Study of the snow pavement interface : GELCRO project

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Abstract

In GELCRO project, we develop a model enabling forecasting of the condition of a road surface before snow falls and monitoring of evolution following snowfall. To develop specific knowledge on snow/pavement interface, an experimental site was selected. Snowfalls and highly changeable weather were the characteristics determining this selection.

The site is equipped with six experimental sections of road representing widely used surfaces in France. Various probes are inserted in these sections. Manual measurements are made during or just after a snowfall and snow/road composite samples are taken. An original technique has been developed in a cold laboratory (-20°C) and enables the observation of the snow/pavement interfaces.

Complete observation and analyse of different snowing events should help us to better understand snow pavement interface and to make a parameterisation of typical situations. These results will be used for future development and validation of GELCRO model.

1 Introduction

Snow precipitation's have a direct impact to all road users. Forecasting of road and weather conditions allows maintenance personnel to improve the management of operation and maintenance resources, such as reducing the use and costs of maintenance activities. However we miss knowledge to understand and predict the evolution of snow precipitation on the pavement. The Gelcro project has been initiated to increase that knowledge. The main object of this project is to develop a system in order to forecast the evolution of a snow layer deposited on the pavement. This system should take into account the climatic conditions, the different snow qualities (dry, wet) and the composition of the pavement because these parameters are fundamental to forecast road conditions.

The model named Gelcro is built from two one-dimensional coupled numerical models :

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- Crocus (Brun et al., 1992), a physically based model which simulates snow cover evolution. It takes into account snow quality and snow evolution with new precipitations. There is a basic ground description, since this model was developed to forecast avalanches.

- Gel1D (Frémond, 1979) Knowing the physical properties of the different layers of the pavement, it calculates temperature evolution and frost propagation in the pavement. However, the atmospheric part of this model is simplified and it does not take into account precipitations.

Coupling these models should enable a forecast of the behaviour of falling snow on a pavement. This new model, called GEL:CRO is under development (Lassoued R., 1999). It takes into account pavement composition, the nature and intensity of the precipitation, atmospheric conditions and the "history" of the material (presence of a snow layer for example).

To achieve coupling, physical properties of the interface between snow and pavement have to be determined and introduced into the new model via proper parametrization. To obtain such a parametrization we have to describe snow/pavement microstructure. For this study, an experimental site was chosen for its high snowfall frequency and the variety of meteorological situations.

2 Material and Method

2.1 Site description

On this site, we have built six experimental pavements (2m x 3m) representative of building techniques presently used in France (cf. Figure 1).

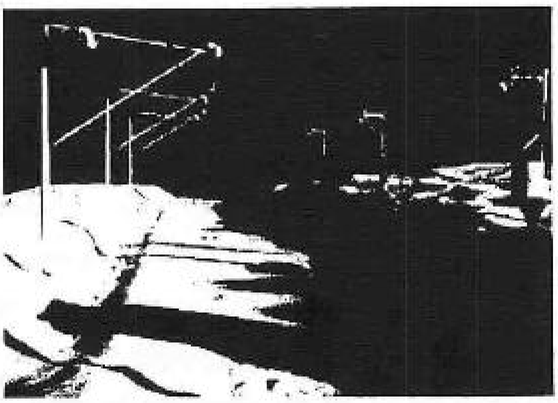

Figure 1: Picture of the 6 experimental pavements. Three CCD camera take a picture of the pavements every 30 min., every 10 min. during the snowfall.

There are thin structures (usually used in departmental roads) and thick structures (usually used in highways) with either bituminous or cement gravel mixture. We also modified the surface layer while using semi-grainy bituminous concrete, very thin bituminous concrete, drainage bituminous concrete... One of the six experimental pavement is made of detachable samples of pavement (15cm x 15cm x 4cm). After each snowfall a snow/pavement specimen is sampled in order to be analysed in cold laboratory.

These pavements are equipped with numerous sensors such as snow depth sensors, temperature probes and video camera. This makes possible to observe pavement snowing up and to characterise snow evolution for different weather conditions. The site is also equipped with a complete weather station including specific snow cover measurements.

2.2 Standard snow characteristics measurements

After each snowfall standard properties measurements are performed. They consist in :

- measuring snow height on each pavement
- measuring snow density
- describing the stratigraphy and specifically the snow/pavement interface (dry, wet,...), measuring slush layer height when present.
- measuring snow temperature with a vertical resolution of 0.5 cm to obtain a detailed thermal profile.

