



# Assessment of frost heave for mechanistic-empirical design

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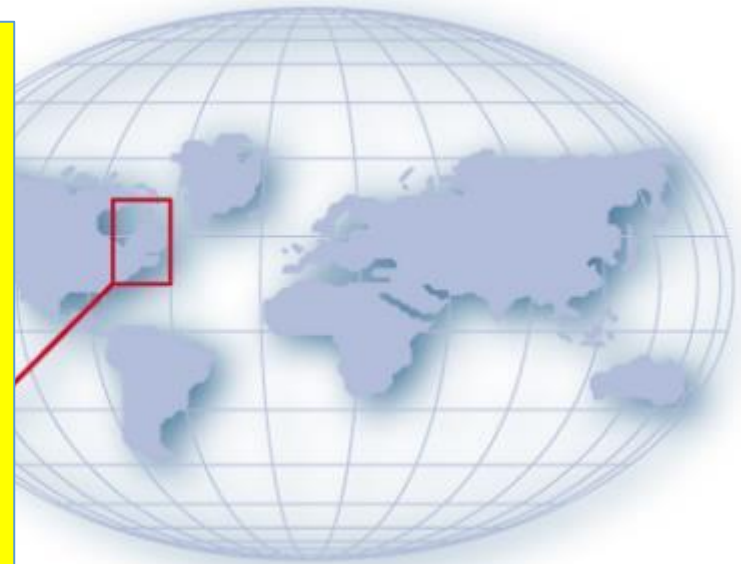
**Université Laval**

# Context



## Québec city:

- 4 months of winter ( $-10^{\circ}\text{C}$  on average)
- Coldest temperature  $\approx -35^{\circ}\text{C}$
- Freezing index  $\approx 1200^{\circ}\text{C}\cdot\text{d}$
- Frost penetration under pavement surface  $\approx 2\text{ m}$
- Frost heave typically between 50 and 150 mm
- Snow fall between 3 and 4 m
- Total precipitation  $\approx 1000\text{ mm}$



## Challenges

Large road network and low population density

Vital communication links

Low levels of funding

Severe climatic conditions

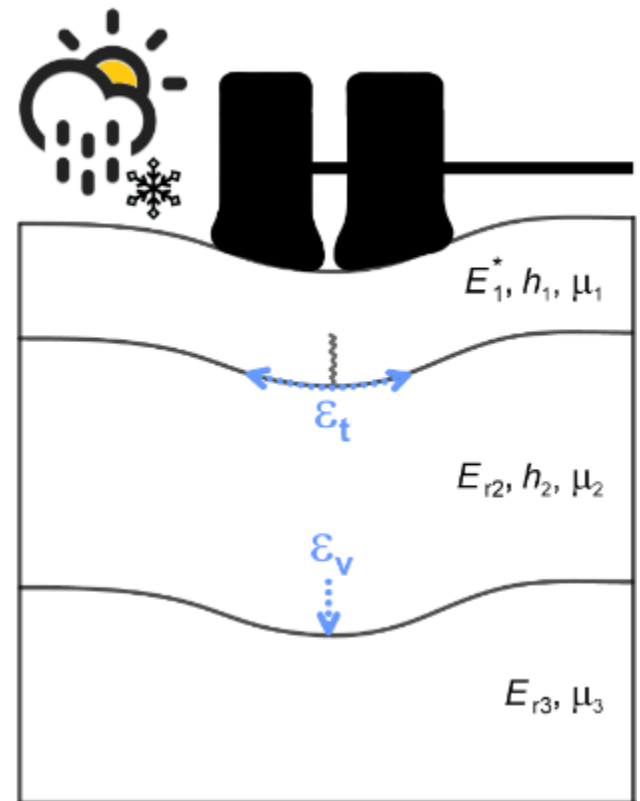
Moisture, Frost action

# Frost action on pavements



# Design practice in Quebec

- Pavement structural design done using AASHTO method
  - HMA designed considering regional temperature averages
  - Pavement granular materials assumed to be stable
  - Seasonal variation of subgrade soil properties dealt with using “effective modulus”
- Frost heave design based on an allowable frost heave criterion and empirical frost protection
- Moving towards M-E design



# Frost design

- Minimum pavement thickness based on freezing index, soil type and functional class
- Frost penetration and heave (SSR model):
  - Segregation potential (SP) + Climate/Site conditions
- Calculated frost heave vs allowable frost heave criteria
- Design : adjustment of total thickness, insulation replacement



