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FINDING A BETTER WAY

Modelling of pavement structures degradation

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Background

A realistic life cycle assessment modelling of the pavement structure is one of the critical elements in any pavement asset management system.

Three level of design used in Sweden:

DK1 Catalogues

DK2 Simple performance (fatigue & rutting criteria)

DK3 Advanced level

A Mechanistic – Empirical (M-E) approach is under development:

- To predict the structural degradation of road structures
- Backbone in a new pavement asset management system.

Objectives

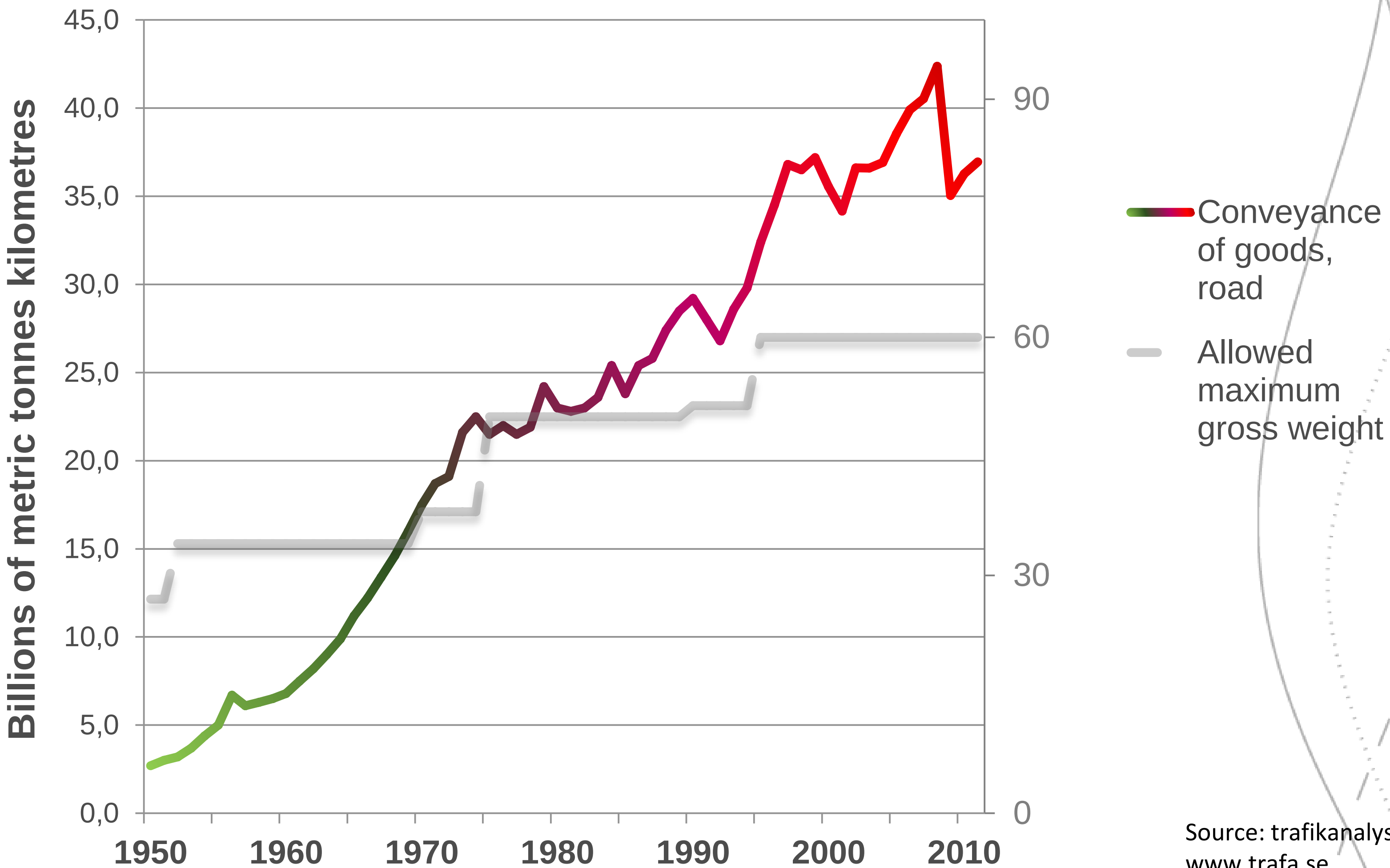
To formulate, develop and test performance prediction scheme for rutting and fatigue cracking based on mechanistic empirical (M-E) approach taking into account:

- Variable traffic loading (axle load spectra)
- Climate (temperature and moisture)

Implementation and calibration of available material models for response and performance predictions.

End result: M-E performance prediction program.

