FROST HEAVE MODEL IN A PAVEMENT DESIGN PROGRAM - ERAPAVE PP

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Foto Raphael Biscaldi, Unsplash

OUTLINE

- Background
- ERAPave PP Damage models
- Component models
  - Mechanical response and Temperature models
- Frost heave model
- Validation frost heave model
- Ongoing works

BACKGROUND

- Pavement design in Sweden is carried out using PMS Objekt:
    - permanent deformation is assumed to originate only from the subgrade
    - a simplified characterization of materials and traffic is employed
- ERAPave PP is being developed with the objectives:
    - improve the permanent deformation prediction for each pavement layer including the subgrade
    - a better characterization of materials as well as traffic

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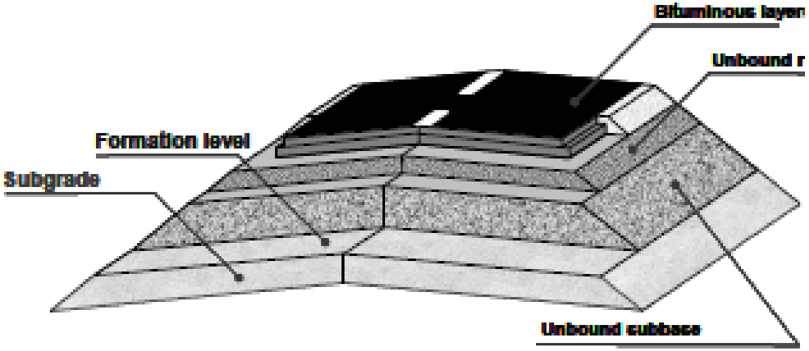
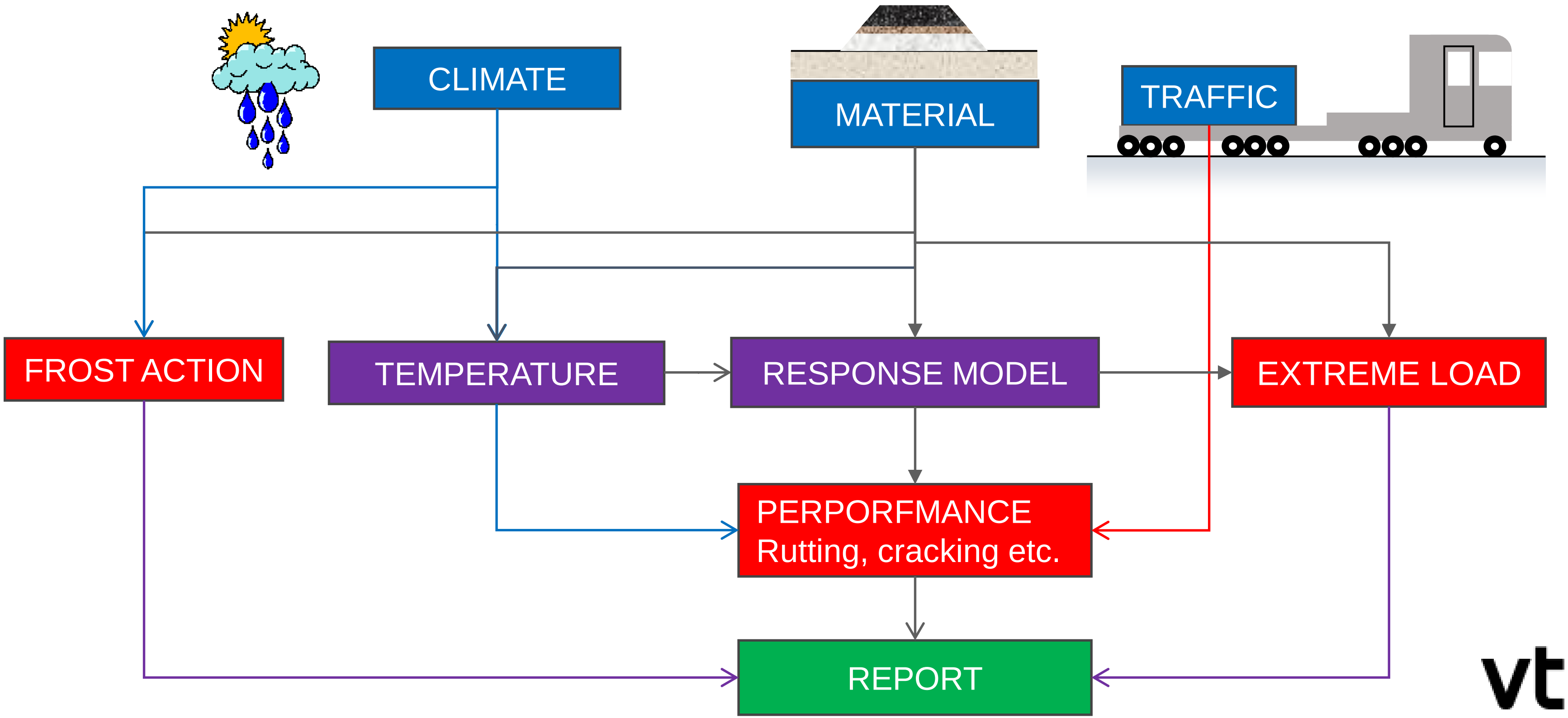
DAMAGE MODELS IN ERAPAVE PP

- ERAPave PP establishes layer types and thicknesses:
  - to limit damage (to acceptable levels), for anticipated loading and environmental conditions using available/selected materials
  - damage including in ERAPave PP are:
    - rutting (deformation)
    - wear due to studded tire
    - fatigue cracking
    - damage due to extreme loading
    - frost damage