# Frost penetration calculation

## Heat balance

- SSR Finnish model
- Heat balance at frost front for each time interval (dt)

$$q_- = q_+ + q_f + q_s$$

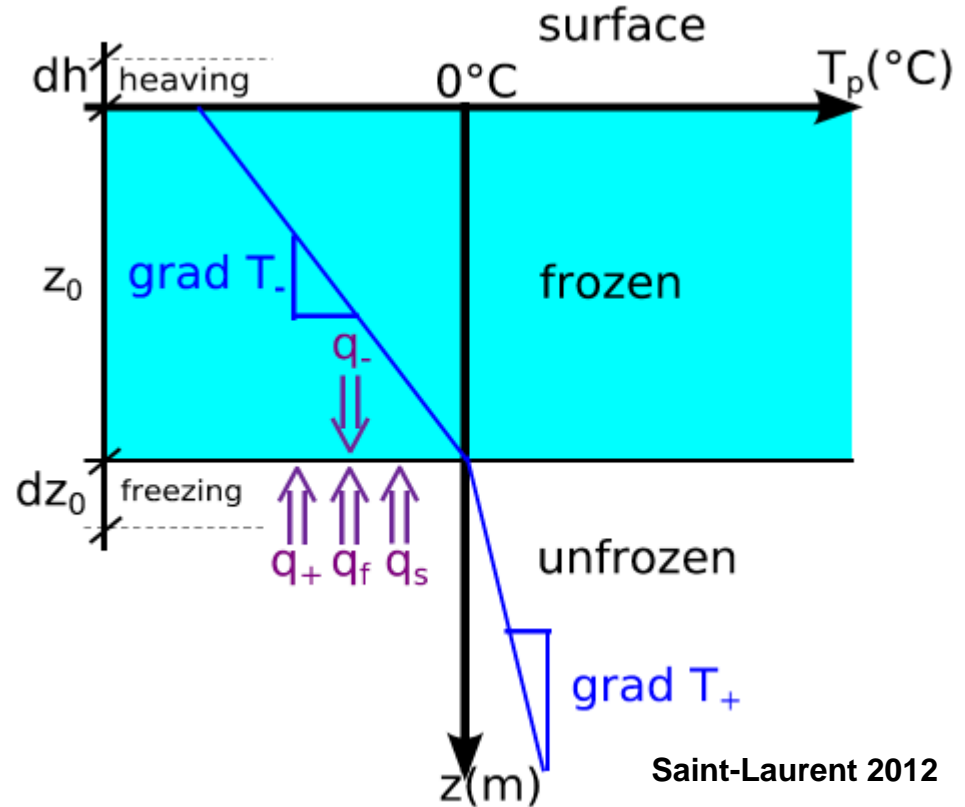
$$q_- = k_f \text{Grad}T_-$$

$$q_+ = k_u \text{Grad}T_+$$

$$q_f = L \frac{dz_0}{dt}$$

$$q_s = L_w SP \times \text{Grad}T_-$$

$$dh = 1,09 \times SP \times \text{Grad}T \times dt$$



- Frost heave calculation for each time interval frost penetration increment using segregation potential theory

# Frost susceptibility (SP) Segregation Potential

Frost susceptibility	SP mm <sup>2</sup> /°C·hour
Negligeable	< 0,5
Low	0,5 à 1,5
Moderate	1,5 à 3
High	3 à 8
Very high	> 8

$$dh = 1,09 \times SP \times GradT \times dt$$





# Frost design

Chaussée - [Projet1]

Fichier Edition Affichage Modules Outils Fenêtre ?

Projet1 - Gel et soulèvement

Élévation (m)

Température (°C)

Jour

Paramètres de route

Station météorologique: Québec a

Zone: Sud, T<sub>sup</sub>: 20,5, T<sub>ms</sub>: 4,0, IG<sub>n</sub>: 1236, σ<sub>IG</sub>: 161