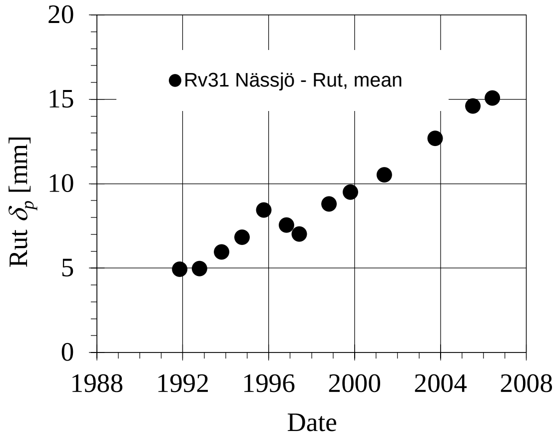
Sweden: Development of heavy traffic



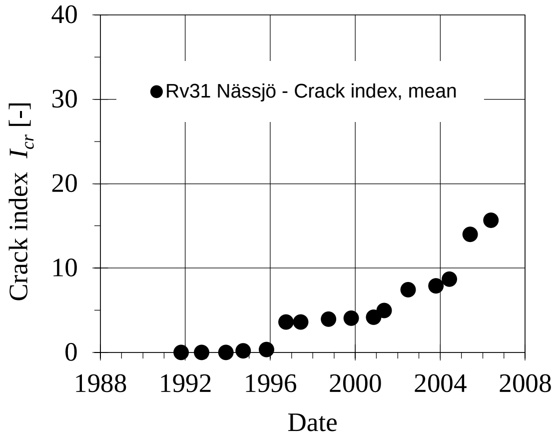
Source: trafikanalys mfl.
www.trafa.se

Distress mechanisms

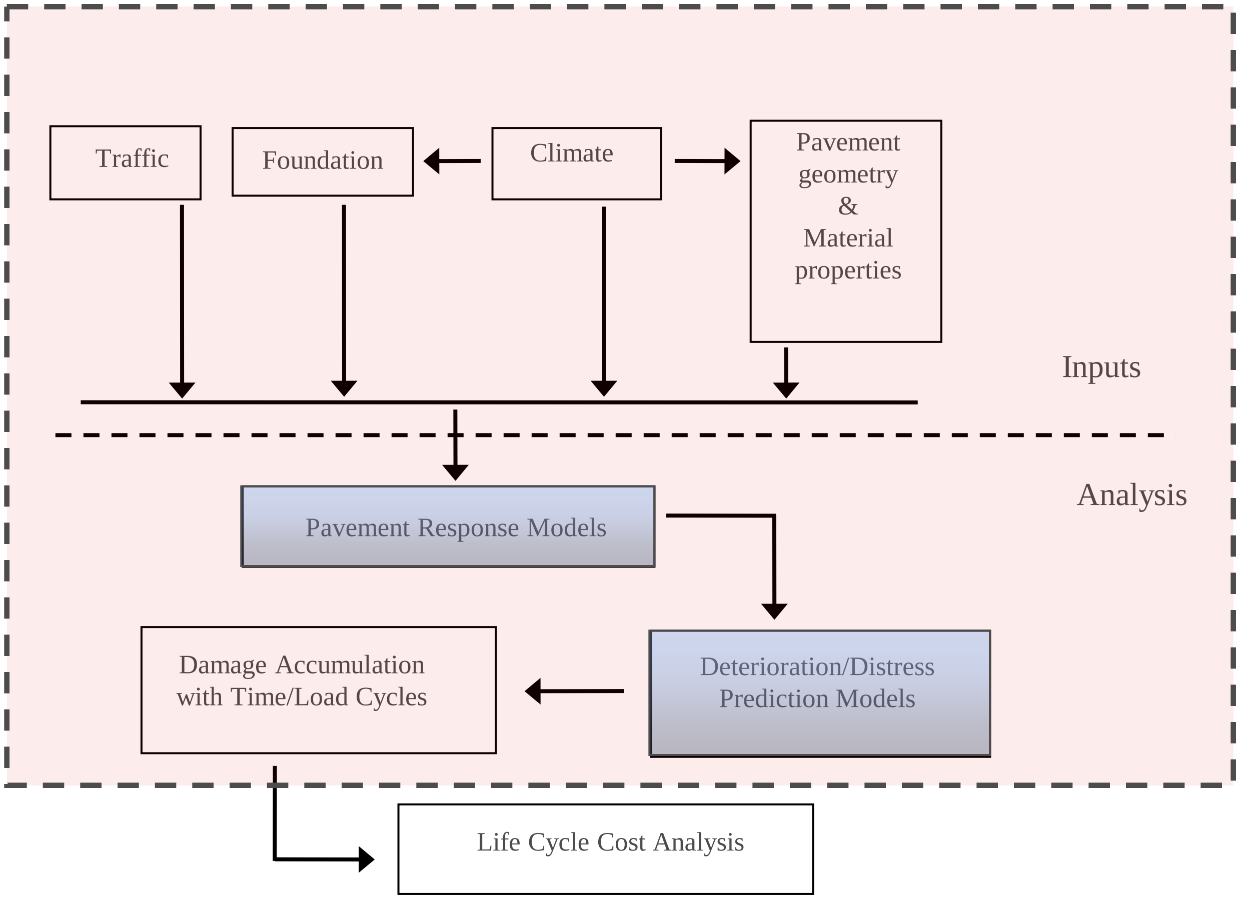
Rutting



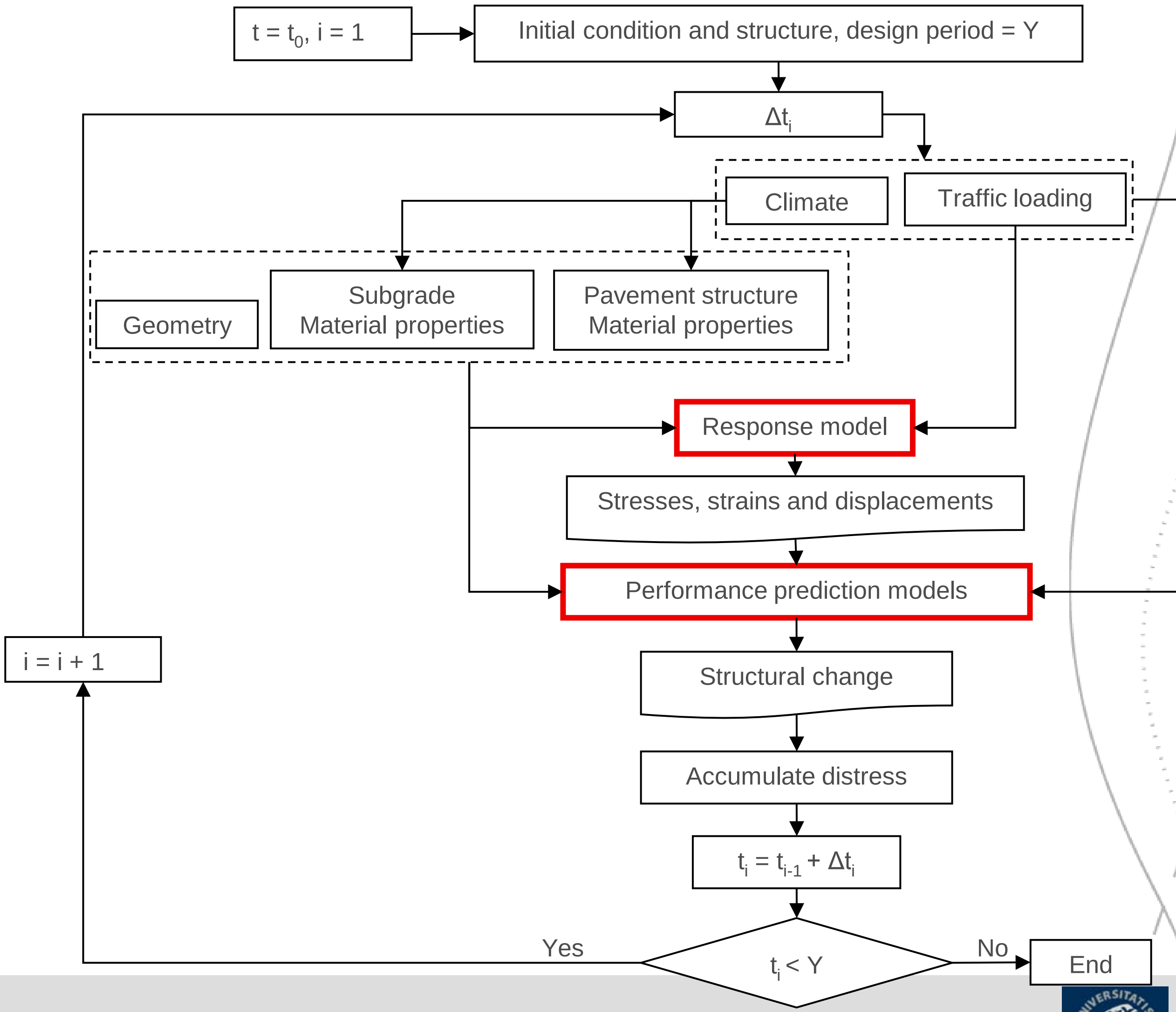
Fatigue cracking