ERAPAVE PP COMPONENTS



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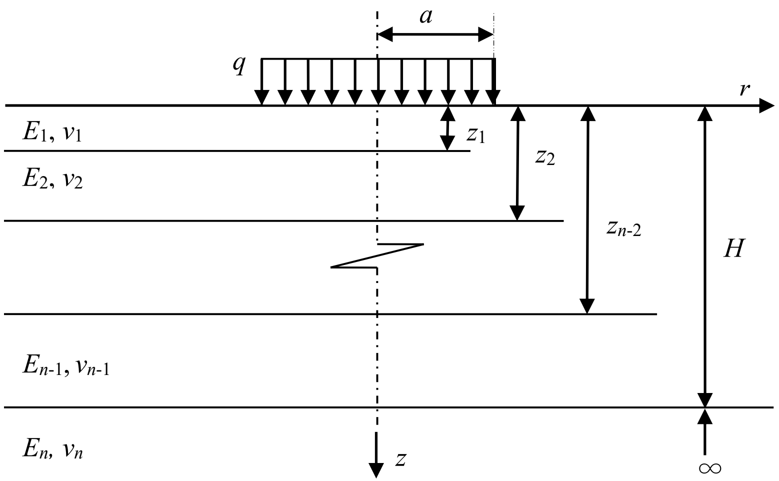
MECHANICAL MODEL - RESPONSE

- Layered elastic theory is used to estimate stresses ands strains
- Modulus and poisons ratio of each layer are the input parameters
- A circular contact area is assumed for the analysis
- No direct link with frost heave model

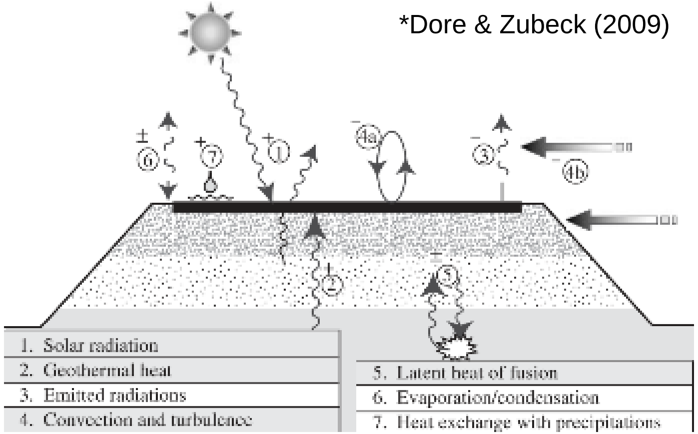


TEMPERATURE MODEL

- Main heat transfer modes considered:
  - Conduction/convection
  - Radiation

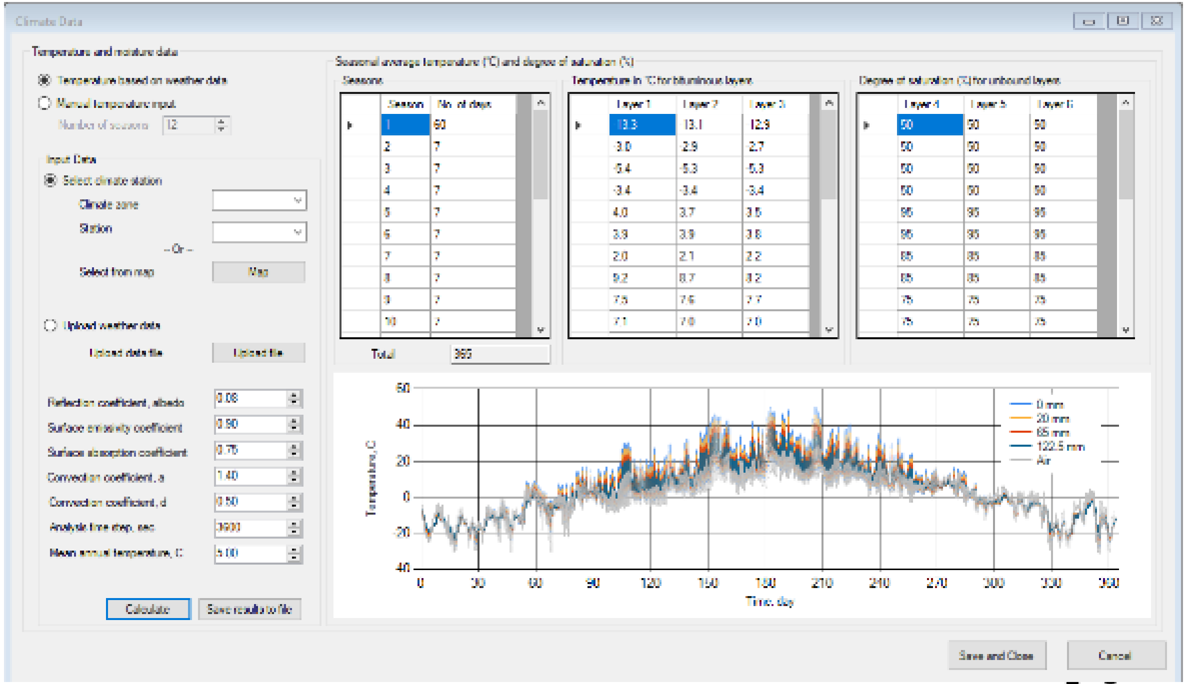
$$\frac{\partial^2 T}{\partial z^2} = \frac{\rho c}{k} \frac{\partial T}{\partial t}$$

- A numerical approach based on finite control volume (FCVM) is employed.



*Dore & Zubeck (2009)

TEMPERATURE MODEL CONT.