Simulation: Climat, PR: 15, IG: 1477

ÉCAS (millions): 5,0

Transporté à l'an prochain: 0 mm

STRUCTURAL | **GEL** | GEL (1994)

d (m)	Eau (%)	SP <sub>0</sub> (mm <sup>2</sup> /KH)	a (MPa <sup>-1</sup> )	K <sub>u</sub> (W/mK)	K <sub>f</sub>	S <sub>r</sub> (%)	L <sub>f</sub> (Wh/m <sup>2</sup> )	Coût (\$/m <sup>2</sup> )
0,0	0,0	0,0		1,48	1,48	0	1250	23,97
4,0	4,0	0,0		1,77	1,89	52	7897	4,28
8,0	8,0	0,0		2,10	2,49	56	14018	4,50
1,3	40,0	3,0	7,0	1,26	2,20	99	39500	Total
								32,75

CL avec I<sub>p</sub> > 12 (I<sub>L</sub> < 0,9) Total = 895

Réinitialiser les matériaux

Graphie Z (m) 1,748 h (m) 0,089

CHAUSSEE

# Frost design

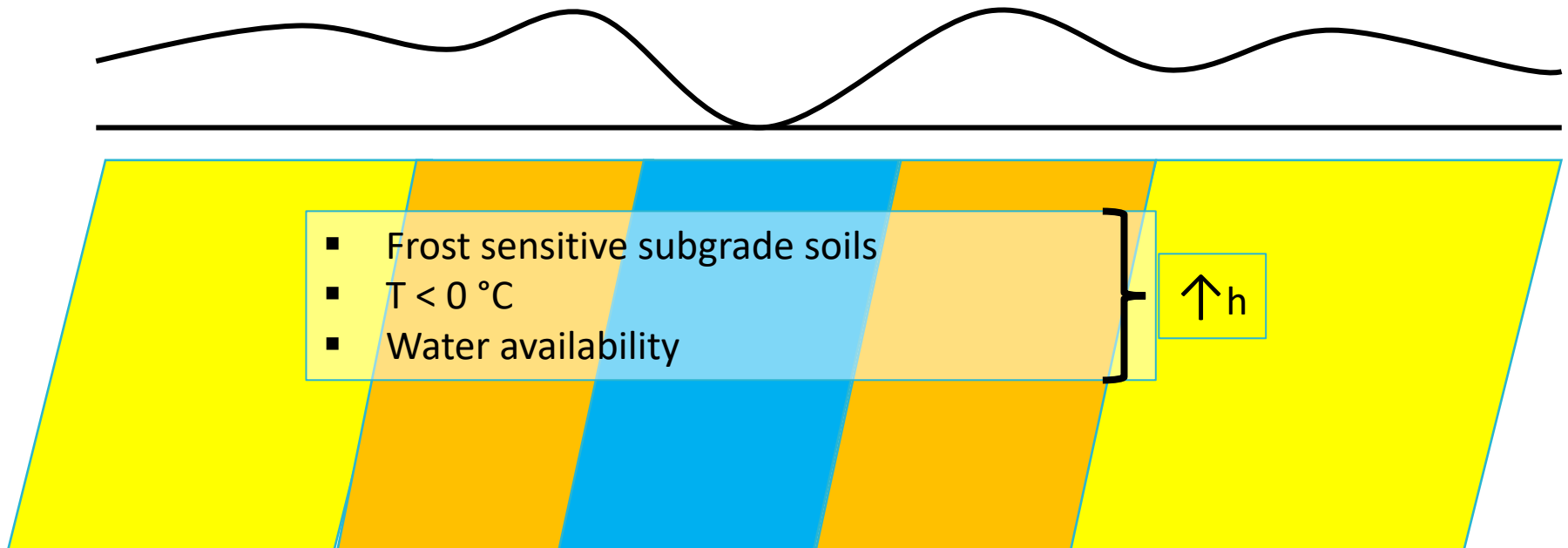
Determination of frost depth and associated heave

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The screenshot displays the i3cme software interface for frost design. The main window features the i3cme logo and a background image of a snowy road. The interface is organized into several sections:

- Menu Bar:** Tools, Help
- Navigation Buttons:** Eight blue buttons with icons and labels: GENERAL INFORMATION, DESIGN OBJECTIVES, DEFINITION OF THE LOAD, CLIMATE DATA, PAVEMENT STRUCTURE, PERFORMANCE MODELS, FROST ANALYSIS, and START CALCULATIONS.
- Left Sidebar:**
  - Pavement structure:** A list of materials: 1 Asphalt mixture, 2 Asphalt mixture, 3 MG 20, 4 MG 112, 5 SM fin.
  - Basic climatic data:** Fields for Average annual air temper, Air transfer coefficient, Method 1: Sinus Simulation, Normal airfreezing index, Determination of the free, Standard deviation (F), Rigorous surface freeze, Amplitude of the sinus, and Duration of the freeze p.
- Right Panel:** A vertical axis labeled 'Elevation (m)' ranging from 0.75 to -3.0. Above it, a table of calculated input parameters is visible, showing values for  $R_f$  (W/mK) and checkboxes.

