Assessment of pavement response during spring thaw using heavy vehicle simulator testing

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ABSTRACT

Two indoor laboratory studies using a heavy vehicle simulator were performed at Laval University on two very different pavement structures. The flexible pavements structural response was tested in thawing conditions for different loading conditions. These tests were performed to document how the flexible pavement response changes with thaw depth, and to validate the main findings and information available in the literature regarding pavement response during spring thaw and Spring Load Restrictions (SLR) policies. The results collected during the experiment are in accordance with some general findings identified in the literature. More specifically, signs of weakening appear as soon as the thaw front reaches the granular layer beneath the asphalt concrete, at a depth of about 250-300 mm, and peak response values of up to 200% are observed either while the structure thaws or once thawing is almost completed in the subgrade soil.

Keywords: Flexible pavements response, spring thaw, heavy vehicle simulator.

1. INTRODUCTION

In parts of North America affected by seasonal freezing, the conditions prevailing during spring thaw are known to be critical and, when combined with the effects of heavy vehicle traffic, they are one of the main factors contributing to annual pavement structural damage. In order to reduce pavement damage during these critical conditions, many transportation agencies enforce Spring Load Restrictions (SLR). These regulations apply to axle and vehicle weight. They are enforced at various moments and based on criteria such as temperature, pavement response, fixed dates, etc. Given the close relationship between heavy vehicle loads and pavement damage, SLR helps control the deterioration rate of pavement structures, enabling them to meet their design life.

A significant part of yearly pavement damage occurs during the spring thaw period [1,2,3]. This damage increase is attributed to thaw weakening mechanisms [4], which cause the stiffness of soils and unbound granular materials to reach a yearly minimum. Based on observations made on the Quebec road network (Canada), about 30 to 85% of the yearly cumulated pavement damage, depending on the pavement class, occurs during the spring thaw period [3].

The weakening of flexible pavement during spring thaw can be divided into two distinct periods [5], referred to as early and late spring. Thaw front progression typically occurs from the pavement surface downward, but also from the frost front upward [6]. The melting of ice lenses and snow, in addition to more frequent liquid precipitations, asphalt brittleness and poor drainage conditions are all factors explaining this typical decrease of stiffness and resistance to permanent deformation of unbound layers and soils, and the overall pavement deterioration rate increase.

Since spring thaw is a critical period to consider in studying the complex interaction between loads and pavements, a research project was initiated to investigate these conditions under controlled laboratory conditions. This paper summarizes the results of two research projects, performed at Laval University, using an indoor test pit, a heavy vehicle simulator and an environmental condition simulator. These two projects allowed collecting information on flexible pavement response during thawing, while taking load variations into account.

2. EXPERIMENTAL PAVEMENTS AND SENSORS

The experimental pavements used for the project were built in an indoor test pit at Laval University. The pit dimensions are 2 m wide, 6 m long, and 2 m deep. As presented in Figure 1, two different pavement structures were studied. Pavement 1 was 750 mm thick; it was built on a silty sand (SM) subgrade (SG). Pavement 2 was 480 mm thick and; it was built on a low plasticity clay (CL) subgrade. Pavement 1 consisted of 100 mm asphalt concrete (AC), 200 mm granular base (B) and 450 mm granular subbase (SB), while pavement 2 consisted of 180 mm asphalt concrete and 300 mm granular base. The experimental pavements were instrumented to monitor temperatures, water content, stresses, strains and surface deflection (pavement 2 only) in the layered systems. Table 1 summarizes the sensors used for both pavements, as well as their respective position in the layered systems.