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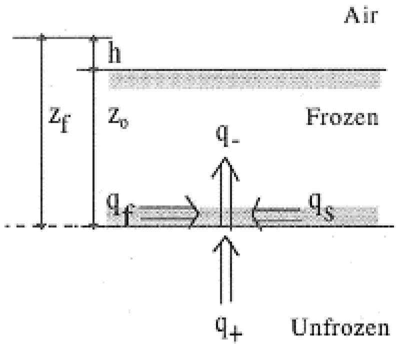
SSR FROST HEAVE MODEL IN ERAPAVE

- Thermal balance at the freezing front.

$$\underbrace{k_f \nabla T_- = L\frac{\Delta z_0}{\Delta t}}_{\text{Stefan (1889)}} + \underbrace{k_t \nabla T_+}_{\text{Skaven Haug (1971)}} + \underbrace{L_w SP\, \nabla T_-}_{\text{Konrad \& Morgenstern (1981)}}$$



- Thermal properties - frozen and unfrozen
- Volumetric property
- Latent heat
- Segregation Potential, SP
- % fine content

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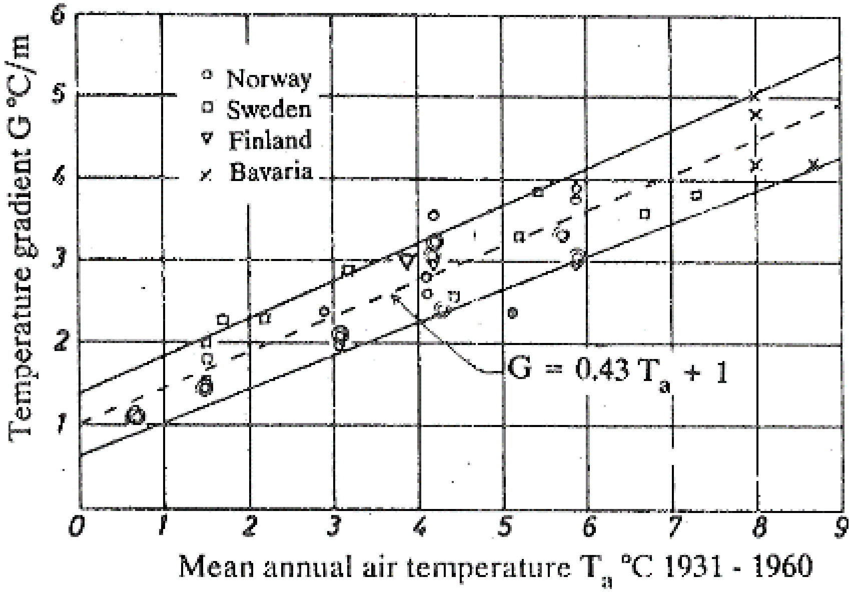
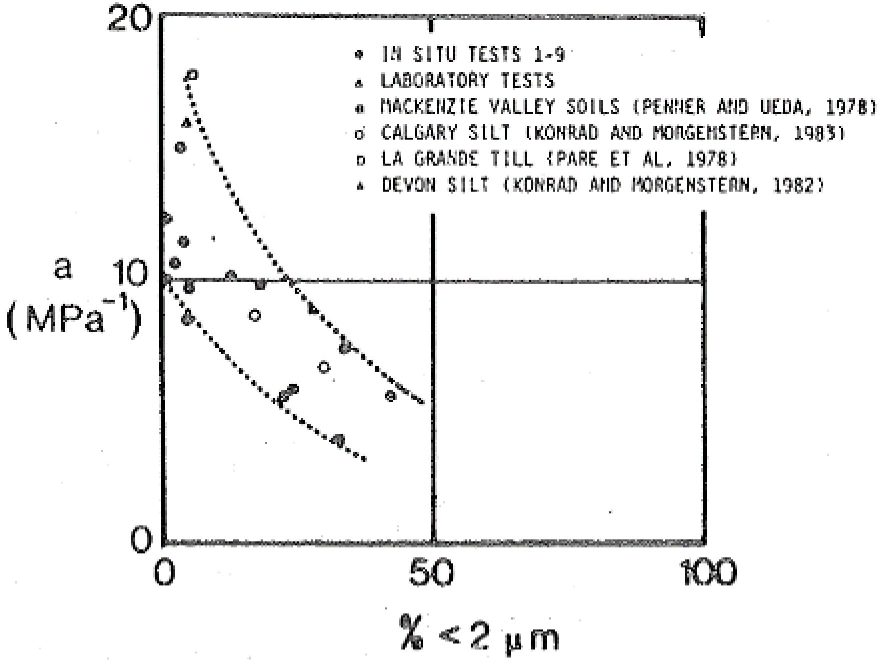
GROUND TEMPERATURE GRADIANT

$$k_f \nabla T_- = L\frac{\Delta z_0}{\Delta t} + k_t \nabla T_+ + L_w SP\, \nabla T_-$$

