of old layers.

# Conclusion

Important degradations of the upper part of pavements have been observed since several years, taking the form of removal of matter. These degradations take place suddenly, in a few hours, over large distances.
Some common factors to the apparition of these problems have been identified through field experience (strong frost/thaw event, presence of water in the asphalt concrete), as well as aggravating factors (imperfect milling of interfaces, defect in the drainage system, stacking of thin layers and/or covering of old surface or binder courses).
Based on these observations, the French road directory has defined a research program to answer the questions asked by road operators about the origin of these problems, the identification of road sections at risk, and the possible preventive/healing solutions to adopt.
The experiments presented in this paper have consisted in comparing the free deformation of samples composed of dry and partially water saturated asphalt concretes subjected to frost/thaw cycles.
The results obtained show significant effects (several hundreds of micro strain) of contraction/expansion localized at the freezing front; these are due to the variation in volume of the pore water during the phase change from liquid to solid and vice versa.
We believe that the phenomena observed are at the origin of the aforementioned degradations. Nonetheless, a Ph.D. thesis is planed to confirm and specify the mechanisms involved in order to be able to define operational provisions for the future.

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