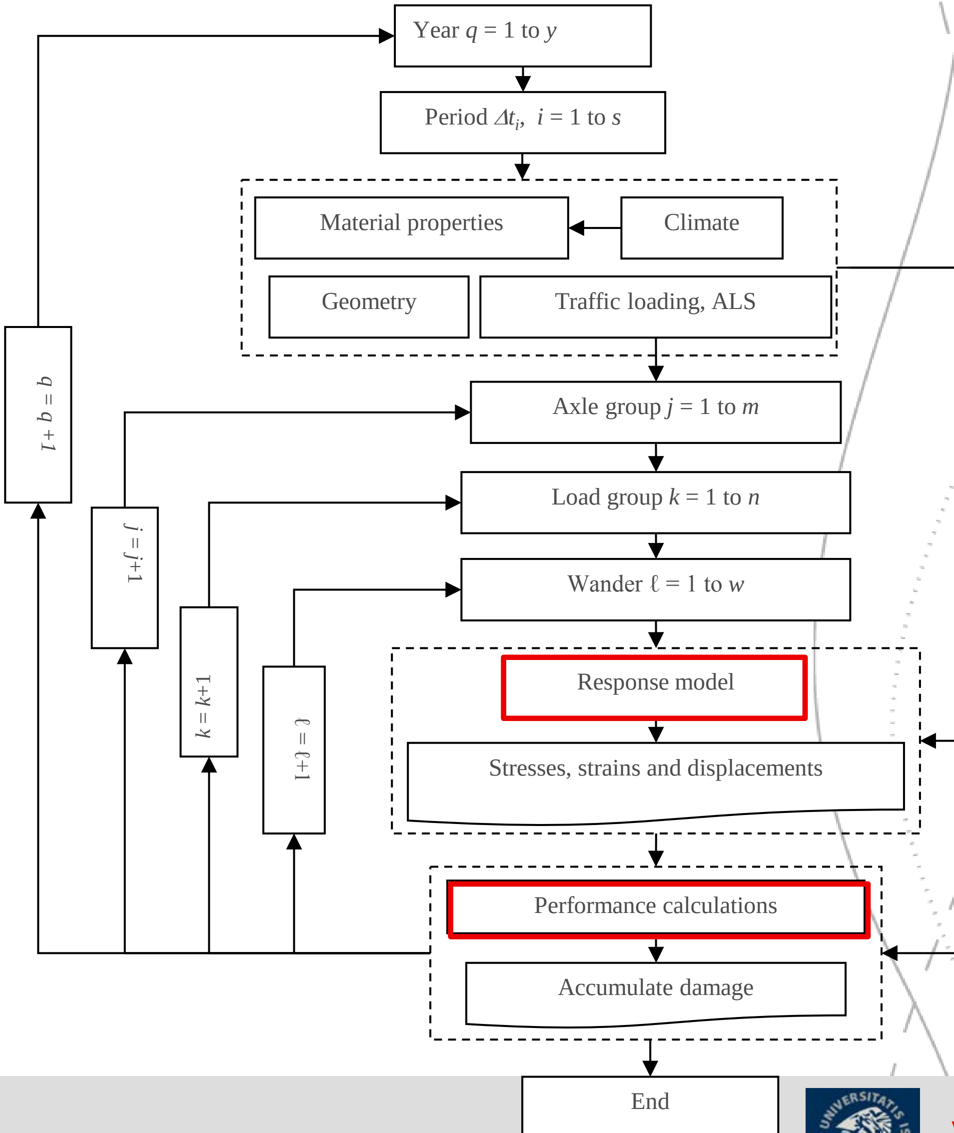
LCCA


Traffic
Foundation
Climate
Pavement geometry & Material properties
Inputs
Analysis
Pavement Response Models
Damage Accumulation with Time/Load Cycles
Deterioration/Distress Prediction Models
Life Cycle Cost Analysis

Performance calc.