# Frost action and its relationship with roughness



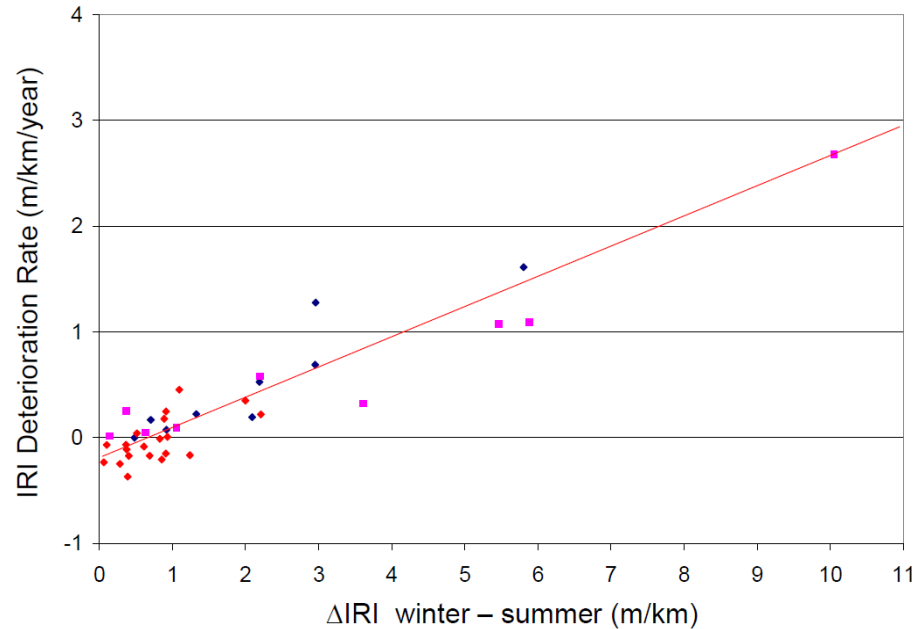
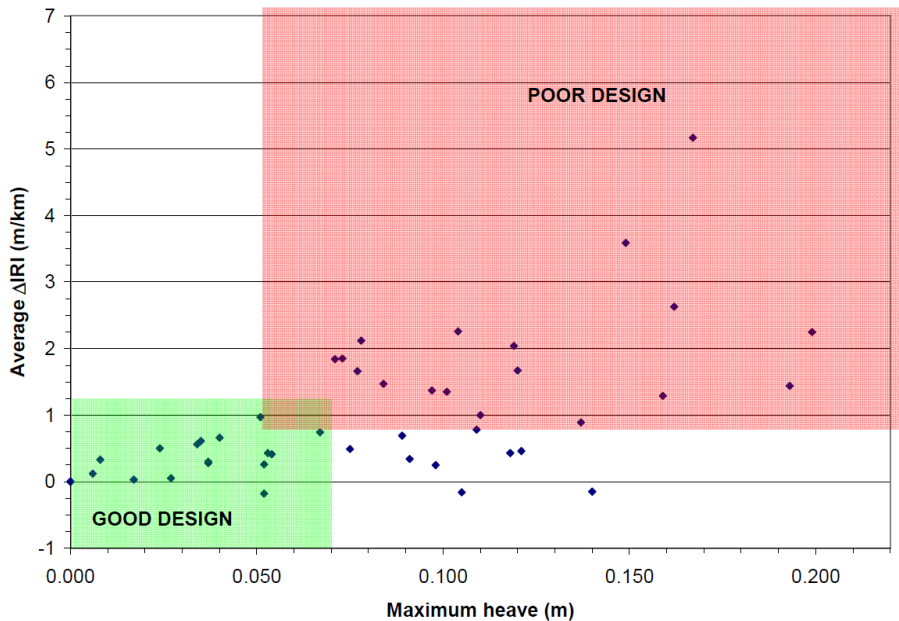
## Roughness deterioration