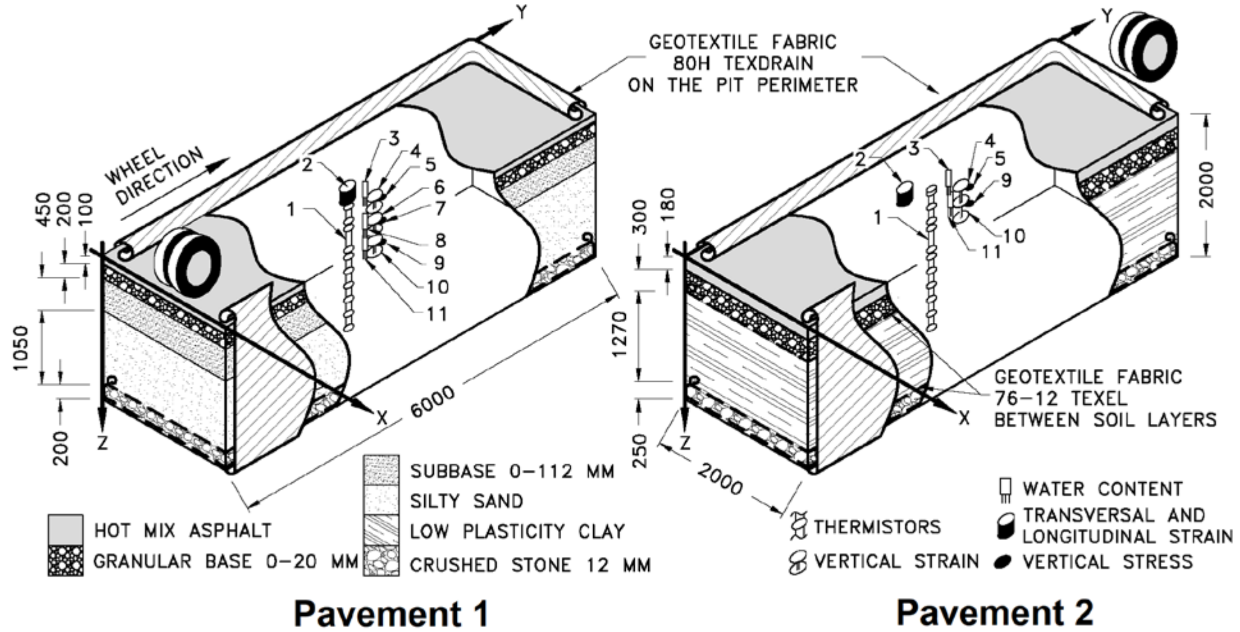

FIGURE 1. Tested flexible pavement structures

3. TEST CONDITIONS AND PROCEDURES

Laval University's heavy vehicle simulator was used to traffic the test pavement (Figure 2). The heavy vehicle simulator has the ability to replicate environmental and mechanical conditions experienced by real pavement structures. The simulator is portable and was positioned over the test pit once the test pavements were constructed. The test conditions for both test pavements are documented in Table 2 and only differ with respect to carriage speed. The results collected during freezing were presented in other papers [7,8,9]. The pavement response during thawing was measured for half-single axle load of 5000 kg, which is the legal load limit in Quebec for a half-single axle, as well as for a load reduction of 20% (4000 kg). Prior to thawing, the pavements were frozen using a test chamber temperature of -10 °C. Thawing was induced using a test chamber temperature of 10 °C. Throughout the complete freezing and thawing cycles, the bottom temperature was kept constant at 1 °C using a temperature controlled concrete slab. Figure 3 presents an example of strain measurements in the base layer of pavement 1 for each step throughout the complete response characterization cycle.

TABLE 1. Sensors type and position in the experimental pavement systems

			Pavement 1	**Pavement 2**
No°	Gage / Test	Layer	Position (x,y,z) (mm)	Position (x,y,z) (mm)
1	Thermistors	All	(1000, 3000, z)	(1000, 3000, z^1)
2	Tensile strain	AC	(1000, 3000, 100)	(820, 2750, 180)
3	Water content	B	(1000, 3100, 252)	(930, 3350, 342)
4	Vertical strain	B	(1000, 3250, 276)	(990, 3480, 245)
5	Vertical stress	B	(1000, 3370, 199)	(990, 3590, 317)
6	Vertical strain	SB	(1000, 3250, 600)	-
7	Vertical stress	SB	(1000, 3370, 525)	-
8	Water content	SB	(1000, 3100, 556)	-
9	Vertical stress	SG	(1000, 3370, 820)	(990, 3580, 532)
10	Vertical strain	SG	(1000, 3250, 900)	(990, 3480, 460)
11	Water content	SG	(1000, 3100, 837)	(980, 3350, 505)
	Surface deflection		-	(1000, 3000, 0)

[z] Depth of thermistors (mm): 50, 100 (in AC mat), 300, 500 (in granular base), 600, 900, 1000, 1200, 1400, 1600 (in subgrade), 1800, 2000 (in clean gravel).