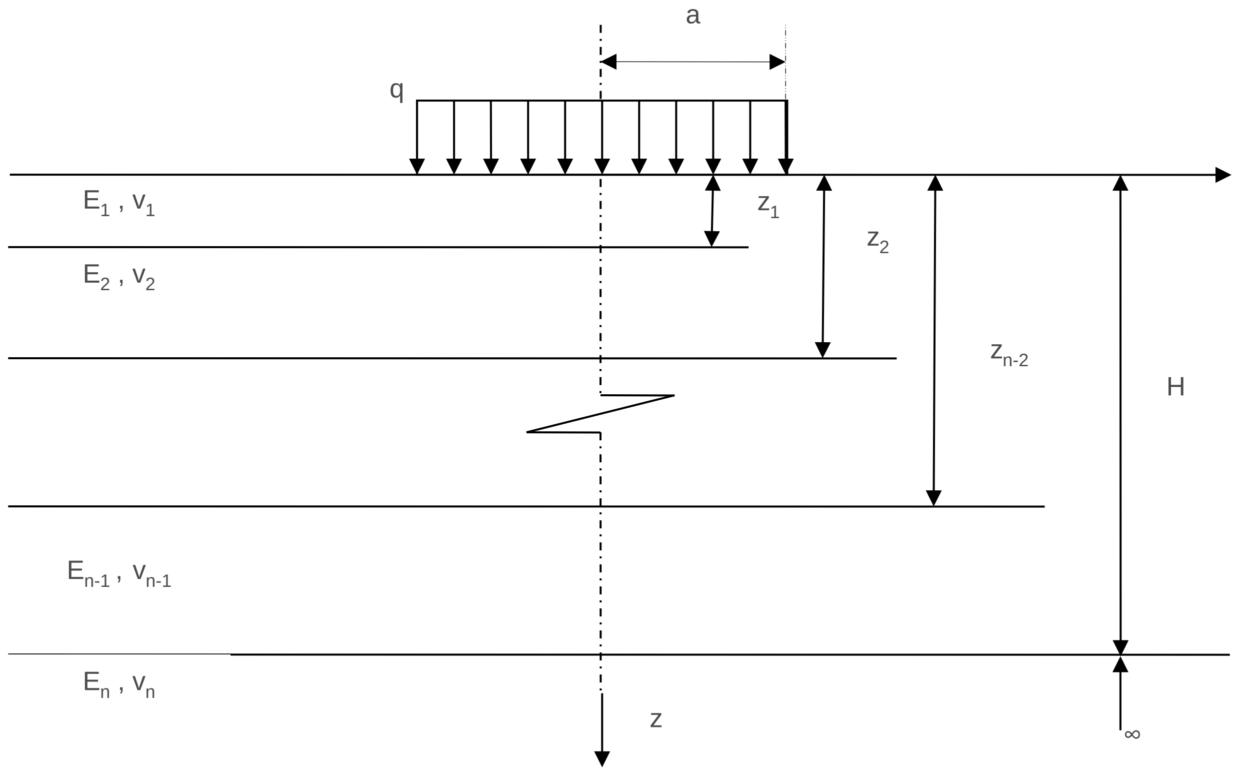


Performance calc.

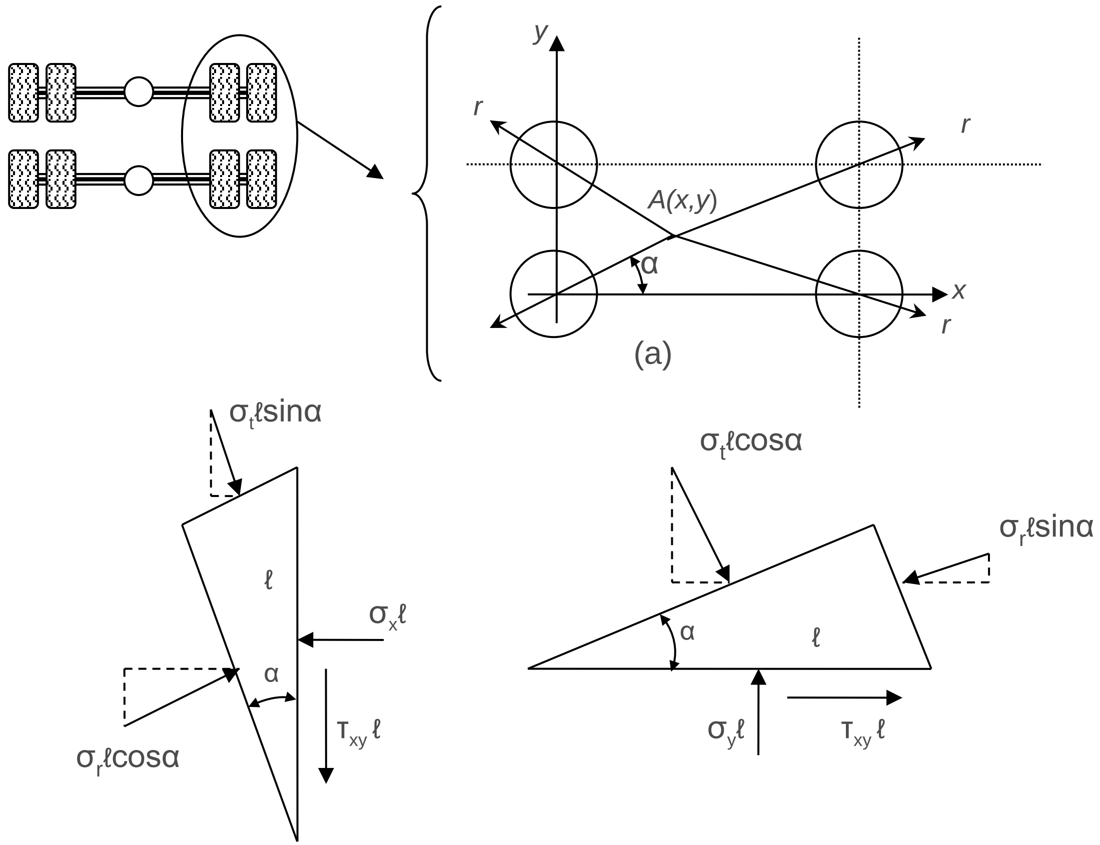


Response calc. (ERAPave)

