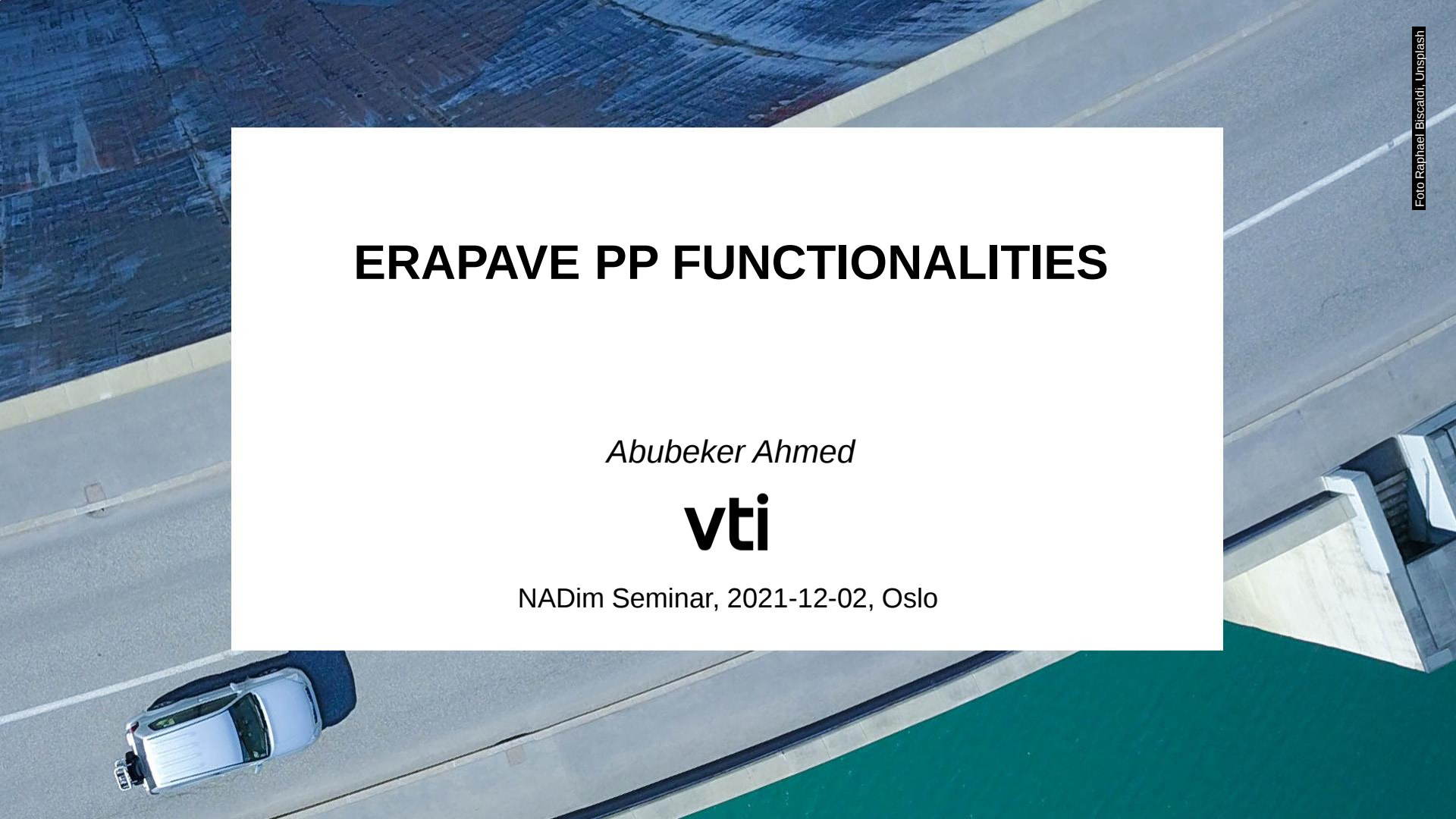


An aerial photograph of a road scene. A white car is driving on a grey asphalt road. To the right of the road is a green area, possibly a lawn or a different type of pavement. The background shows a blue and white textured surface, possibly a wall or a large piece of art.