TABLE 2. Test parameters

Parameter	**Value**
Carriage speed (km h^{-1})	5 and 9*
Half-axle loads (kg)	5000 and 4000
Tire dimensions	305/70R/22.5
Tire pressure (kPa)	710
Depth water table (m)	1.5

*5 and 9 km h^{-1} for pavement 1 and 2, respectively

In this paper, as response changes between standard conditions and thawing conditions are investigated, the results are expressed as relative values with respect to initial measurements obtained at a surface temperature of 10 °C. Therefore, values lower than 100 % indicate pavement response with a lower amplitude than initial measurements, while it is the opposite for values higher than 100 %. All results collected as the tested pavement conditions changed with time (t) and temperature in the pavement structure were normalized to the reference measurements at t=0 h (before freezing) and for a load of 5000 kg; they are expressed as relative values using

$$\mathrm{RV}(\%) = \frac{\text{Value at t}\left(\text{all loads}\right)}{\text{Value at t} = 0\left(5000\ \text{kg}\right)} \tag{1}$$

FIGURE 2. Laval University heavy vehicle and environmental conditions simulator

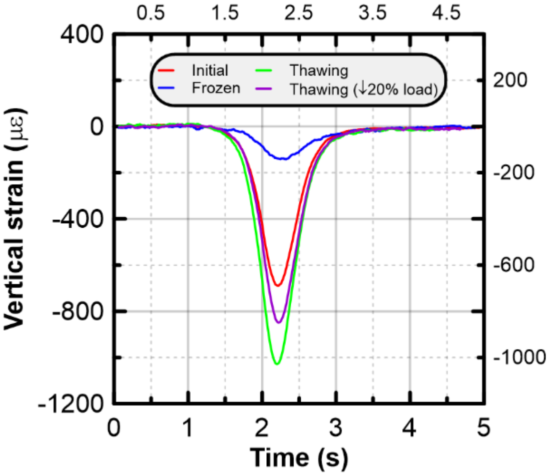

FIGURE 3. Example of vertical strain measured in a granular layer (pavement 1) showing the effect of freezing/thawing

4. RESULTS AND DISCUSSION

Figure 4 presents an example (pavement 1) of the typical strain results that were collected during thawing for a half-single load of 5000 kg. Strain peaks were extracted from the raw response signals and used to calculate RV(%). The AC temperature during thawing, the 0 °C isotherm depth, as well as the evolution of the relative strain (tensile strain for AC; vertical strain for B, SB and SG), are presented in Figure 4. Key information is summarized in the Figure. For example, Point A marks the time where AC temperature (mid-depth) reaches 0 °C, while Point B, Point C and Point D indicates the moment the thaw front reaches the top of the B, SB and SG, respectively. It should be noted that the vertical strain sensor signal for the SG was lost during freezing due to frost heaving occurring in the soil, causing over extension of the gage. Signal came back during the recovery period of the pavement, but it is assumed that the sensor was damaged as the vertical strains were significantly smaller than the reference initial measurements during thawing of the subgrade. The results show, however, a gradual recovery of the layer. It can be observed that response peaks occurred mostly at the same time, during thawing of the subgrade. The subbase shows the more pronounced RV (210%), followed by the base (150%) and asphalt concrete (120%). The pavement response started to increase once the thaw conditions were set and mostly once the AC temperature started to increase. The RV values start increasing once the AC temperature is about 0 °C. Signs of pavement weakening are documented with a thaw depth of 250-300 mm (measured in both pavement 1 and pavement 2), as most of the RV values get close to 100 % once the granular base has thawed and the thaw front reaches the top of the subbase (Point C). A moderate increase of pavement response is noticed during the thawing of the subbase, but more important changes are noticed once the subgrade starts to thaw (from point D). It can also be observed that the RV attained values in the range of 100 % again after the cycle, but the granular layers show RV values higher than initial reference measurements, which induced some weakening mechanisms in the layers due to the freezing and thawing cycle. It is expected that longer monitoring and repeated axial loads could have contributed to gradual recovery of the RV towards 100%.