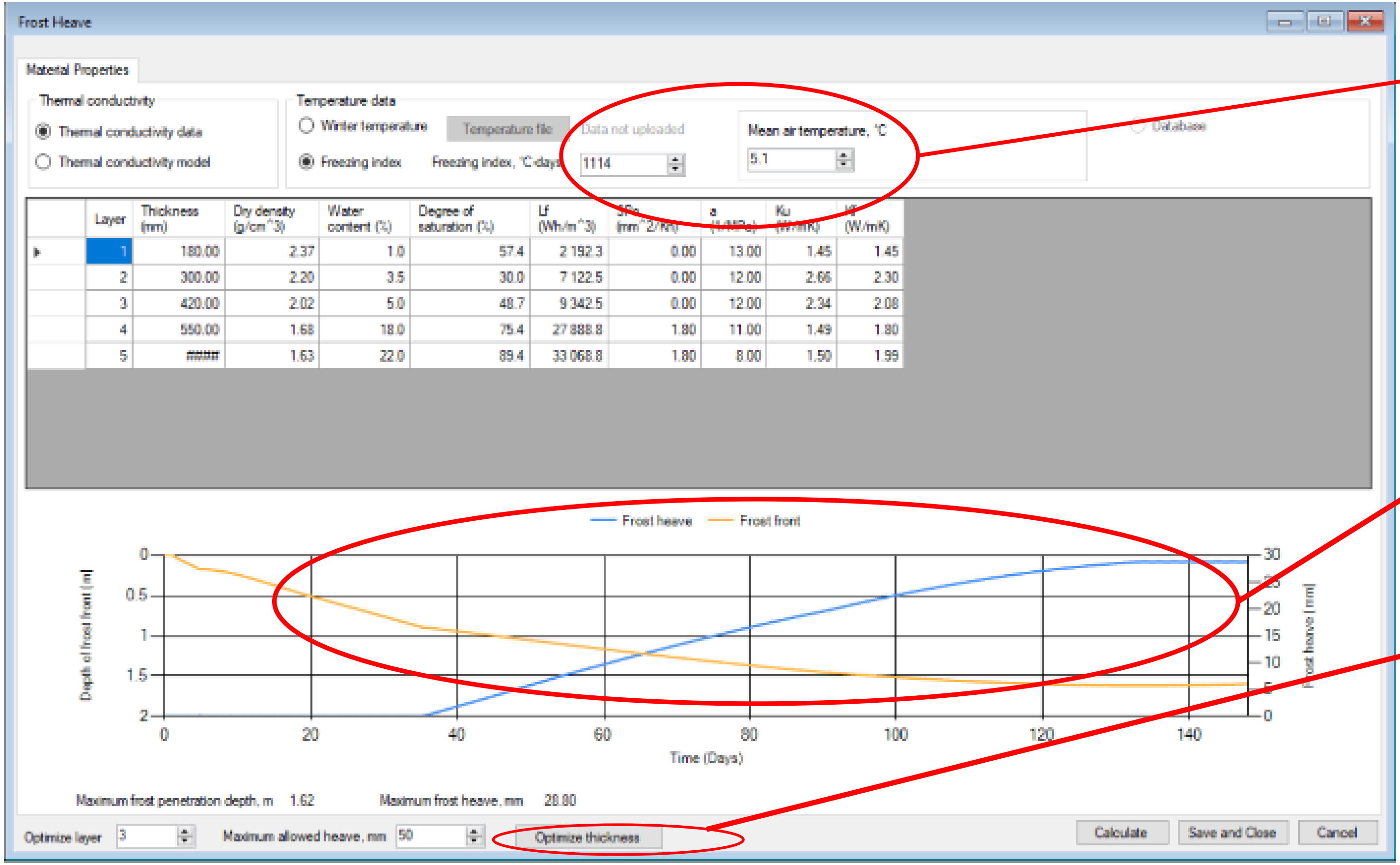


Skaven Haug (1971)



Knutsson et al. (1985)

FROST HEAVE INTERFACE



Layer	Thickness (mm)	Dry density (g/cm^3)	Water content (%)	Degree of saturation (%)	Lf (Wh/m^3)	SPo (mm^2/Kh)	a (1/MPa)	Ku (W/mK)	Kf (W/mK)
1	180.00	2.37	1.0	57.4	2 192.3	0.00	13.00	1.45	1.45
2	300.00	2.20	3.5	30.0	7 122.5	0.00	12.00	2.66	2.30
3	420.00	2.02	5.0	48.7	9 342.5	0.00	12.00	2.34	2.08
4	550.00	1.68	18.0	75.4	27 888.8	1.80	11.00	1.49	1.80
5	#####	1.63	22.0	89.4	33 068.8	1.80	8.00	1.50	1.99