ERAPAVE PP FUNCTIONALITIES

Abubeker Ahmed

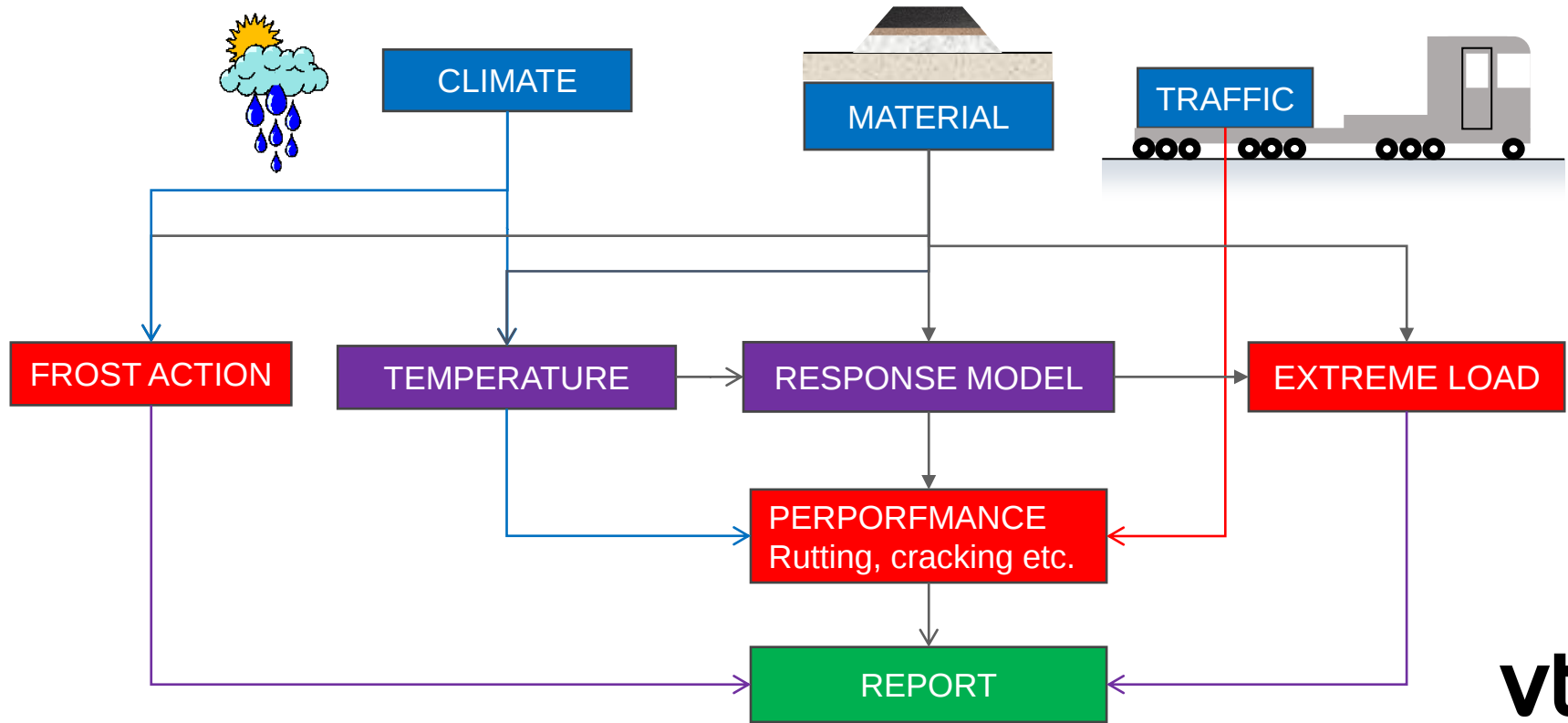
vti

NADim Seminar, 2021-12-02, Oslo

OUTLINE

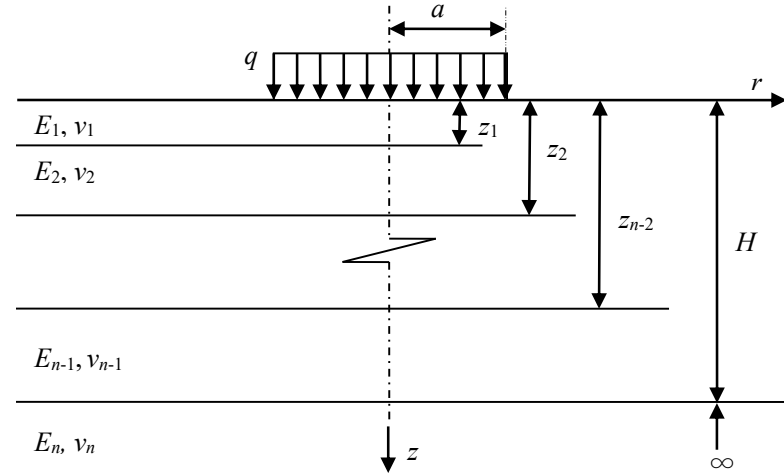
- ERAPave PP components
- Component models
 - Mechanical model
 - Material models
 - Temperature model
 - Performance model
- Report dashboard
- Questions?

ERAPAVE PP COMPONENTS



MECHANICAL MODEL - RESPONSE

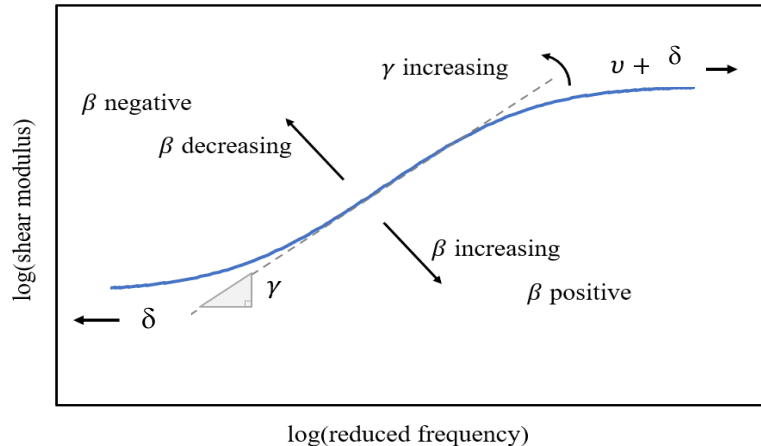
- Layered elastic theory is used to estimate stresses and strains
- Modulus and Poisson's ratio of each layer are the input parameters
- A circular contact area is assumed for the analysis



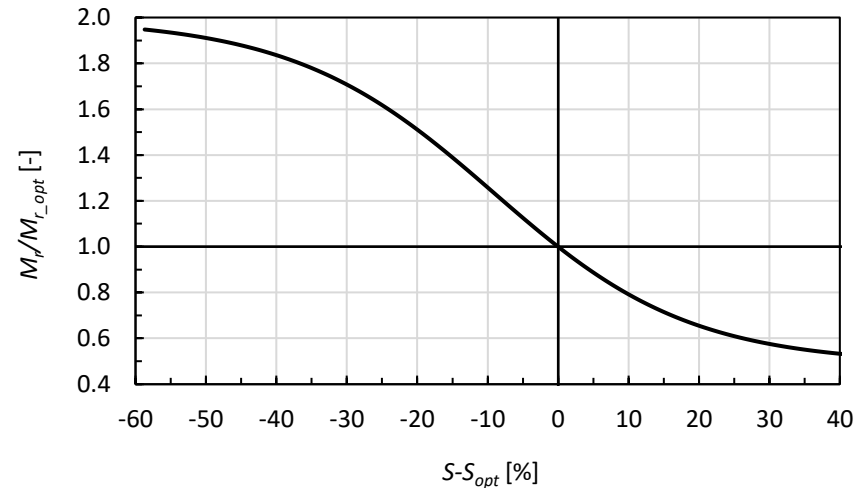
MECHANICAL MODEL - MATERIAL

- Master curve parameters for asphalt mixtures and resilient modulus for UGMs

$$|E_m^*| = v + \frac{\alpha}{1 + e^{\beta - \gamma \log(f_r)}}$$



$$\log \frac{M_R}{M_{R_{opt}}} = a + \frac{b - a}{1 + \exp \left(\ln \frac{-b}{a} + k_m (S - S_{opt}) \right)}$$



TEMPERATURE MODEL- BACKGROUND

Main heat transfer modes to be considered:

- Conduction/Convection
- Radiation
- Convection

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

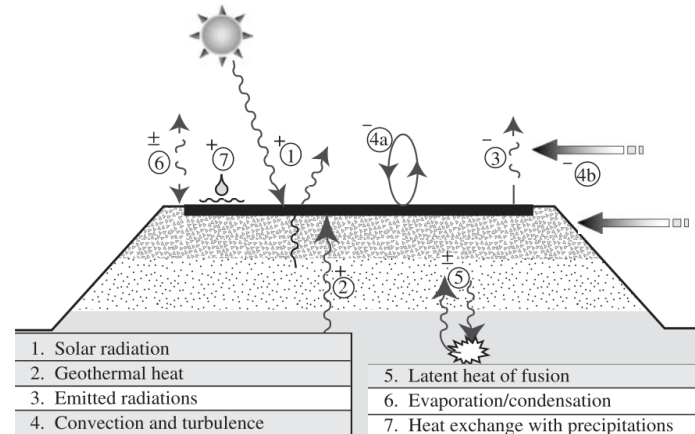
T Temperature [°C]

z Depth within the pavement layer [m]

ρ Dry density of the material [kg/m³]

c Mass specific heat capacity [J/(K·kg)]

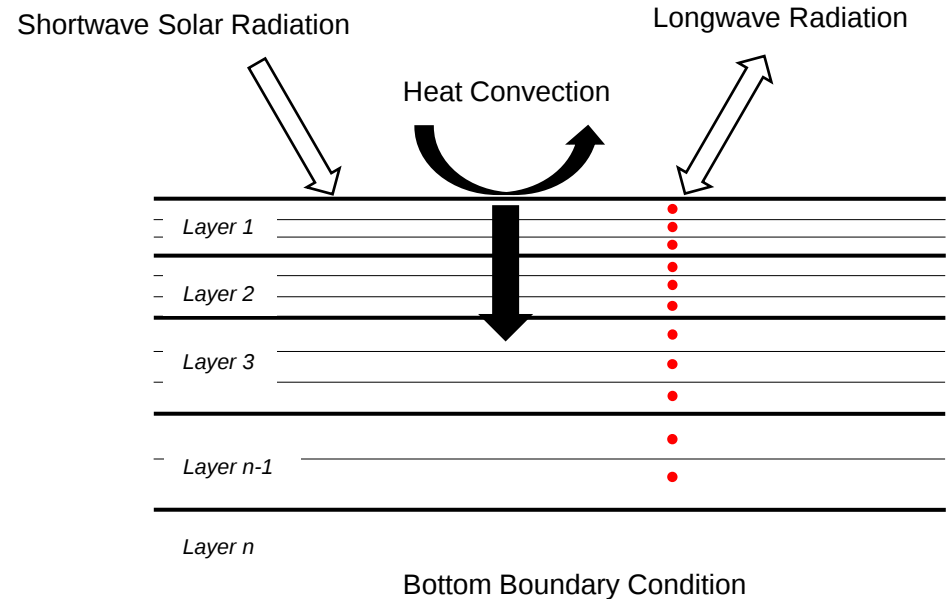
k Thermal conductivity constant [W/(m·K)]



*Dore & Zubeck (2009)