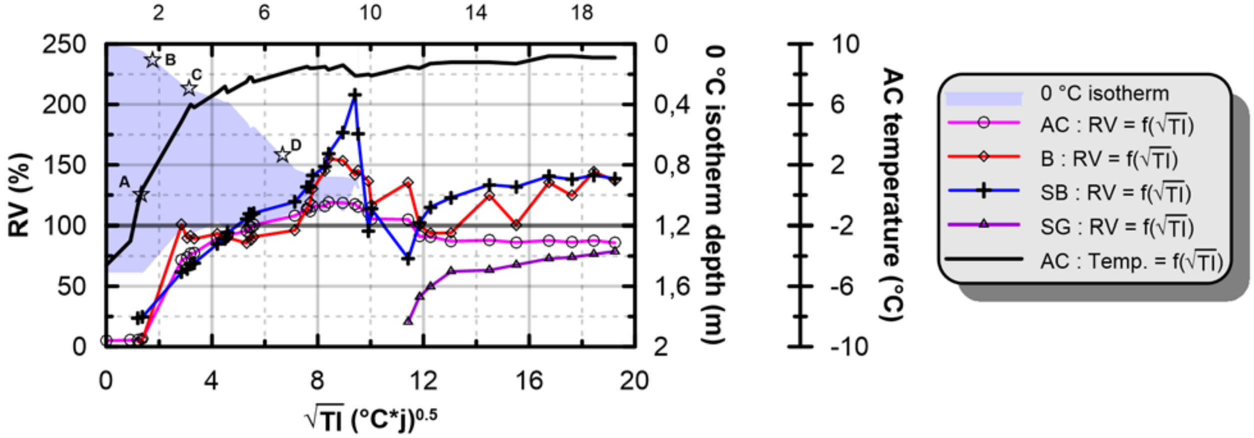

FIGURE 4. Example of relative values for strains collected during thawing for a half-single axle load of 5000 kg (pavement 1)

Table 3 summarizes the main peak relative values (stress, strain and deflection) measured for each experimental pavement, as well as the timing of this maximum value (during thawing or recovery). It can be observed that the thicker pavement, which also has the thinnest asphalt concrete layer, experienced higher relative values most of which were measured during thawing. The thinnest pavement, with the thicker asphalt concrete, experiences slightly lower relative values most of which are observed during the recovery of the clayey subgrade layer. The effect of a 20% load decrease (5000 to 4000 kg half-single axle load) is also documented in Table 3. The decrease documented as a percentage of the RV measured at 5000 kg, quantifies the general response amplitude decrease with lower half-single axle loads. The values presented are average values of the measurements taken during the complete thawing cycles. Although some variations are observed (11 to 28%), in thawing conditions, the 20% half-single axle load decrease induce a response variation in the range of 15%, with the subgrade and asphalt concrete layers being the more sensitive and less sensitive, respectively.

TABLE 3. Maximum relative peak and effect of 20% load reduction for each layer and experimental pavement

Layer	Parameter	Relative peak (%)*		Effect of 20% load reduction	
		P1	P2	P1	P2
Granular base	Vertical stress	100 (T)	170 (T)	↓16%	↓17%
	Vertical strain	150 (T)	134 (R)	↓10%	↓14%
Granular subbase	Vertical stress	195 (T)	-	↓18%	↓
	Vertical strain	210 (T)	-	↓15%	↓
Subgrade	Vertical stress	205 (T)	80 (T)	↓23%	↓28%
	Vertical strain**	75 (R)	-	↓14%	↓20%
Asphalt concrete	Tensile strain	125 (T)	85 (R)	↓11%	↓13%
Pavement	Surf. Deflection		148 (R)	-	↓21%

*T: Thawing; R: Recovery. **Sensor did not function during thawing

4. CONCLUSIONS

Two experimental projects were performed to study the effect of freezing and thawing on the flexible pavement response of two structures: one thick pavement built on silty sand subgrade and one thin pavement built on clayey subgrade. A heavy vehicle simulator was used to induce freezing and thawing conditions, as well as to periodically load the pavement to document response parameters as a function of frost and thaw penetration. This paper summarizes the main observations collected during the thawing cycles, which are consistent with findings identified in the literature. More specifically, signs of weakening first appear as soon as the thaw front reaches the granular layer beneath the asphalt concrete, at a depth of about 250-300 mm, and peak response values of about 200% of the initial reference measurements are observed either during the thawing of the structure or once thawing is almost complete in the subgrade soil. The thicker pavement structure experienced most of its response peaks while the pavement was still thawing, while the thinner pavement shows response peaks during recovery as well. The 20% load reduction as the pavements thaw induced a general decrease of stresses, strains and deflections in the flexible pavement systems by about 15%, but the subgrade and asphalt concrete layers were found to be less influenced by axle load variations, which may lead to more pronounced damage during spring thaw.

5. REFERENCES

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