2.3 Study of snow/ pavement interface

2.3.1 Method of sampling snow/pavement specimens

A PVC core sampler is introduced vertically in the snow deposited on the pavement sample. The snow is removed around the core sampler. Then a thick cold (-40°C) copper cylinder is put around the PVC sample. An ice seal is made at the basis of the cylinder with slush. A cooled liquid filler (diethyl phthalate : very low miscibility with water, freezing point of -5°C, density at 20°C : 1,118) is poured between the PVC core sampler and the copper cylinder at ~-10°C, a temperature that is below the freezing point of water. Pore structure in snow allows some capillary rise into the pore space of the snow core (Perla, 1982). After impregnation we put dry ice (solid CO_2) around the copper cylinder in order to freeze diethyl phthalate. When the sample is frozen, all metamorphism is stopped (Borel, 1999). Then the sample can be handled, removed from the site and brought in cold laboratory held at –20°C for delayed analysis.

2.3.2 Cutting technique

The problem was to cut then to plane properly a very composite material made of rock, tar, ice and phthalate without melting or displacing any of its components. In our particular case, common liquid cooling could not be used because of the simultaneous presence of water (ice) and oily compounds (tar, phthalate). The CEN has developed a specifically cutting machine to make dry cutting at high velocity with efficient air cooling and dust removal (Borel, 1999). It is very important to reduce as much as possible initial sample temperature. This is achieved by storing samples (clamped into steel sample holders) during 15 minutes in liquid nitrogen.

After cutting, the raw section is planed by disc grinding on the cutting machine. However the contrast between the snow and the liquid filler (diethyl phthalate) is not sufficient to distinguish the bonds between snow, grains and pavement : both of them are white.

To enhance contrast between ice and phthalate the snow/pavement section (at -20°C) is first placed under vacuum to force ice sublimation. After 30 minutes sublimation leaves small pits of 1mm where ice sublimes. The cold room is then set at -10°C and the cavities are filled with liquid black (using Fluka n°46300 dye) dyed diethyl phthalate. Black phthalate is deposited at -6°C using a syringe in order not to melt white solid diethyl phthalate. Then we let the whole freeze at -20°C. After another planing, the grain phase appears black and the pore phase pale grey (cf. Figure 2).

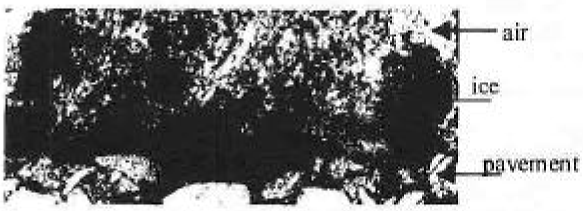

Figure 2 : Image of a snow/pavement section.

Images of the snow/pavement section plane are taken using a 3CCD video camera and are recorded on an analogue video disc recorder.

3 Results

The snowing events collected are then classified into different cases depending of the quality of the falling snow, the weather conditions and the pavement state. Our objective is to make a parametrization of each case. Since this work is still going on, we present here an example, which illustrates the different analysis made and the complexity of the problem.

The example chosen is a case of a wet snow falling on hot wet pavement (5-6th April 1998).

- Weather conditions

The pavement surface temperature was positive (around 12°C). There was no wind and it began to rain at 17:30 the 5th and at 19:00 it began to snow (wet snow for 7 hours). Knowing the sun masking and with a video analysis, we compared sun exposition of each pavement, and pavement 5 and 6 were found to have the same exposition. Pavement 5 is a thick pavement with 8cm of semi-grainy bituminous concrete and 42 cm of gravel-bitume mixture, pavement 6 is also a thick pavement with 8cm of semi-grainy bituminous concrete and 52 cm of gravel-cement mixture.

- Video analysis :

The snow began to stay on the 2 pavements simultaneously. After the snowfall, there was 2 cm snow on both pavements. The snow on the pavement 6 began to melt before the pavement 5 (~30 min. difference) and this pavement was dry sooner. The video analysis is only qualitative and, excepting sun exposition information, can not explain pavement differences.

- Temperature profile analysis for pavement 5 and 6 (cf. Figure 3):

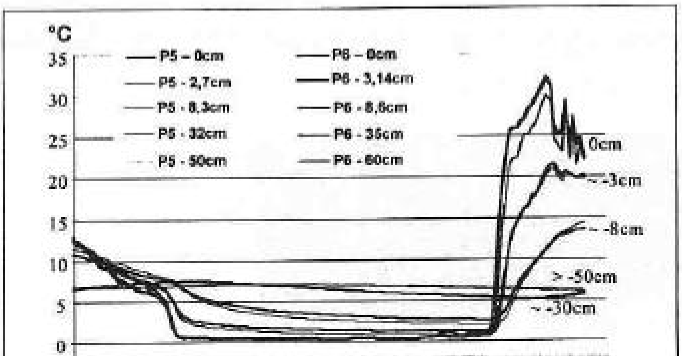

Figure 3 : Temperature profile for pavement 5 and pavement 6 in °C.
Fine lines : pavement 5 (gravel-bitume mixture),
Thick lines : pavement 6 (gravel-cement mixture).