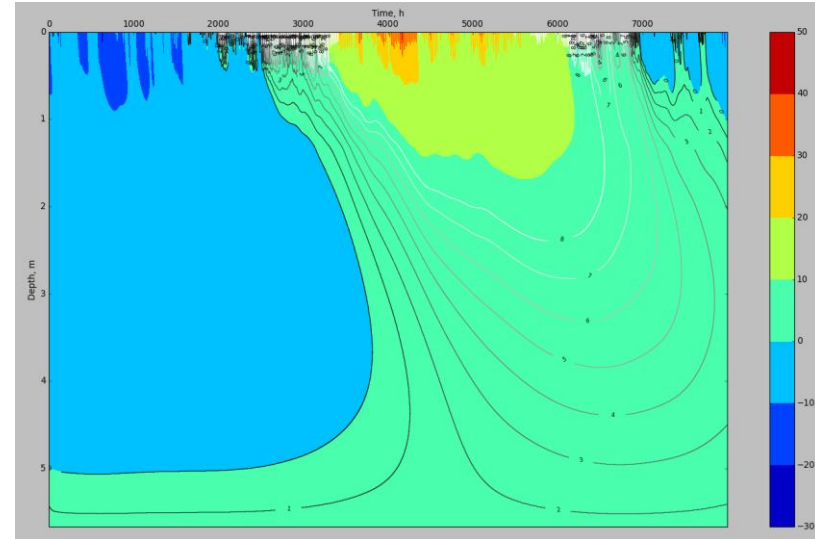
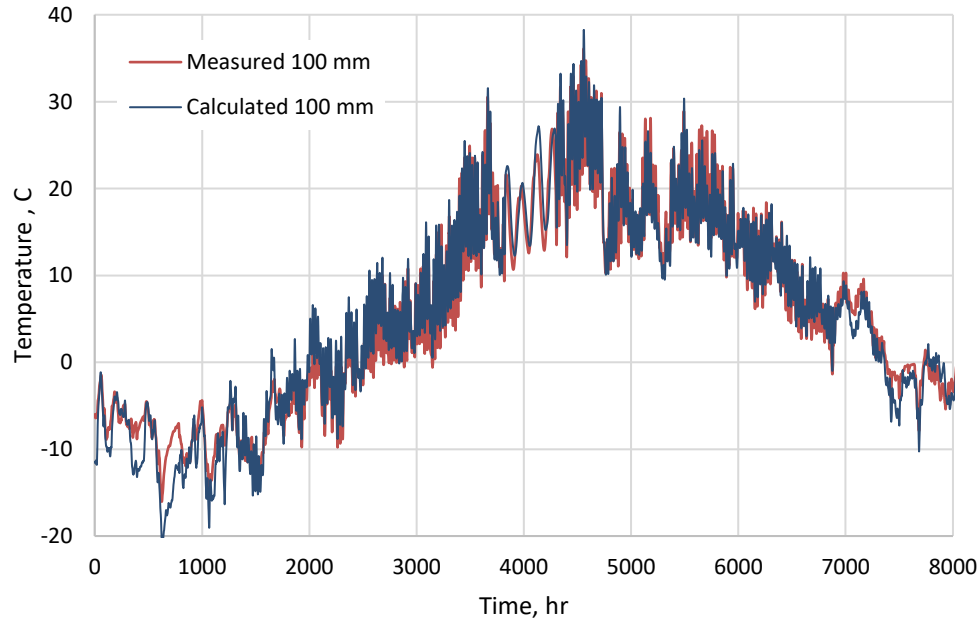
TEMPERATURE MODEL

- Finite control volume method (FCVM)
- A numerical approach for solving the heat equation
- Discretization into small control volumes
- Input for analysis
 - Air temperature
 - Wind speed
 - Solar radiation



TEMPERATURE – EXAMPLE

- Test section - Svappavaara



PERFORMANCE MODELS - RUTTING

- Permanent deformation/rutting

- Asphalt

$$\varepsilon_p(N) = aT^b N^c \varepsilon_r$$

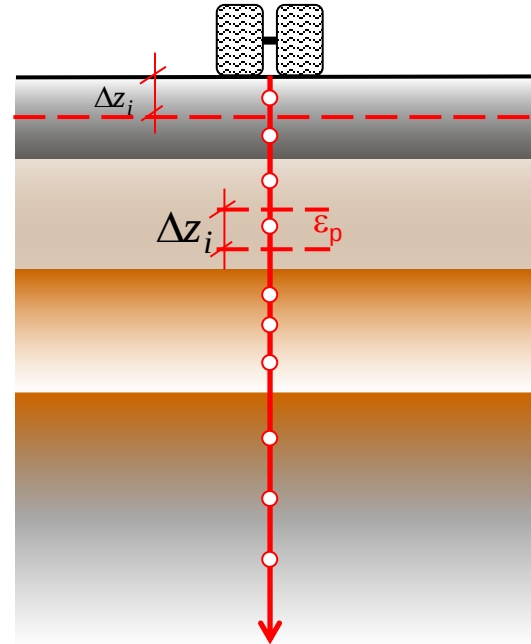
Studded wear tire

$$\varepsilon_{wearing}(N) = \text{VTI model}$$

- Unbound base/subbase/subgrade

$$\varepsilon_p = aN^{b(\varepsilon_r)} \varepsilon_r$$

T	Temperature [°C]
S	Degree of saturation
ε_r	Elastic strain [m/m]
N	Number of load cycles
a, b, c	Model parameters



PERFORMANCE MODELS - RUTTING

- Permanent deformation/rutting

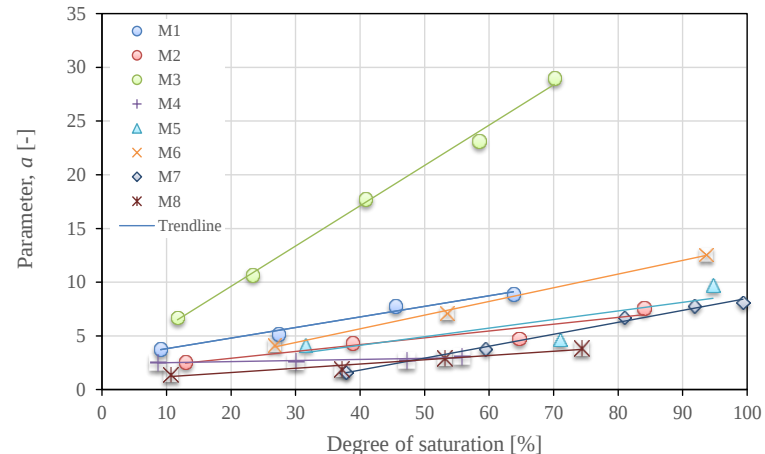
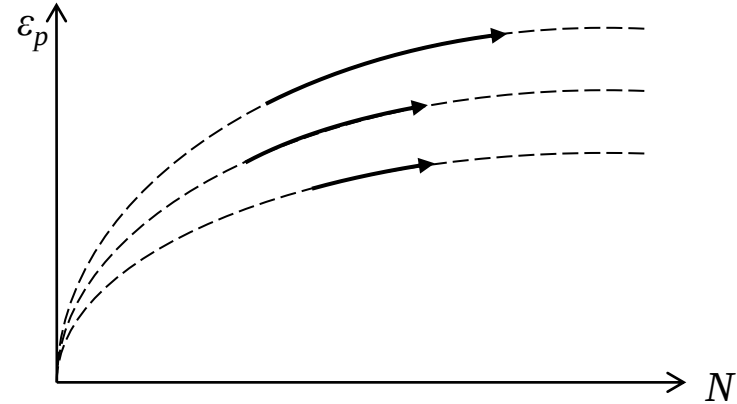
- Asphalt