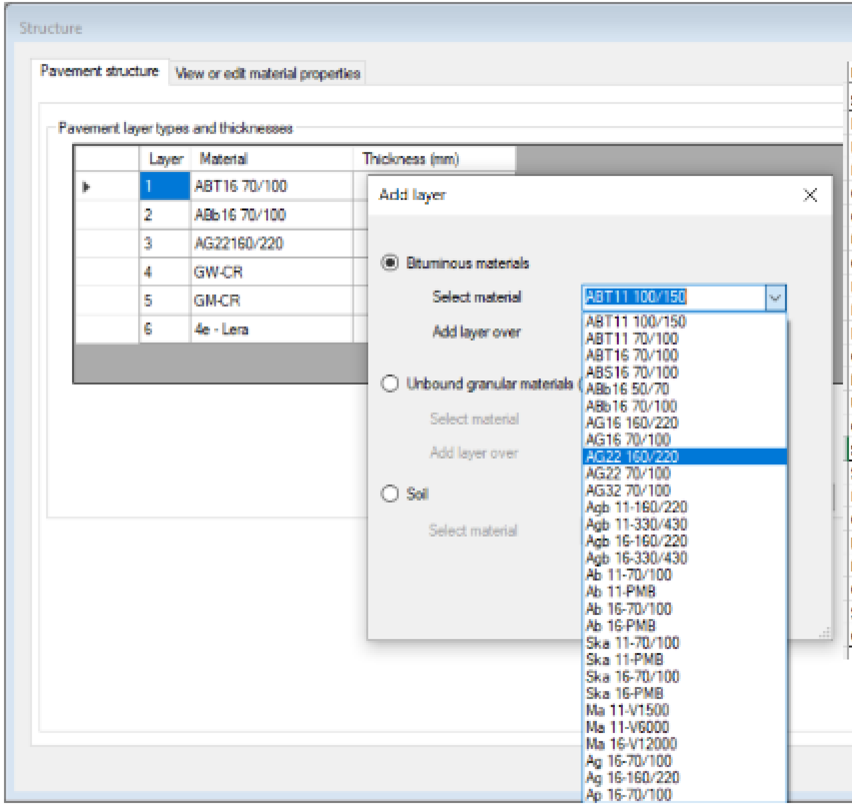
Temperature input

Results: frost heave and freezing depth

Option for thickness optimization

MATERIAL DATABASE

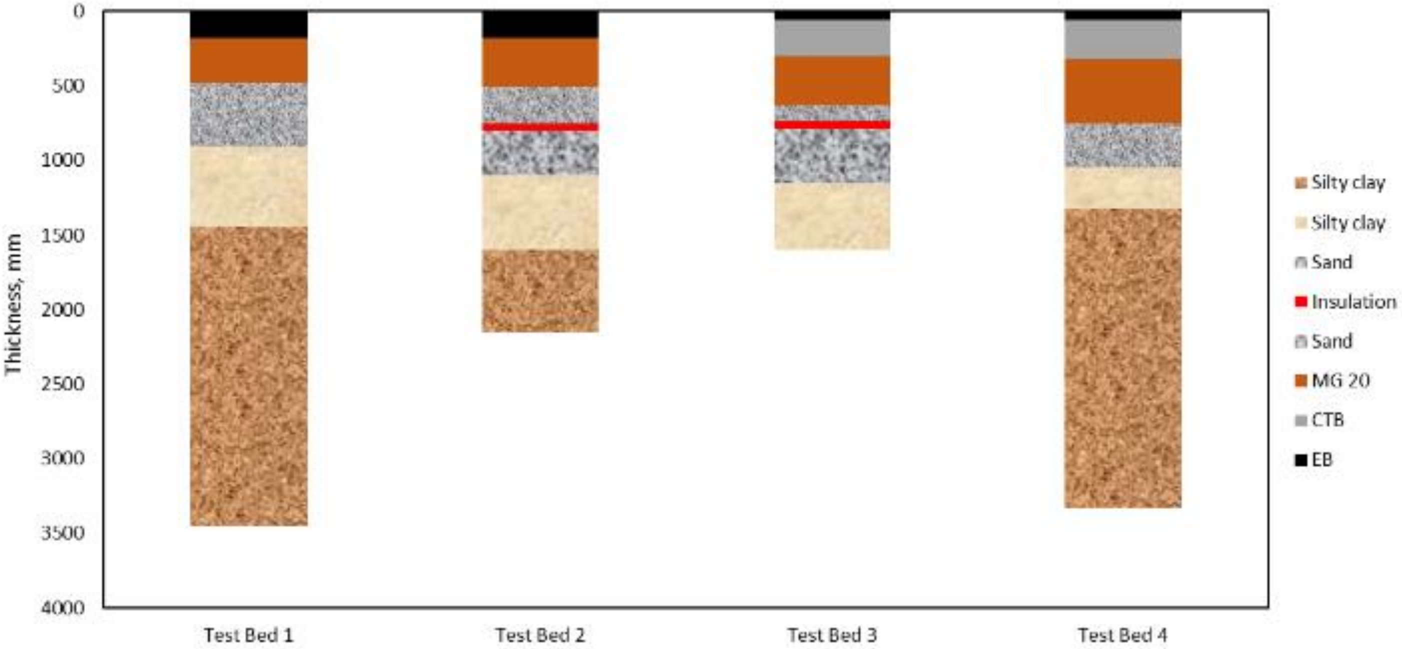
- VTI and NTNU - collecting data for various pavement materials



Material*	dry density (pd)	grain density (ps)	porosity (n)
Superstructure material	kg/m3	kg/m3	(%)
Bitumen-bound bearing and wear layers as well as tie layers	2200	2650	0.17
Bitumen-soaked macadam, upper bitumen-rich	2100	2650	0.21
Bitumen-soaked macadam, lower bitumen-poor	2100	2650	0.21
Cement concrete	2400	2650	0.09
Cement-bound base layer	2400	2650	0.09
Unbound base layer	2000	2650	0.25
Older bearings	2000	2650	0.25
Reinforcement layer paved road (crushed and unbroken)	2000	2650	0.25
Reinforcement layer gravel road	1800	2650	0.32
Reinforcement layer unbound rock crusher	2000	2650	0.25
Older reinforcement layers	2000	2650	0.25
Protective storage	1900	2650	0.28
Unbound base course gravel road	1800	2650	0.32
Gravel wear warehouse	1700	2650	0.36
Subsoil and subsoil materials			
Solid rock	2630	2650	0.01
Blasted stone and crushed blasted stone	1600	2650	0.40
Coarse-grained soil	1800	2650	0.32
Mixed-grained soil with a fine soil content of less than 30%	1900	2650	0.28
Mixed-grained soil with a fine soil content greater than 30%	1700	2650	0.36
Clay	1600	2650	0.40
Silt	1700	2700	0.37
Older coarse fraction	1900	2700	0.30