- Surface cracking
  - Transversal and longitudinal
- Surface distorsion
  - Longitudinal and transversal differential heaving

# Frost action and its relationship with roughness

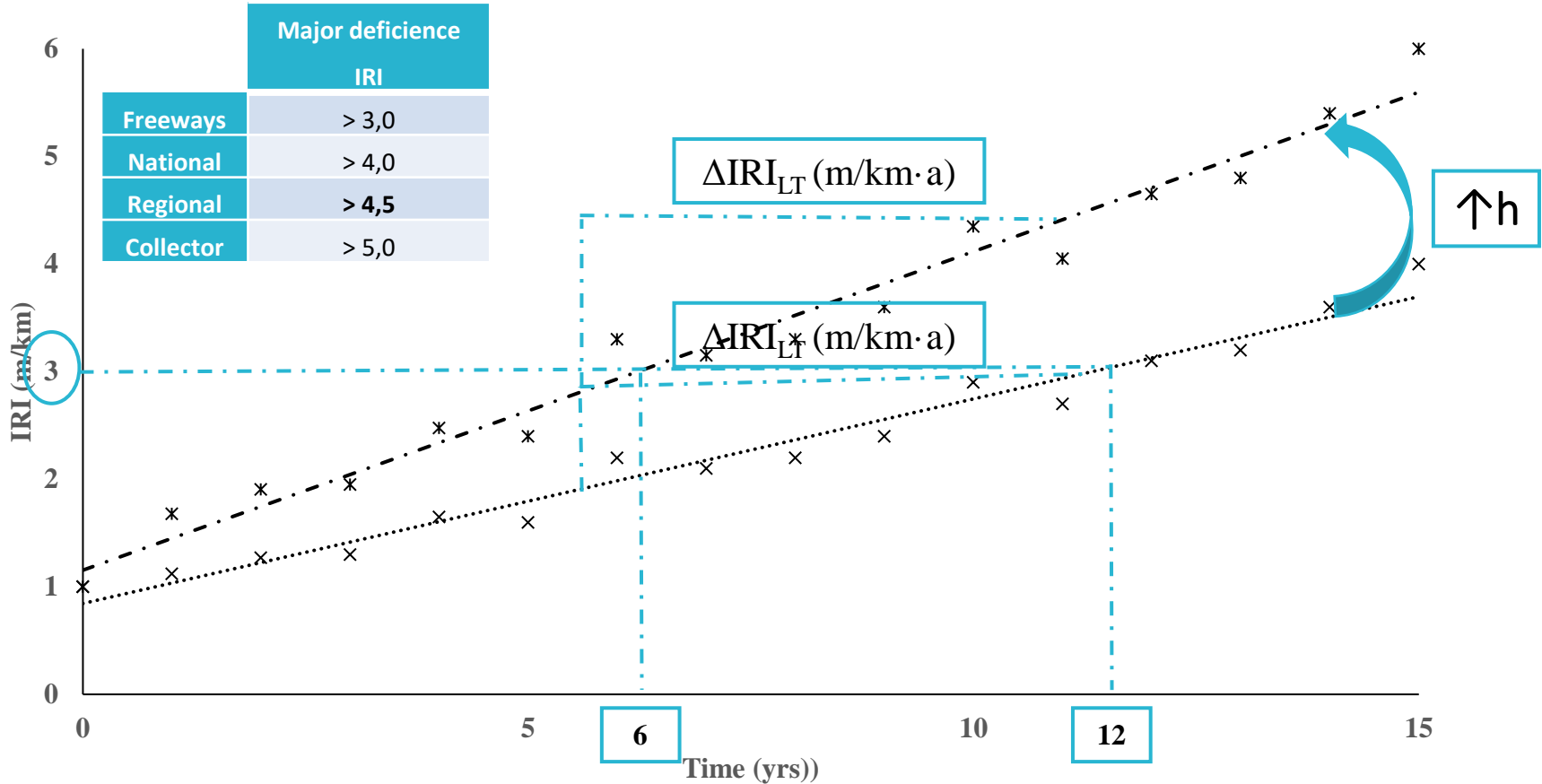
- Criteria based on experience and some relationships between roughness development and frost heave

<b>Freeways</b>	<b>&lt; 50 mm</b>
<b>National</b>	<b>&lt; 55 mm</b>
<b>Regional</b>	<b>&lt; 60 mm</b>
<b>Local</b>	<b>&lt; 70 mm</b>