$$\varepsilon_p(N) = aT^b N^c \varepsilon_r$$

- Unbound base/subbase/subgrade

$$\varepsilon_p = aN^{b(\varepsilon_r)} \varepsilon_r$$

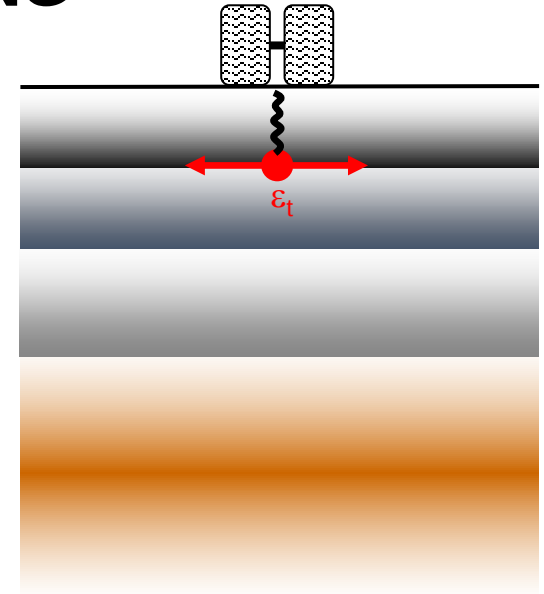
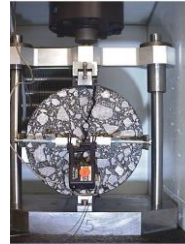
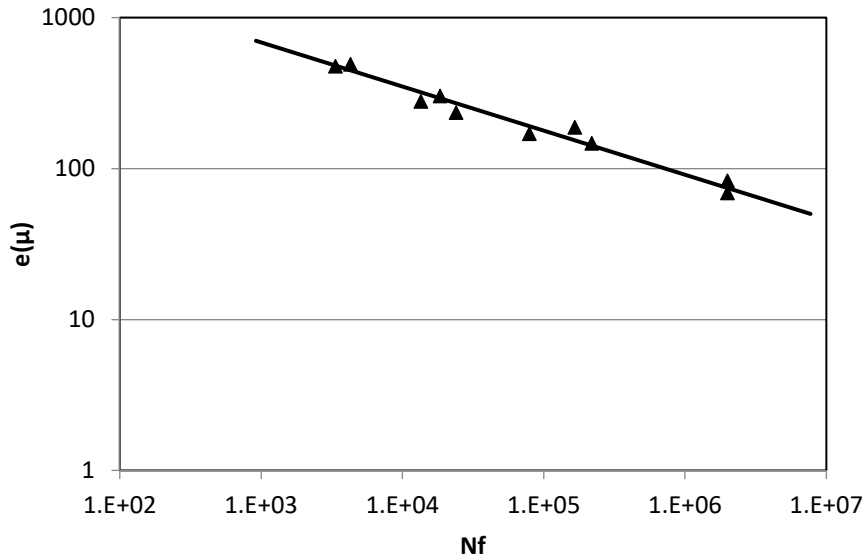
T	Temperature [°C]
S	Degree of saturation
ε_r	Elastic strain [m/m]
N	Number of load cycles
a, b, c	Model parameters



PERFORMANCE MODELS – CRACKING

- Fatigue cracking – bottom-up fatigue cracking
 - Asphalt

$$N_f = k_1 \varepsilon_t^{-k_2} E^{-k_3}$$



ε_t

Elastic strain [m/m]

k_1, k_2, k_3

Model parameters

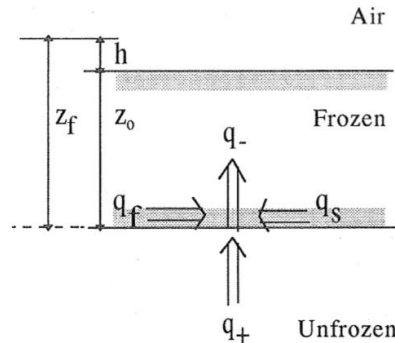
N_f

Number of cycles to failure due to fatigue

PERFORMANCE MODELS - FROST

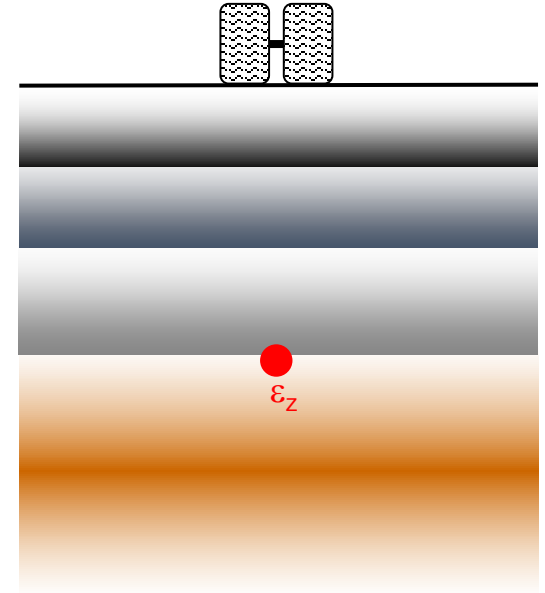
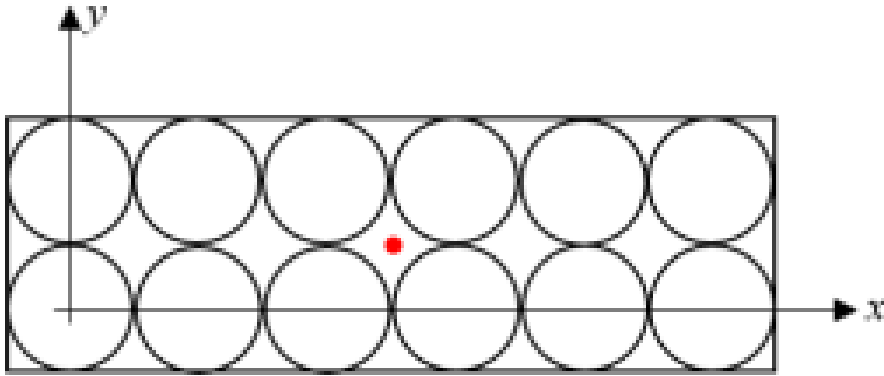
- Frost heave - SSR model

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



- Conductivity - frozen and unfrozen
- Particle and bulk – density
- Segregation Potential, SP

PERFORMANCE MODELS - EXTREME LOADING



ERAPAVE PP - LAYOUT

- Define Pavement
- Define Traffic
- Define Climate
- Control for frost action
- Control for extreme loading
- Long term performance – rutting
- Long term performance – fatigue

PROGRAM LAYOUT - STRUCTURE

Structure

Pavement structure View or edit material properties

Select subgrade type **Ia - Fast berg**

Pavement layer types and thicknesses

	Layer	Material	Thickness (mm)	Description
	1	ABT16 70/100	40	
	2	ABb22 70/100	50	
	3	AG22 160/220	65	
▶	4	GW-CR	80	
	5	GM-CR	420	
	6	5 - Silt	####	5 - Silt