VALIDATION OF THE FROST HEAVE MODEL

- 4 test pavement sections constructed in Quebec in 1998 are analyzed



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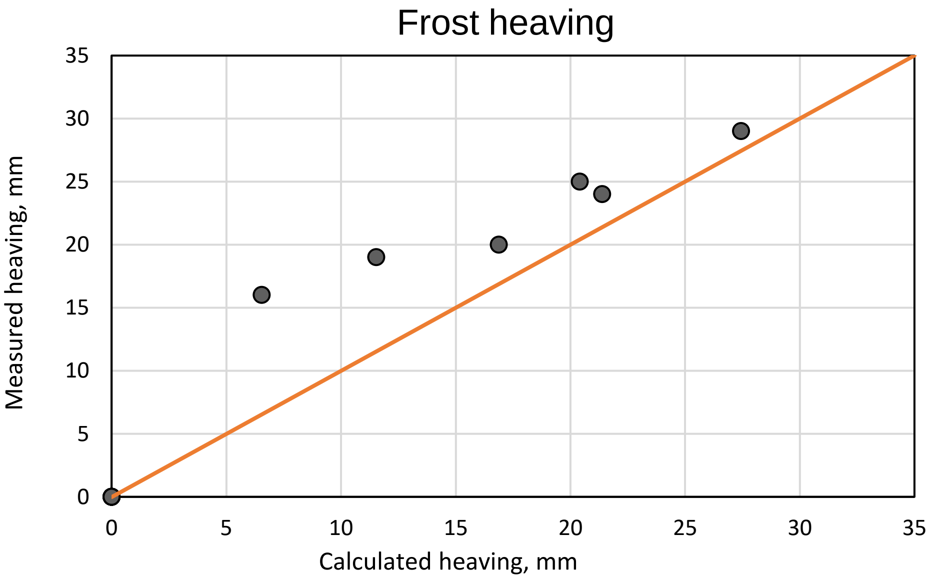
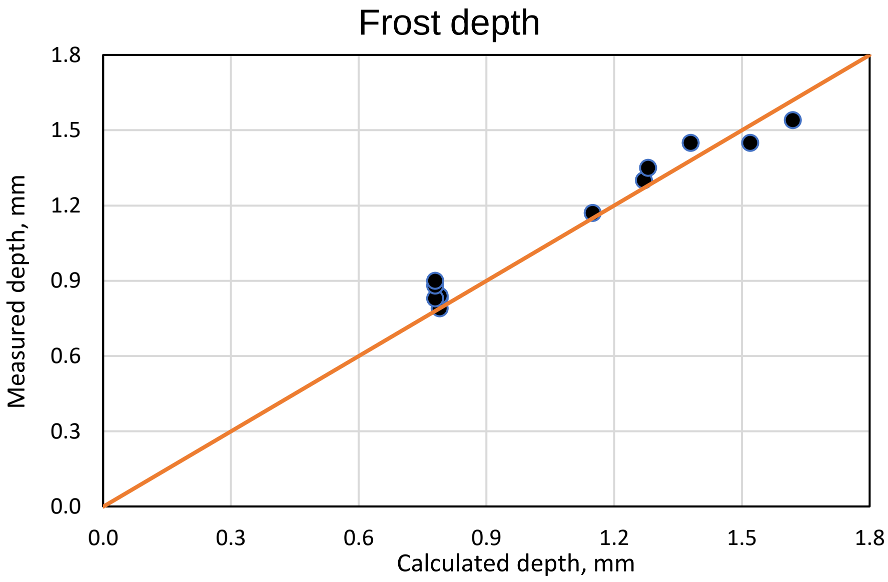
VALIDATION RESULTS





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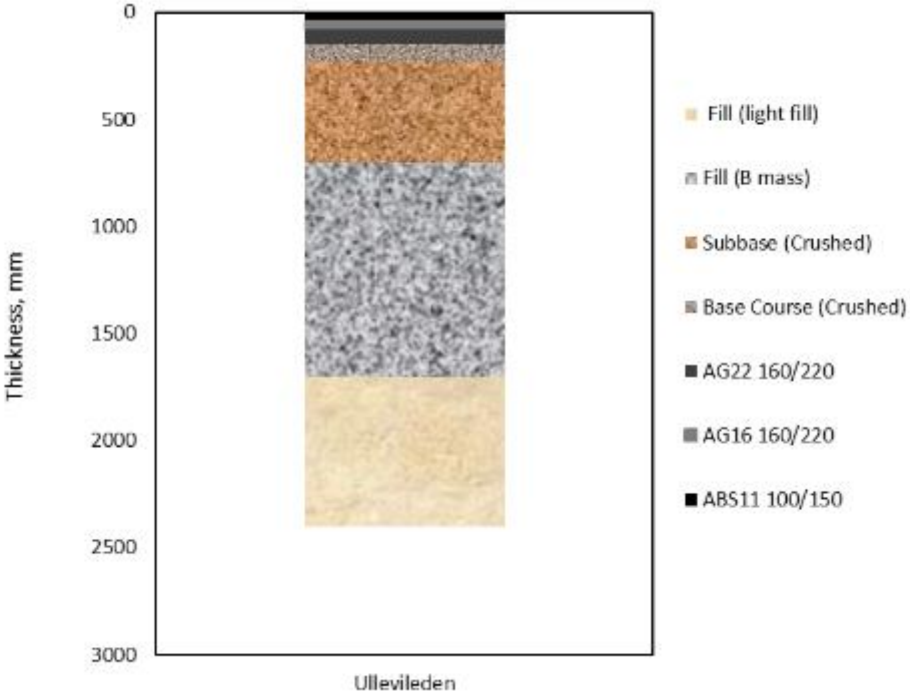
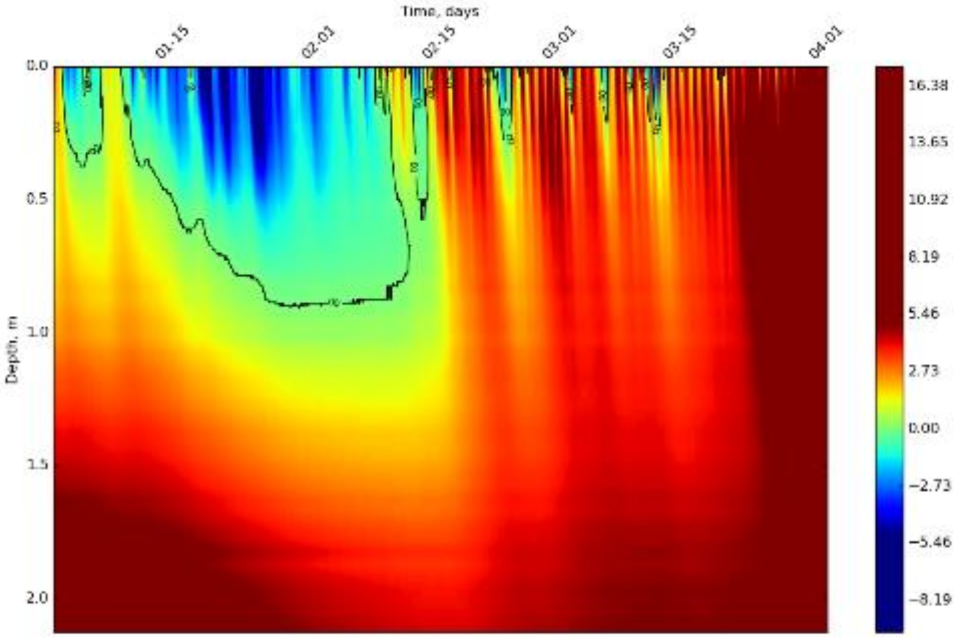
ULLEVILEDEN - LINKÖPING