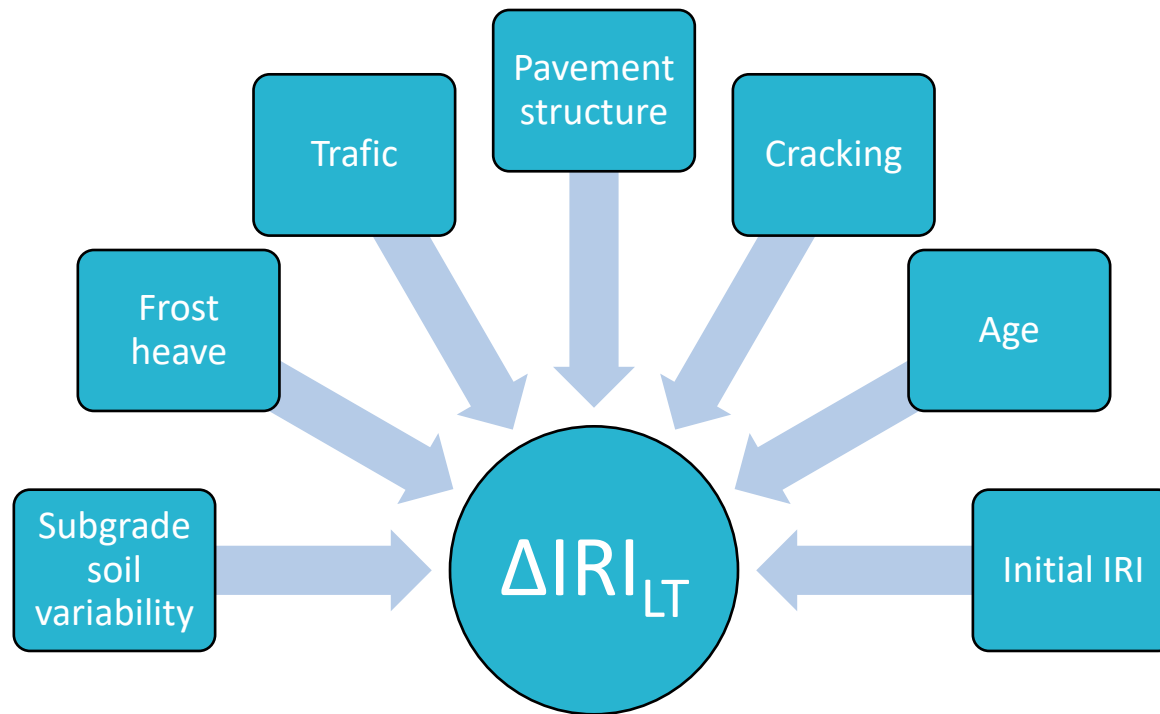


**Saint-Laurent 2012**

# Performance model related to frost action



# Performance model related to frost action



# Performance model related to frost action

- Empirical model (Sylvestre et al., 2017)
- Development with 44 monitored test sections and validated with 22 test sections

Selection of damage law parameters

Modify the database

Select a damage model from the database:

Permanent deformation | Fatigue model | **IRI**

International Regularity Index

$$\Delta IRI_{LT} = 0.6 \left[ 0.001 \times IRI_0^2 + 0.399 \times h^{0.164} \times CV_G^{0.055} + 0.07 \times \log \left( \frac{age^3}{\sqrt{H_{BB}}} \right) + 1.813 \cdot 10^{-8} \left( \frac{ECAS_A^2}{ECAS_{AD}} \right) - 0.648 \right]$$

h:  H<sub>BB</sub>:  ECAS<sub>A</sub>:  Road class:

% with maximum IRI:  IRI<sub>0</sub>:  CV<sub>G</sub>:

Variability:

**VALIDATE THE MODULE**

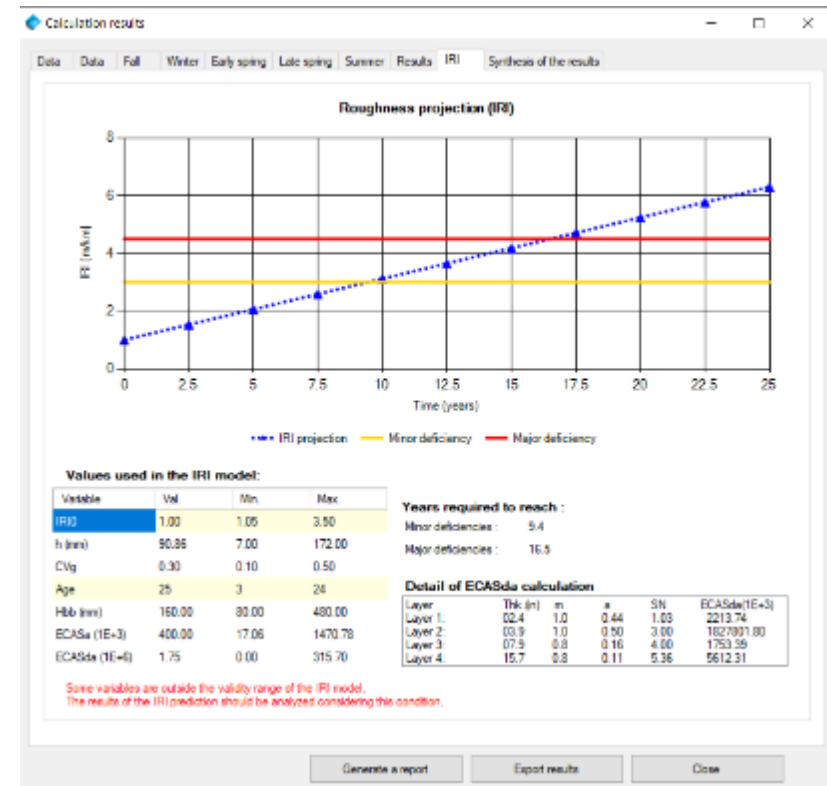
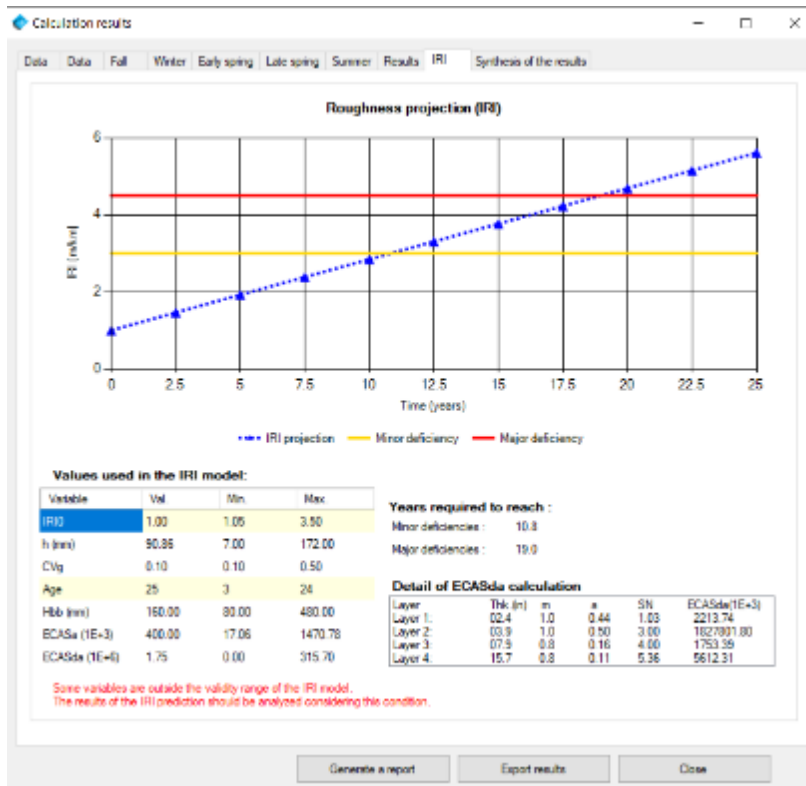
# Example of decreasing frost heave (and increasing bearing capacity)



Increasing pavement thickness



# Example of increasing subgrade soil variability



Increasing subgrade soil variability

# Conclusion

- Frost action is a major factor of pavement damage in Quebec
- Frost heave criteria used for frost design of pavements in Quebec
  - Empirical and ME model
- $\Delta$ IRI used to assess frost action on existing pavement
- IRI deterioration rate includes frost heave to assess pavement life

Merci!  
Thank you!  
Tusen takk!