Add layer Remove layer Move up Change material

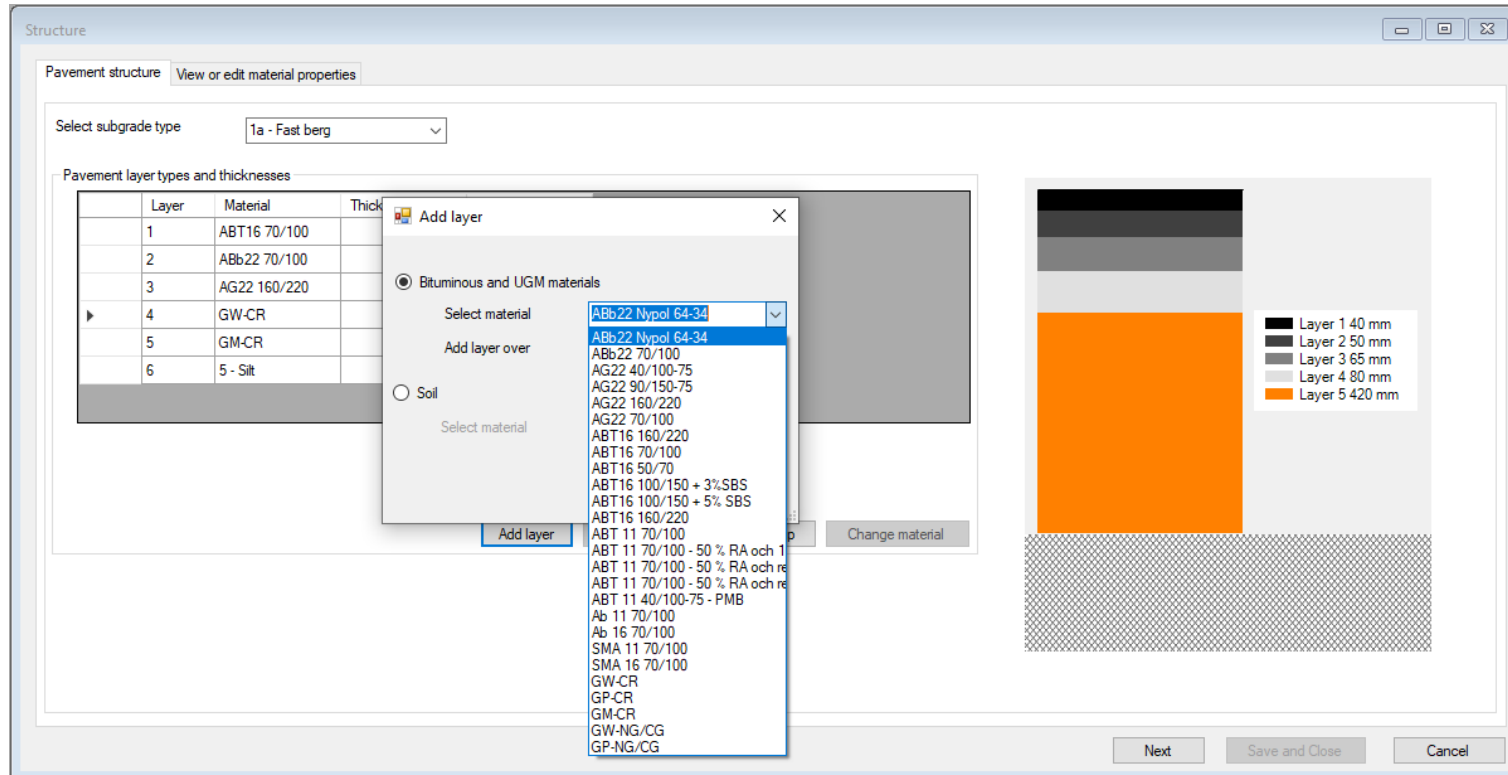
Legend:

- Layer 1 40 mm
- Layer 2 50 mm
- Layer 3 65 mm
- Layer 4 80 mm
- Layer 5 420 mm

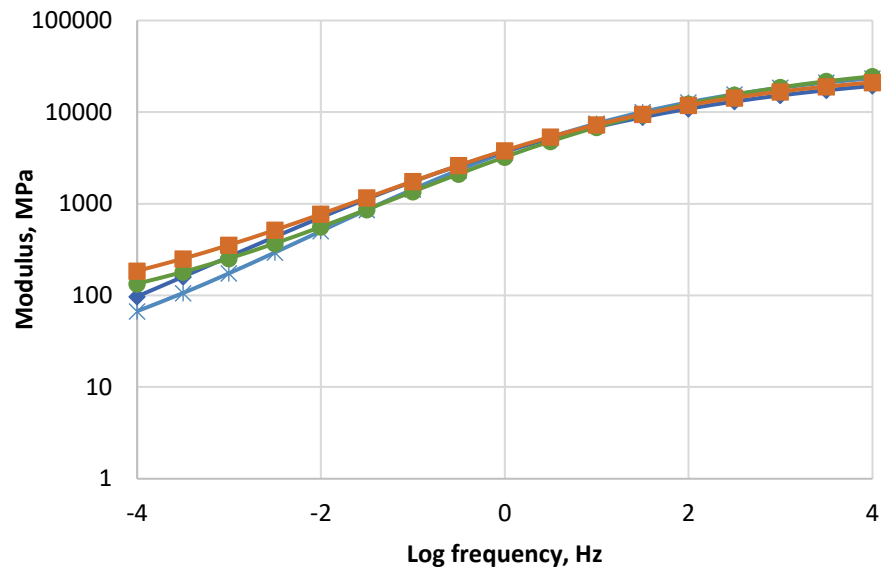
Next Save and Close Cancel

PROGRAM LAYOUT - DATABASE

- Material database

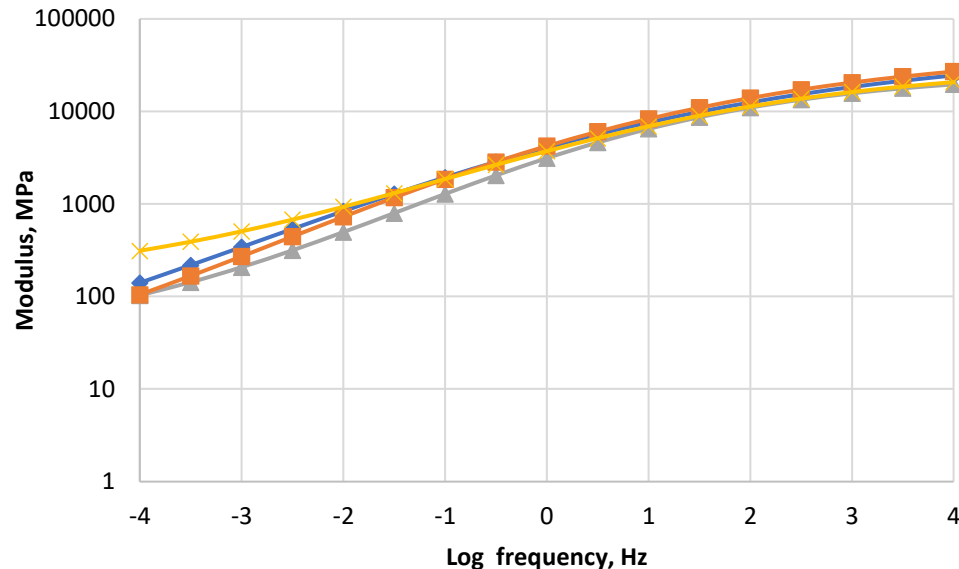


NTNU/VTI DATA



—*— SMA 11 70/100
—●— SMA 16 70/100

—◆— SMA 11-PMB
—■— SMA 16-PMB



—◆— Ab 11 70/100

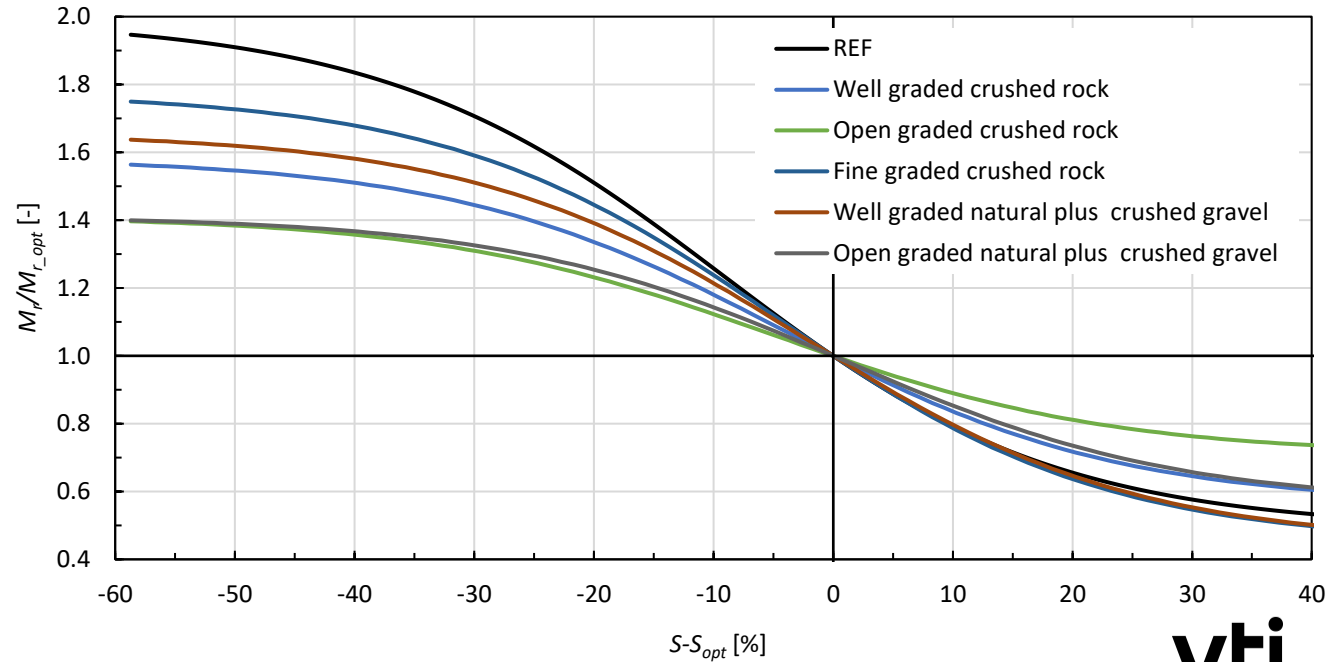
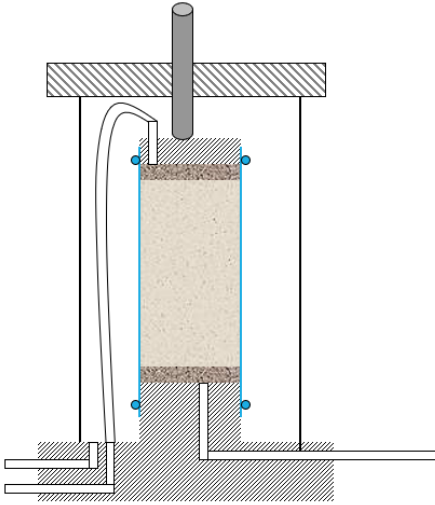
—■— Ab 16 70/100

—▲— Ab 11-PMB

—*— Ab 16-PMB

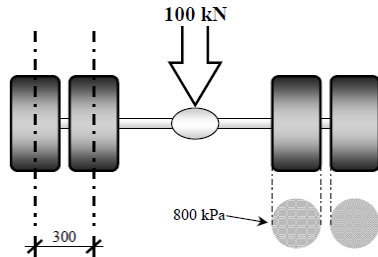
DATABASE - UGMS

- UGM – Resilient modulus

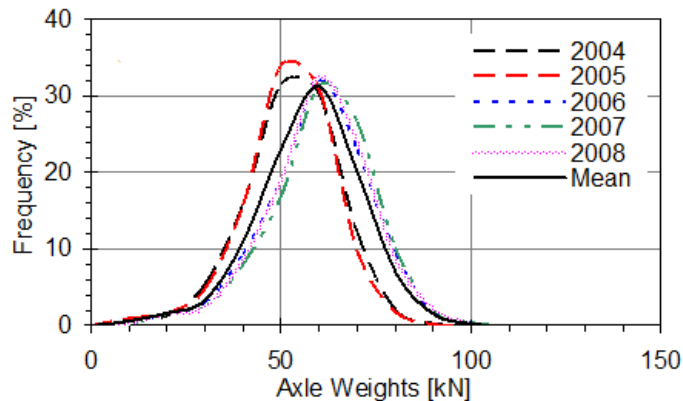


PROGRAM LAYOUT – TRAFFIC

- ESAL



- WIM



Traffic

Traffic input data

Axle Configuration

Axle configuration:

Select WIM data: WIM data is not loaded

Contact pressure (kPa):

Contact radius (mm):

Axle load (kN):

Wheel spacing (mm):

Axle spacing (mm):

Road type:

Heavy traffic wander Std deviation (mm):

Desired heavy vehicles speed (km/h):

ALS summary

Bin (kN)	Steering	Single	Tandem	Tridem

Traffic Volume

AADT per lane:

Load equivalency factor (LEF):

Growth rate (%):

Percent heavy traffic (%):

Design period (years):

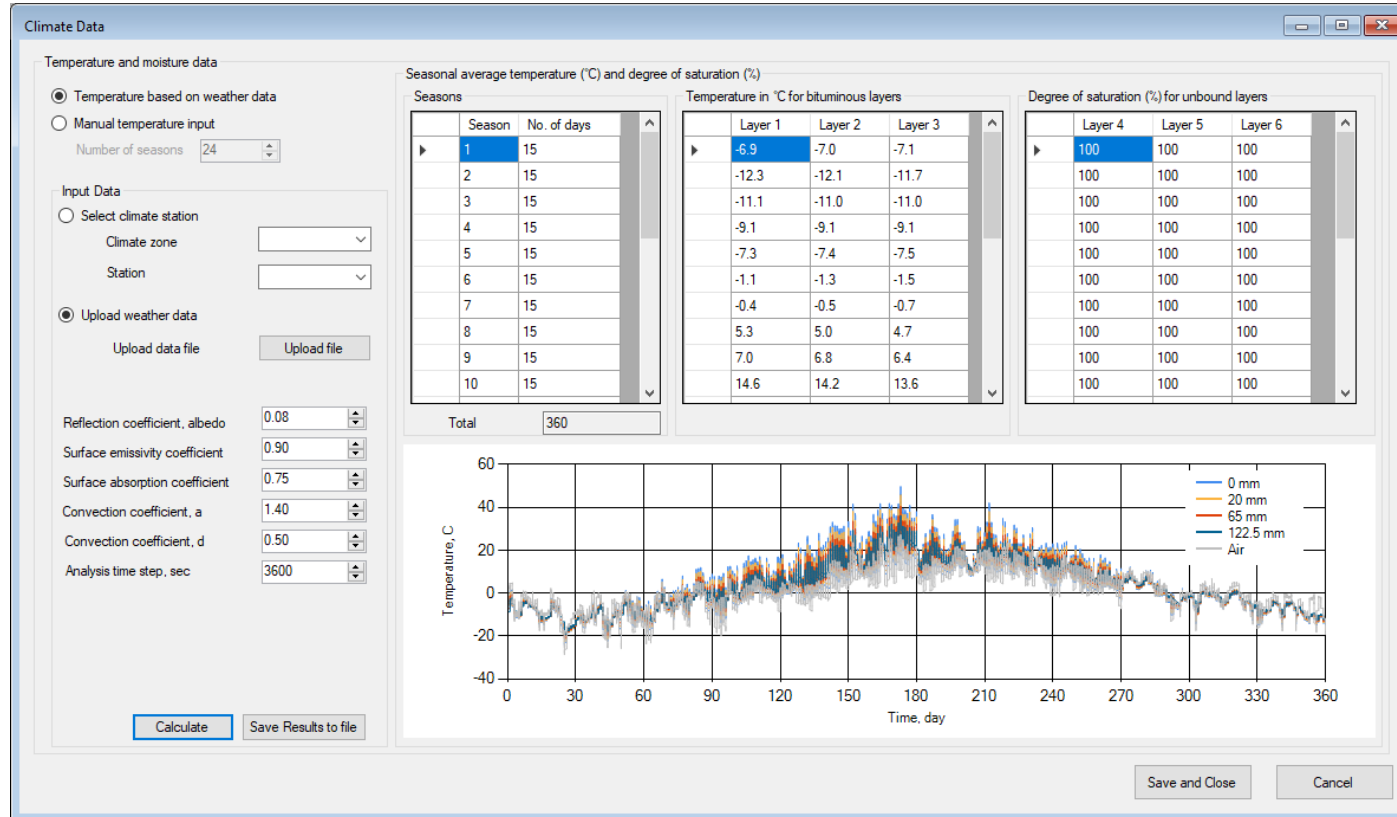
Calculated ESALs:

Distribution of axle types in the AADT (%)

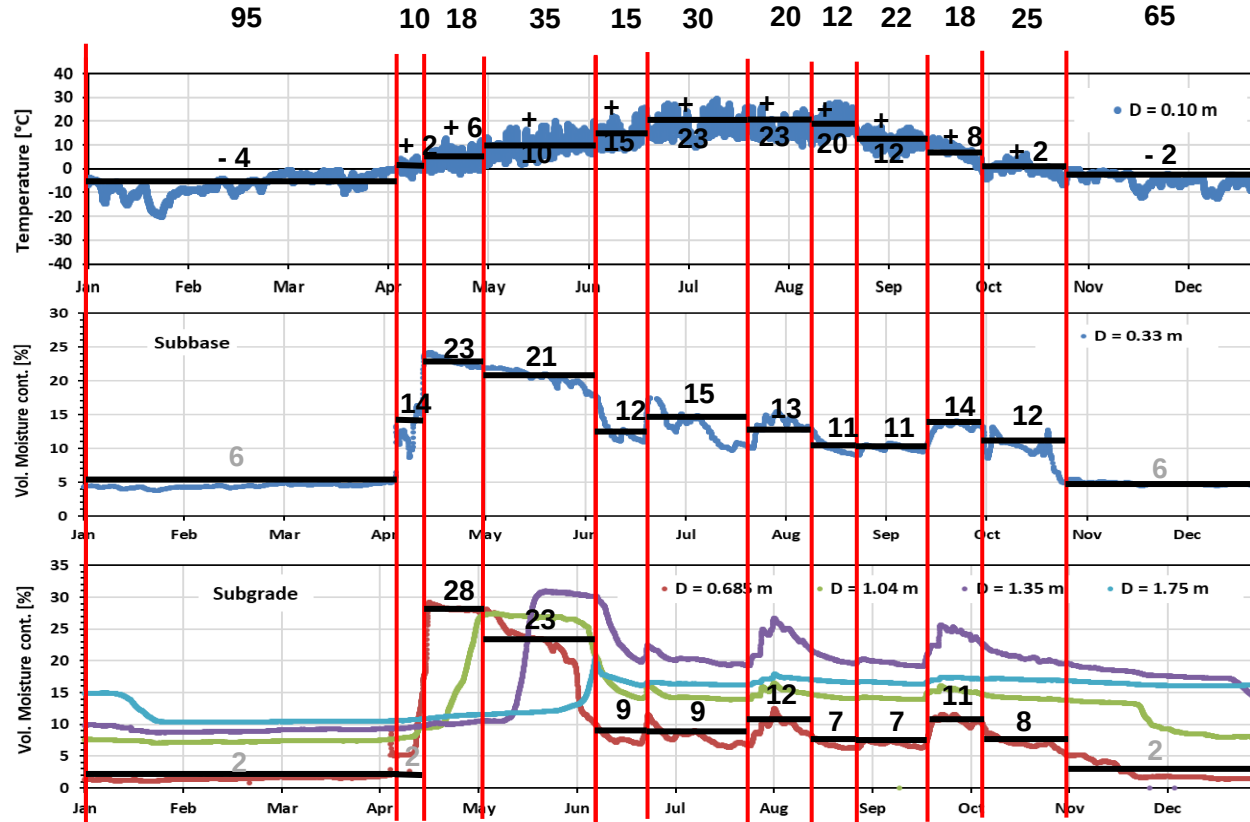
Steering	Single	Tandem	Tridem
100	125	95	25

PROGRAM LAYOUT-CLIMATE

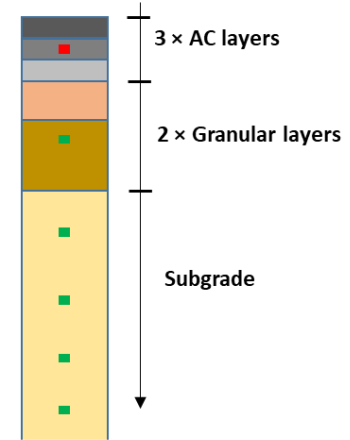
- Air temperature
- Wind speed
- Solar radiation
- Deg. of saturation