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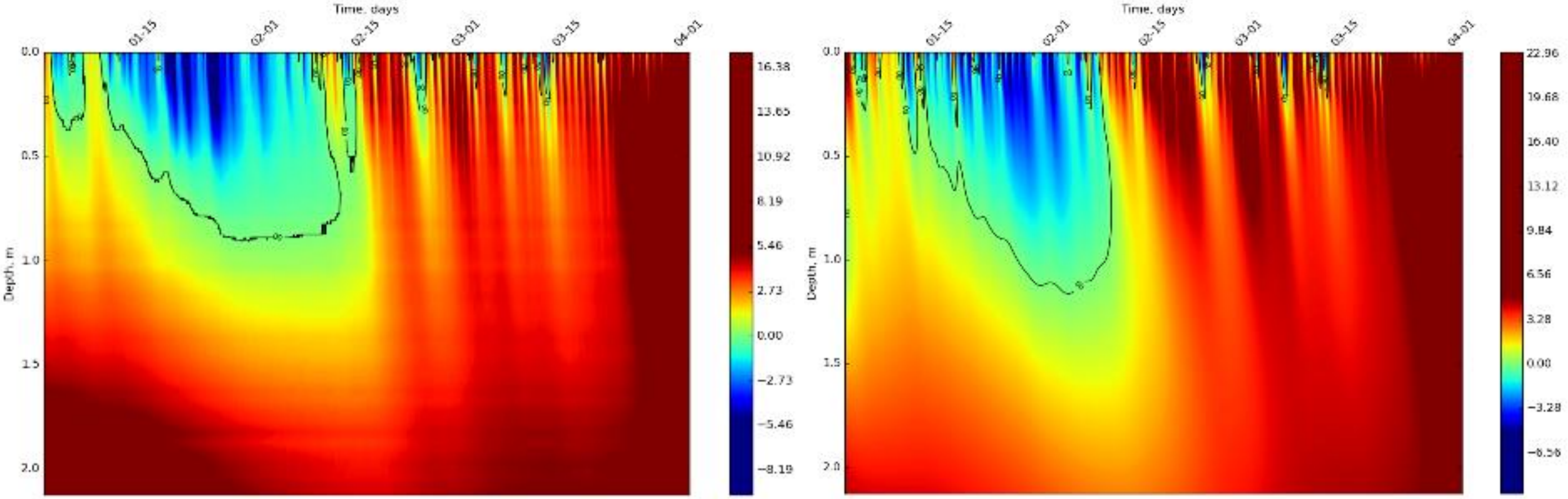