Multi Layer Elastic Approach

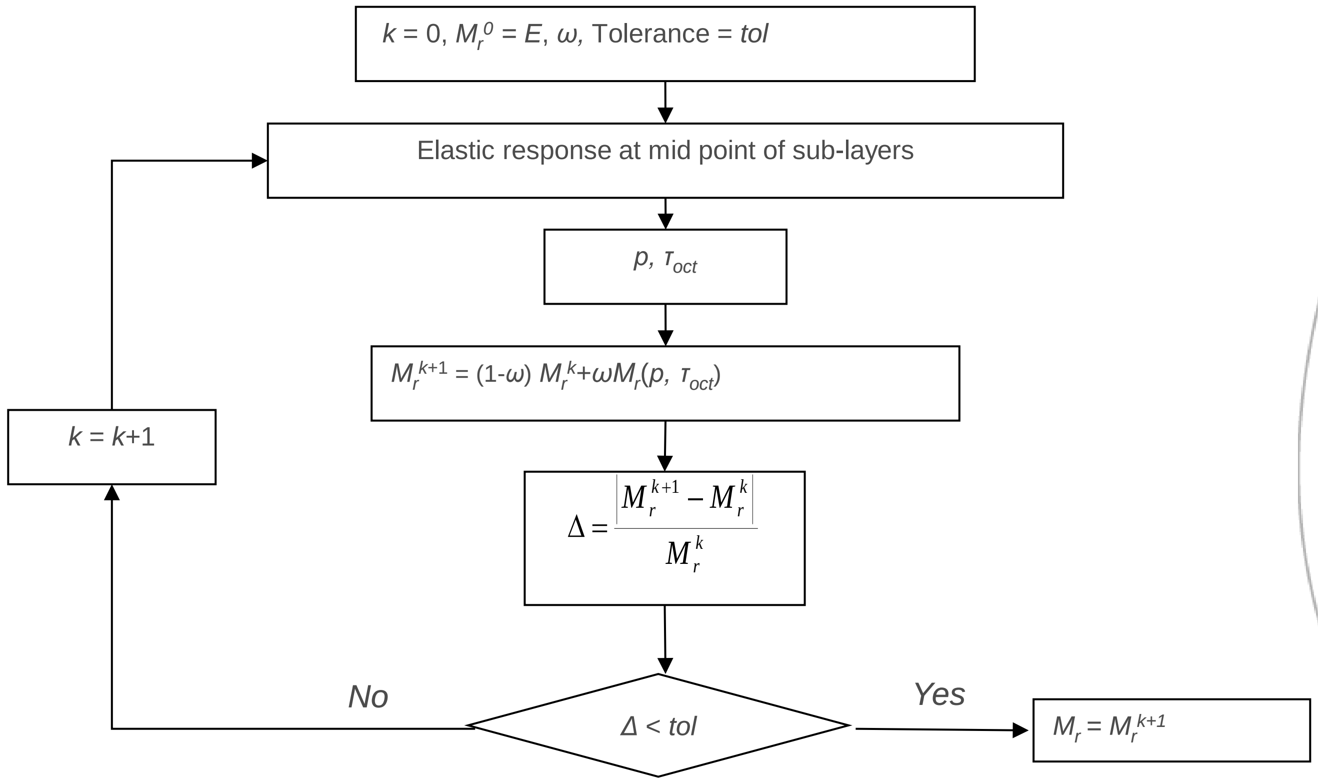


MLEA Superposition



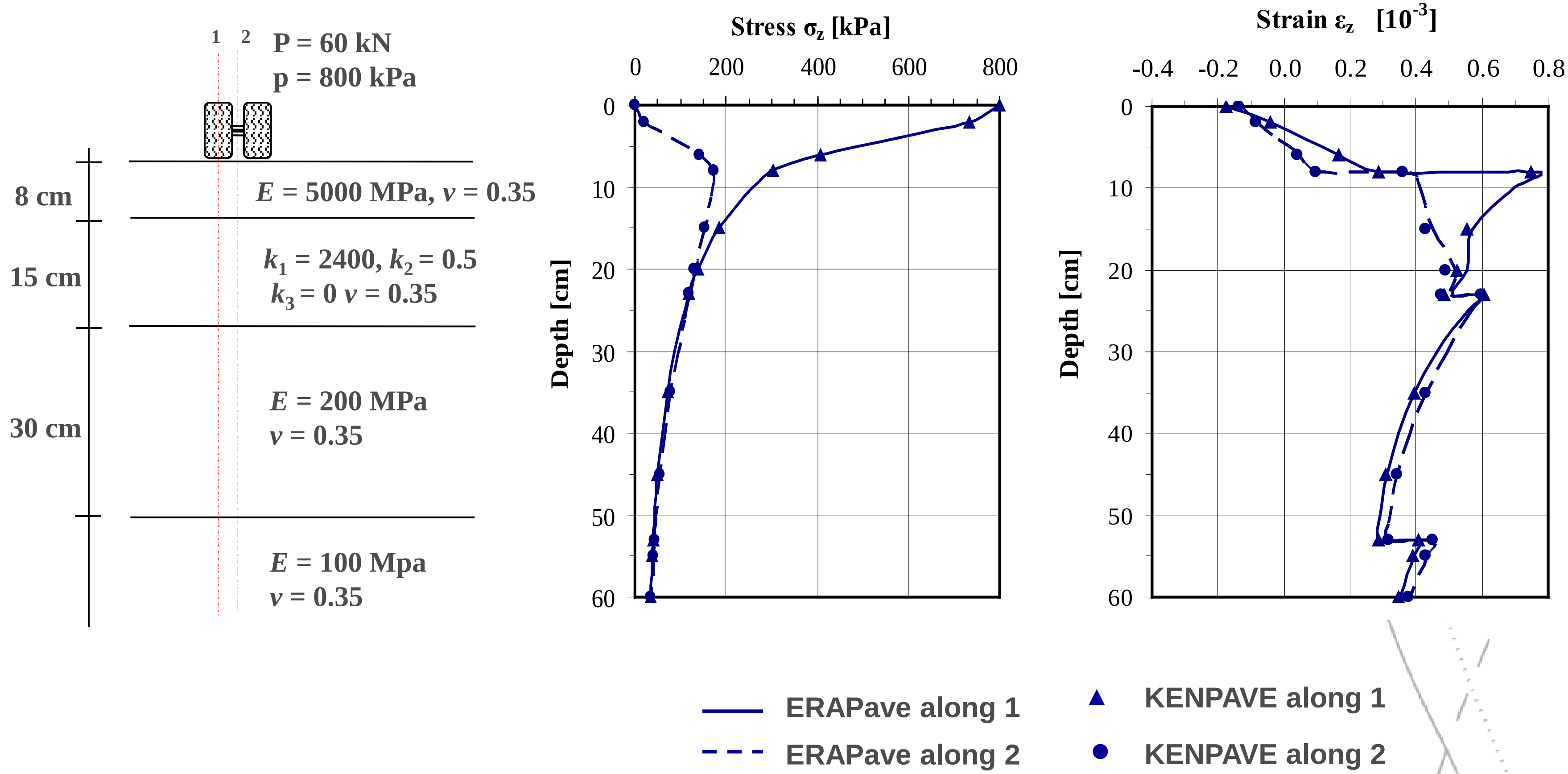
(b) (c)