PROGRAM LAYOUT- MANUAL INPUT



= 365 days



$$e = \frac{G_s \gamma_w}{\gamma_{dry}} - 1$$

$$w = \frac{\gamma_w}{\gamma_{dry}} \theta_{vol}$$

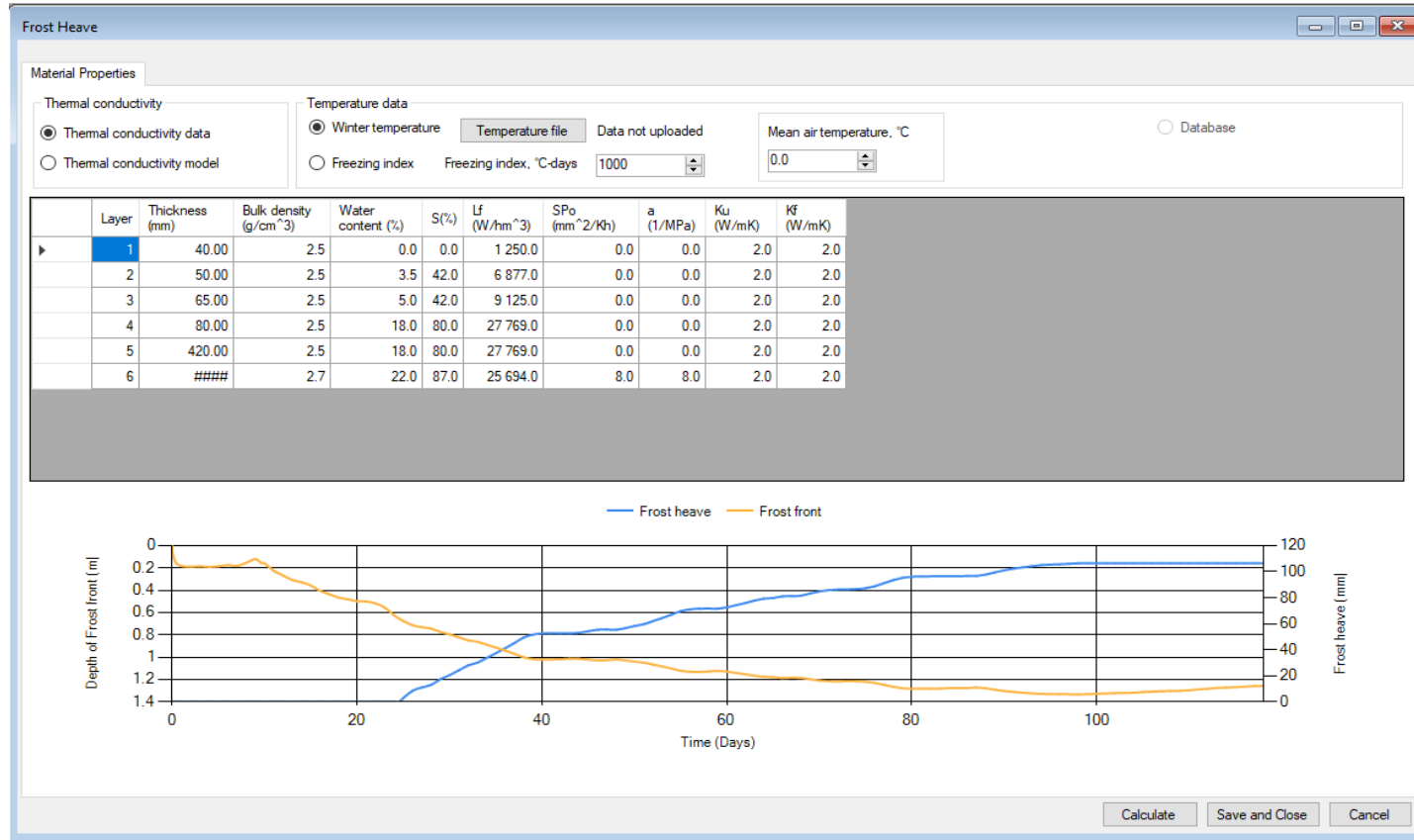
$$S = \frac{w G_s}{e}$$

vti

PROGRAM LAYOUT – FROST HEAVE

Inputs

- Winter temp.
- Freezing index



PROGRAM LAYOUT – EXTREME LOADING

Extreme Single Load

Load configuration and analysis location

Load configuration

Number of wheels: 12

	X, mm	Y, mm	Wheel load, kN	Contact pressure, kPa
▶	0.0	0.0	10.0	1 083.3
	112.8	0.0	10.0	1 083.3
	225.7	0.0	10.0	1 083.3
	338.5	0.0	10.0	1 083.3
	451.4	0.0	10.0	1 083.3
	564.2	0.0	10.0	1 083.3
	0.0	112.8	10.0	1 083.3
	112.8	112.8	10.0	1 083.3
	225.7	112.8	10.0	1 083.3

Analysis locations

Number of analysis locations: 1

	Id	X, mm	Y, mm	Z, mm
▶	1	282.1	56.4	655.0

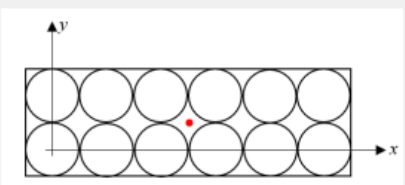
Strain

Strain in $\mu\text{m/m}$

	Period	Id	ex	ey	ez
▶	1	1	-5.8	-7.4	22.6
	2	1	-6.0	-7.7	23.3
	3	1	-6.4	-8.4	24.9
	4	1	-5.9	-7.6	23.4
	5	1	-11.7	-15.3	45.4
	6	1	-12.1	-16.1	46.7
	7	1	-11.8	-16.0	45.9
	8	1	-10.8	-14.7	41.8
	9	1	-8.9	-12.0	34.4
	10	1	-7.0	-9.2	27.0

Max Tjörning: 0.0000 m/m

Calculate Save and Close Cancel



PROGRAM LAYOUT – RUTTING/FATIGUE

Rutting

Permanent deformation models and parameters

Permanent deformation models

Model 1 (MEPDG)

$$\epsilon_p = aT^b N^c \epsilon_r$$

Model 2 (Tseng and Lytton, 1981)

$$\epsilon_p = ae^{-\left(\frac{b}{N}\right)^c} \epsilon_r$$

Model 3 (Rahman et al. 2021)

$$\epsilon_p = (a(S) + b)N^{c(\epsilon_r)} \epsilon_r$$

a, b, c = Material constants
 ϵ_r = Elastic resilient strain
 T = Temperature (°C)
 N = Number of load cycles

Model parameters

	Layer	Material	Model	a	b	c
▶	1	Bound	Model 1	0.03	1.85	0.27
	2	Bound	Model 1	0.03	1.85	0.27
	3	Bound	Model 1	0.03	1.85	0.27
	4	Unbou...	Model 3	0.00	5	250
	5	Unbou...	Model 3	0.00	5	250
	6	Unbou...	Model 3	0.00	10	250

Maximum permitted design total rutting, mm

13.0

Save and Close Save and Close Cancel

Fatigue

Fatigue cracking model parameters

Tensile strain at the bottom of layer

f1 15.40
 f2 3.90
 f3 0.00

$$\log(N_f) = f_1 - f_2 \log(\epsilon_{bt}) - f_3 \log(E)$$

N_f = Number of load cycles until failure
 f_1, f_2, f_3 = Material constants, f_1 also includes laboratory to field shift factor
 ϵ_{bt} = Tensile strain at the bottom of asphalt (µm/m)
 E = Stiffness modulus (MPa)

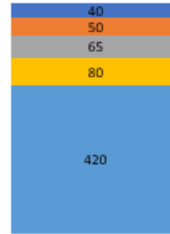
Save and Close Cancel



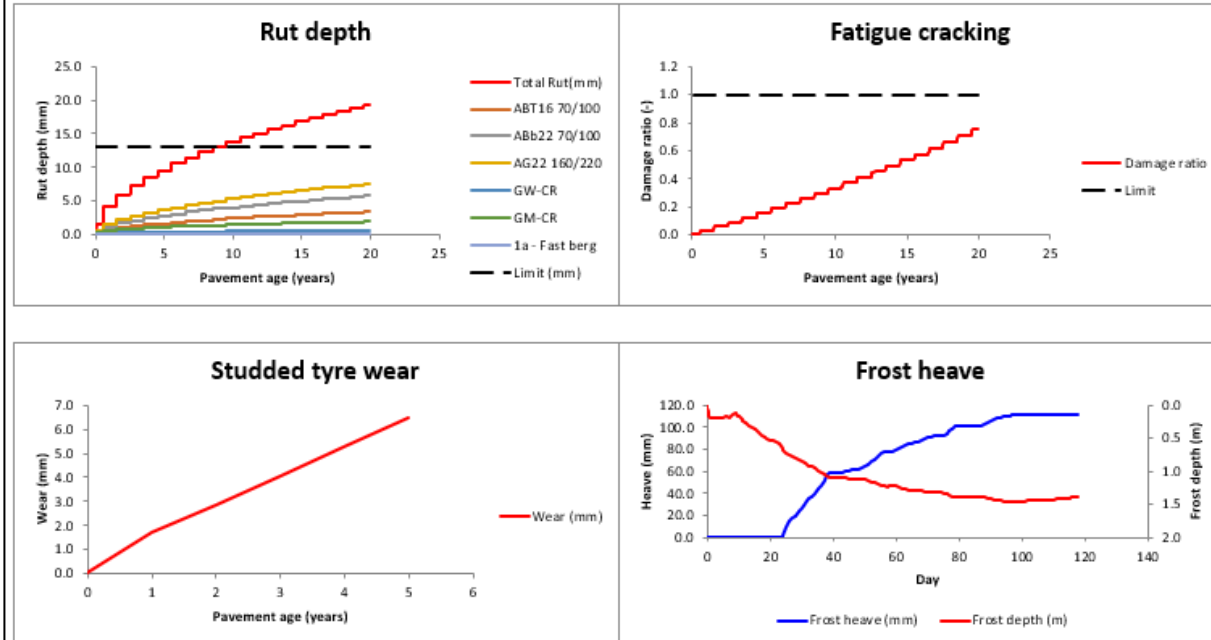
REPORT

Summary

- Input data
- Predicted damages
 - rutting and wear
 - fatigue
 - frost



Layer	Rutting (mm)
ABT16 70/100	3.4
ABb22 70/100	5.8
AG22 160/220	7.6
GW-CR	0.7
GM-CR	1.9
1a - Fast berg	0.0
Total rutting	19.4
Studded tyre wear	6.4
Fatigue life	0.7
Frost heave	111.5
Frost depth	1.4



FUTURE WORK

- Update the material database
- Database of weather stations/data
- Improve user interface
- Calibration/Validation of the component models

Thank you for your attention!