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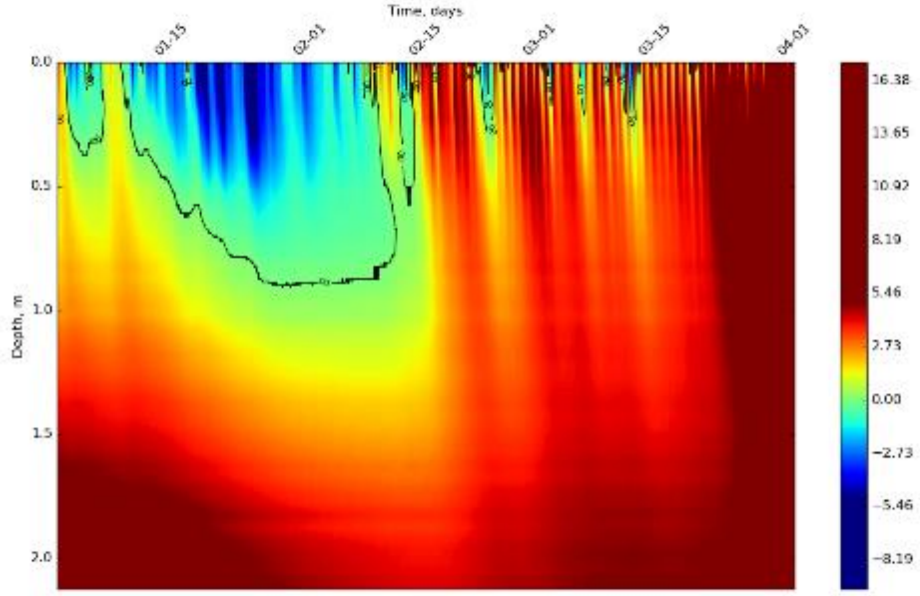
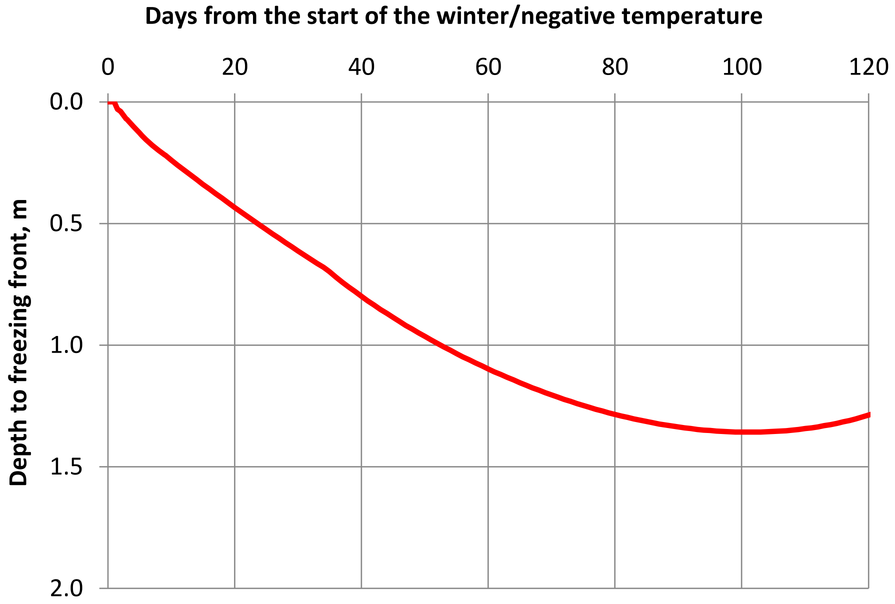
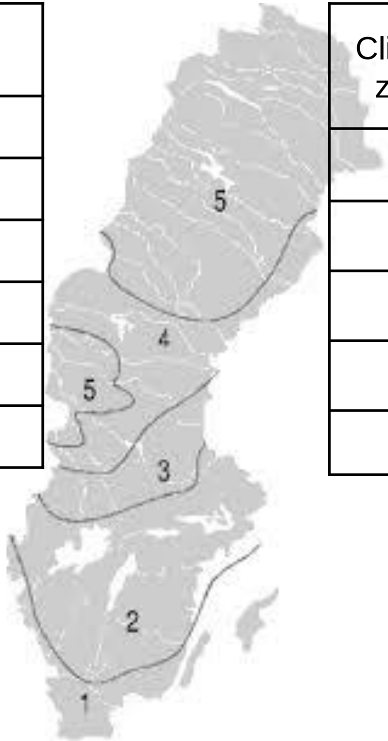




DESIGN CRITERIA – FROST HEAVE

Reference speed (km/h)	Climate zone	Permitted maximum heave (mm)
120	1 - 5	10
110	1 - 2	20
110	3 - 5	50
100	1 - 5	50
80	1 - 5	80
≤ 60	1 - 5	120



Climate zone	Commutative Freezing Index [°C·days]
1	0–300
2	301–600
3	601–900
4	901–1200
5	1201 and above

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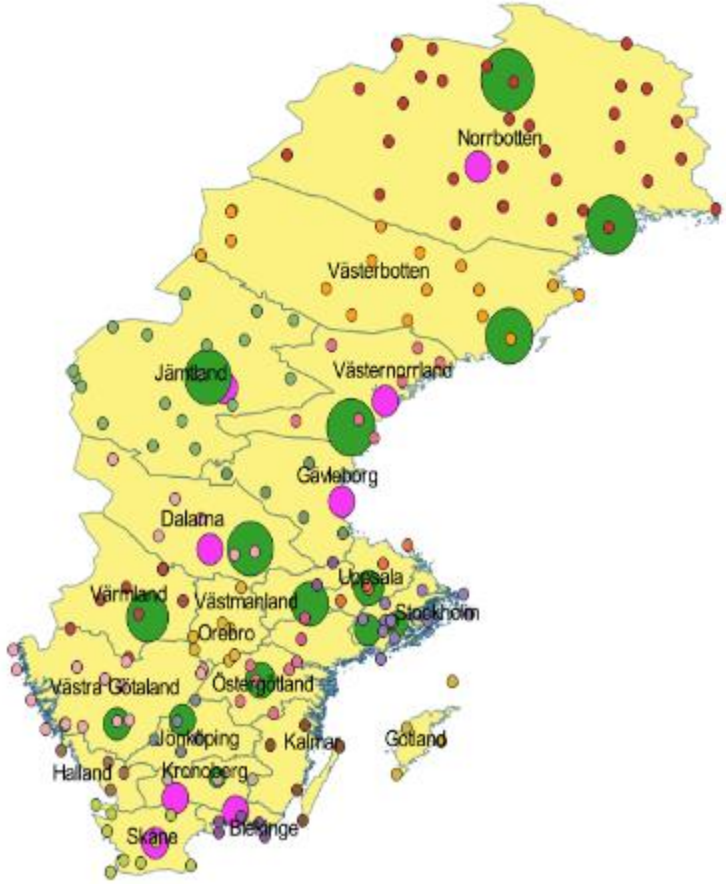
ONGOING WORK

- Update the material database
  - Soils and granular materials
- Database of weather stations/data
- Improve user interface
- Calibration and validation of the component models
  - LTPP
  - Test roads



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Thank you for your attention!

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