Non linear iteration



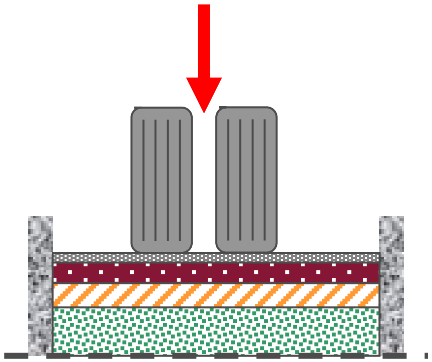
Response calculations

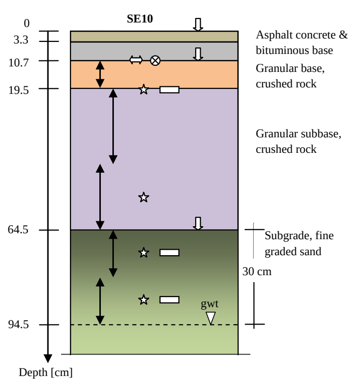
• comparison with other programs



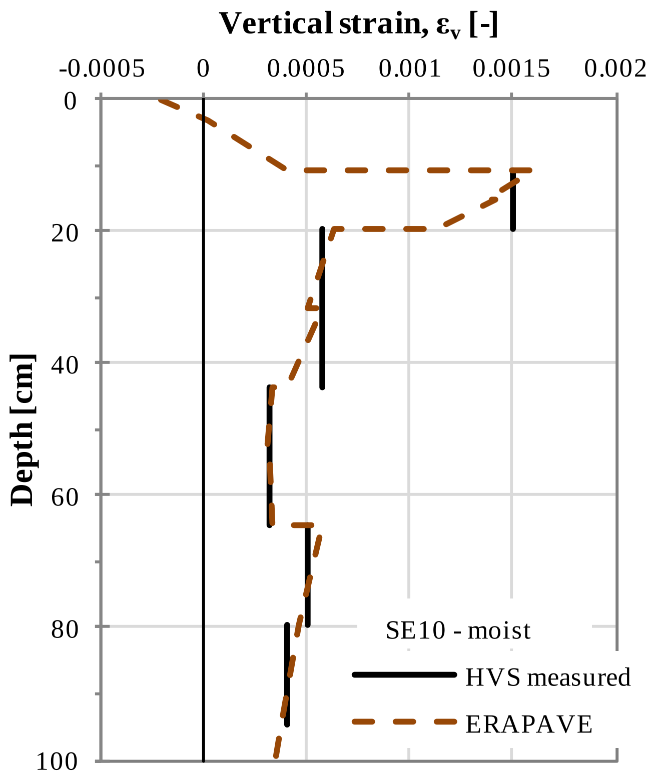
Response - numerical simulations
Vertical strain as a function of depth for SE10