The temperature profile of the pavements was equivalent before the snowfall whatever the depth. After 30cm depth we only observed circadian evolution and the temperature was equivalent for both pavements.

If we look at the surface temperature, it is equal to zero when the pavements are covered by snow, and the temperature decrease is identical for pavement 5 and 6. During the melting (around 10:00) the surface temperature of pavement 6 is more important than pavement 5. These measures are in accordance with the video observation. This difference could be explained if we look at the temperature in the pavement structure. When the pavements are covered by snow, at –3cm and –8.5cm, the pavement 5 is colder than pavement 6, It seems that the gravel-cement mixture of pavement 6 kept the warmth, since the gravel-bitume mixture of pavement 5 has a bigger thermal conductivity so it received more cold. Weight volume differences could also explain warmth accumulation.

- Microstructure snow/pavement analysis

The 6th April, a snow/pavement sample was taken with the method described previously. The resulting section plane images present fuzzy grain contours so that automatic image processing could not be achieved. Therefore images are manually processed. The result of image processing is a three grey-level image where ice, air and pavement can be distinguished (cf. Figure 4).

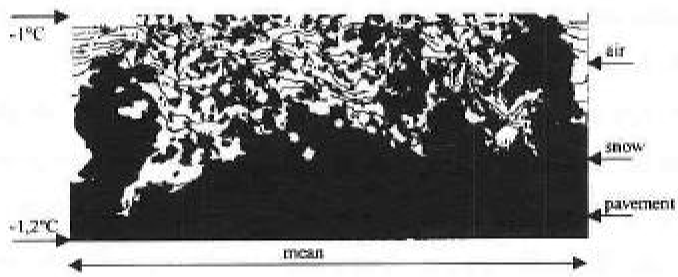

Figure 4 : Three level image of a snow/pavement sample

For GELCRO model, we need to thermally characterize the interface that is to determine its thickness and its thermal conductivity. A program has been develop to resolve a two dimensional steady state conduction problem using Gauss-Seidel finite difference method (Dady, 1969). The image is used as networking. We impose constant temperatures on upper and lower boundaries (i.e. snow surface and pavement) and a zero lateral flux on both sides. We obtain a steady state temperature distribution within the image. Then we mean horizontally temperatures to obtain a one-dimensional vertical temperature profile (cf. Figure 5). This profile is linear for each homogeneous zone so we can define the size of the interface. We compute the thermal conductivity of this interface with the slope of the corresponding temperature profile. In our example, the interface is 7.3mm thick and has a thermal conductivity of 0.66 W/m/K.

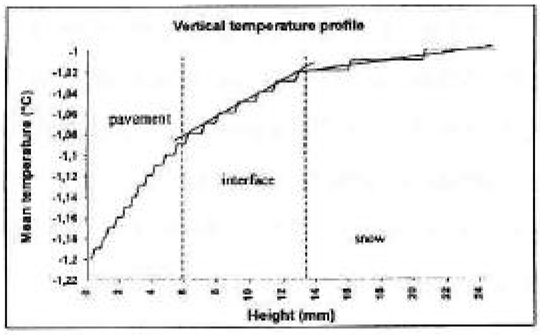

Figure 5 : Vertical temperature profile calculated with the image.
Each different slope corresponds to a different zone. The interface is defined as the heterogeneous zone composed of ice, air and pavement.

4 Discussion

In this paper, we have presented different analysis made for each snow event by using an example. Processing are still going on and it is to early to present a parametrisation. However, this example leads to some conclusions.

For the pavement, the sun exposition and the presence/absence of shade is very important. This phenomenon is classical for operational service, who knows that first and last frost plaques are generally situated on shaded places. The physical structure of the pavement has also an influence of the surface state. This phenomenon was already taken into account in GEL1D model.

For the microstructure analysis, we are able to see and characterise the interface. Moreover computed temperature and measured temperature are in good accordance (Borel, 1999).

However our analysis have some limits: the events are complex, there are a lot of different parameters and it is difficult to make interpretations. We can not make conclusions with one special event. If we consider the microstructure analysis for example, it is only the study of numerous cases that will allow us to find a relationship between interfaces' thermal conductivity and snow and pavement features.

Since it is difficult to have similar events, lots of measurement shall be made to have comparable situations (we have 2 winters of data). Processing are on hand.

Then finished, the interfaces' thermal conductivity will be introduced in the model GELCRO and we will have more knowledge of pavement specificities in winter.

But there is a great difference between a protected experimental site like ours and real roads where there is traffic and de icing treatments. The aim of GELCRO is to provide from meteorological forecasted conditions, an objective forecasting of the evolution of falling snow on the pavement. So it shall take into account traffic and de-icing treatment.

Next winter (99-00), we will simulate traffic on our experimental pavements while compressing the snow. We will also simulate de-icing treatment (prevention and care). Numerous snow/pavement will be sampled to study the effects of those new parameters on interface microstructure.

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