60kN / 800kPa

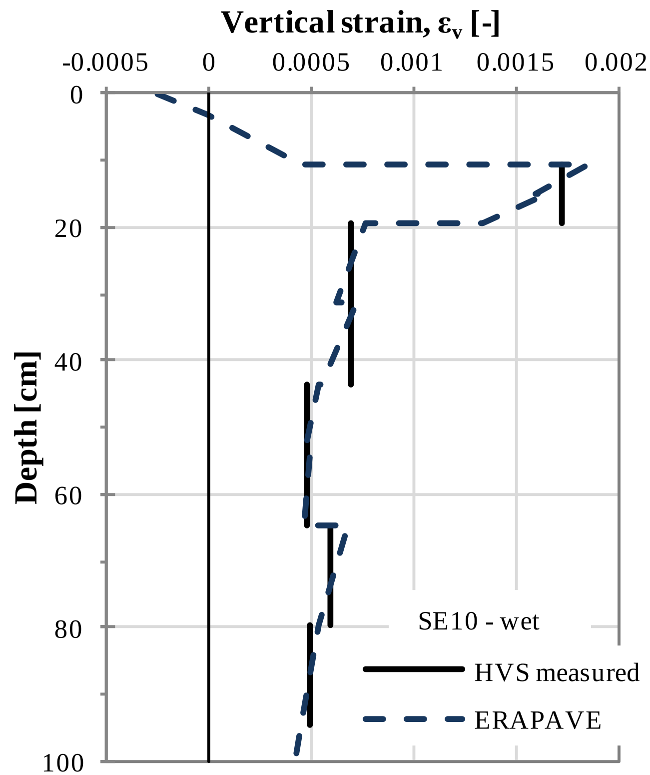




"Moist" state

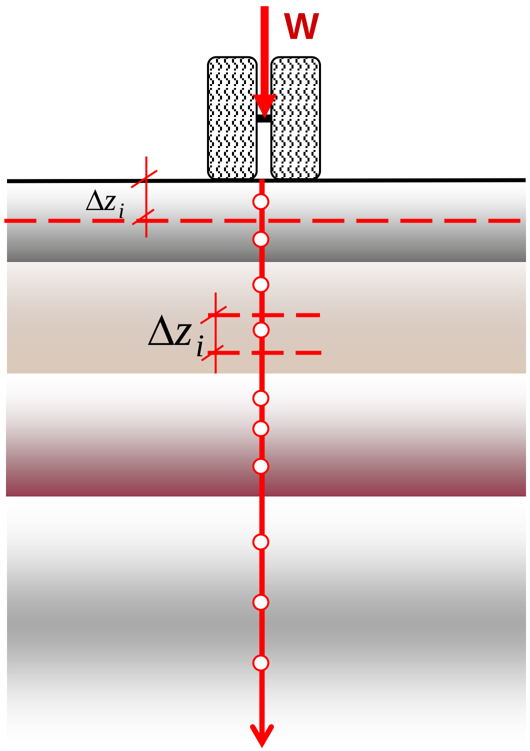


"Wet" state



Increased moisture content in the wet state caused the stiffness of the unbound layers to decrease and therefore higher strains are recorded.

Prediction of permanent deformation



Asphalt

$$\hat{\varepsilon}_p(N) = a_1 \varepsilon_r T^{a_2} N^{a_3}$$

Base and Subbase

$$\hat{\varepsilon}_p(N) = CN^b \frac{R}{A-R}$$

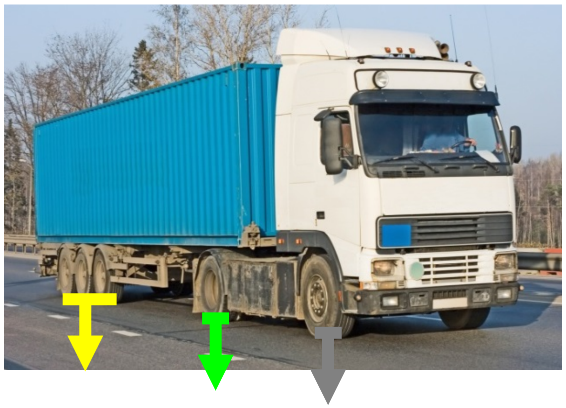
Subgrade

$$\hat{\varepsilon}_p(N) = \varepsilon_0 \varepsilon_r e^{-\left(\frac{\rho}{N}\right)^{\beta}}$$

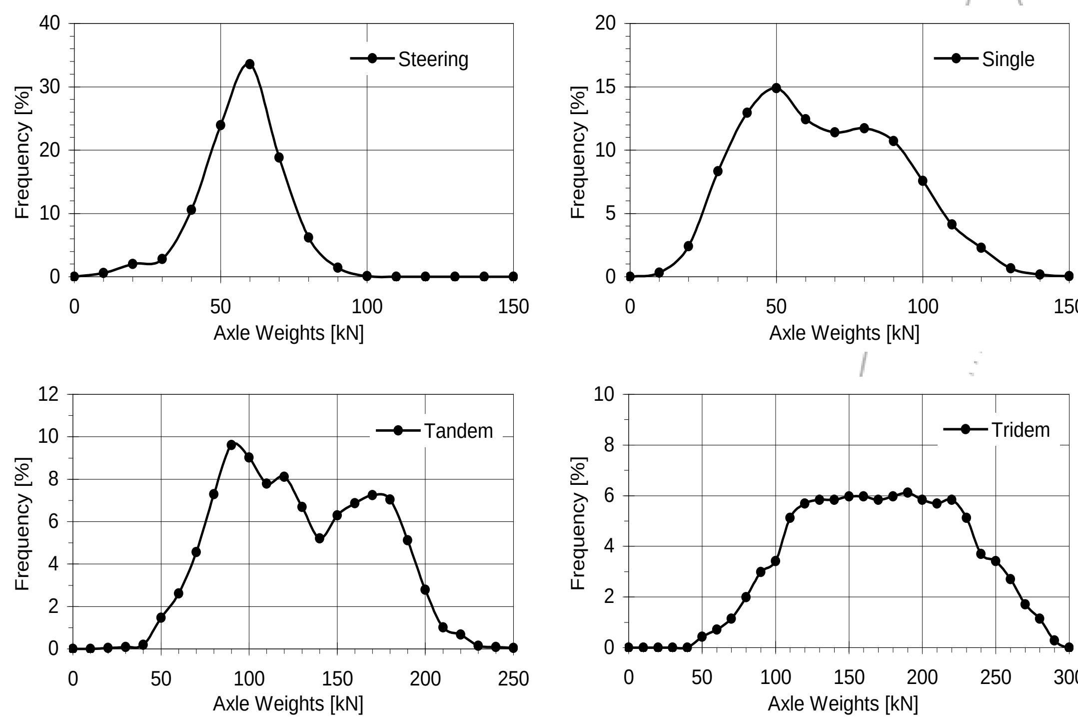
Permanent deformation on the surface

$$\hat{\delta}_p = \sum_{i=1}^{n} \hat{\varepsilon}_{p_i} \Delta z_i$$

Traffic loading: Axle Load Spectra (ALS)



Weigh-In-Motion (WIM) data



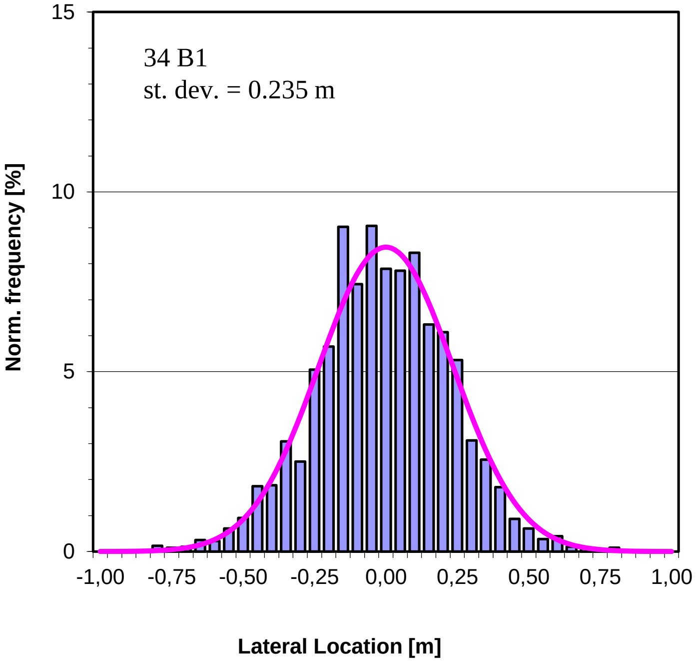
Steering axles

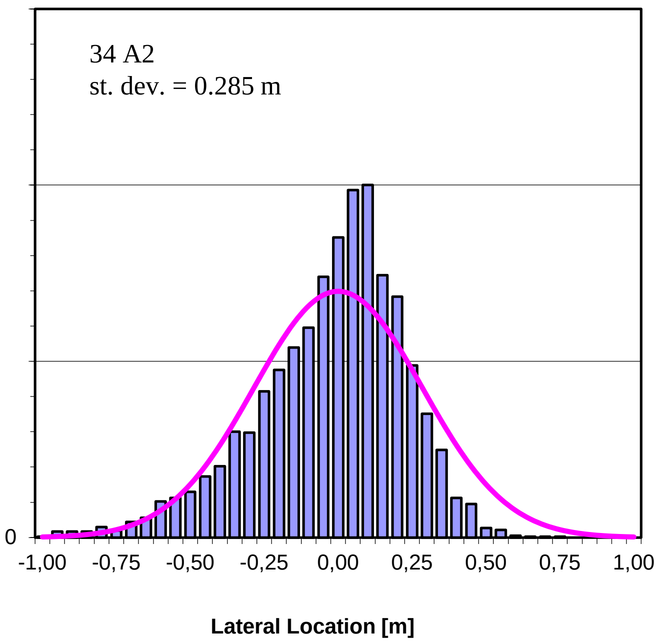
Single axles

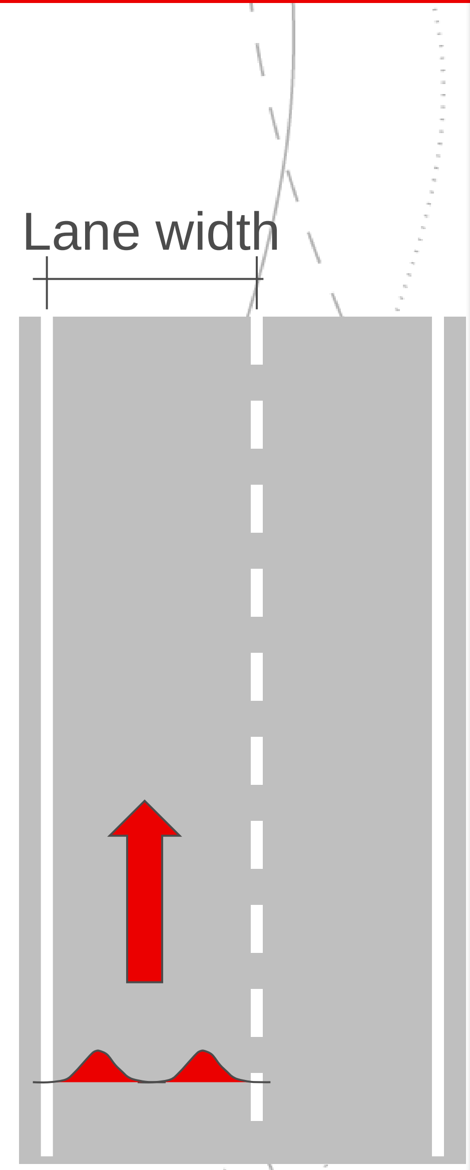
Tandem axles

Tridem axles

Lateral Wander

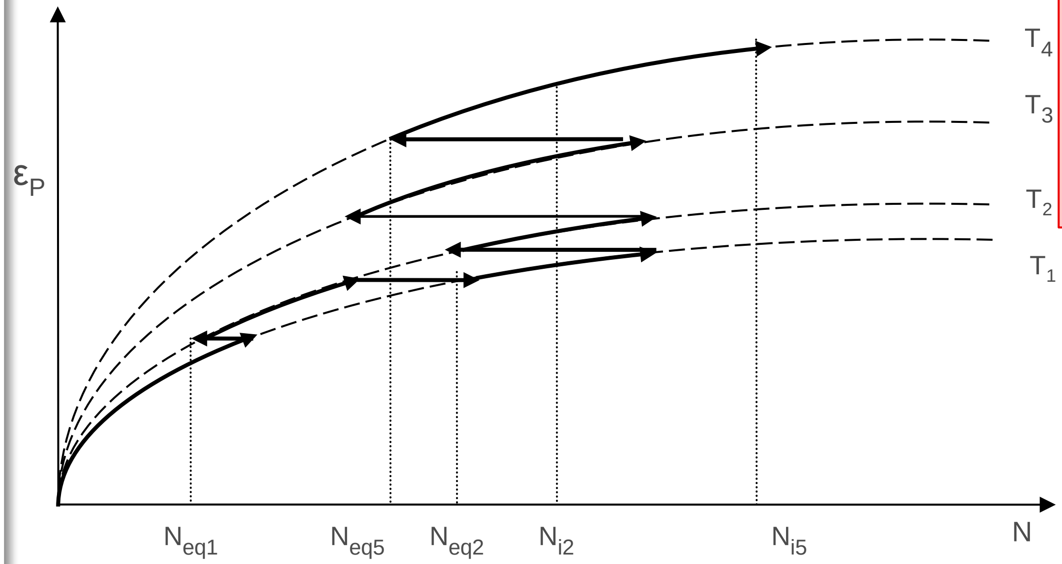






Accumulation (Superposition) of perm. strain

Time hardening approach



Step j

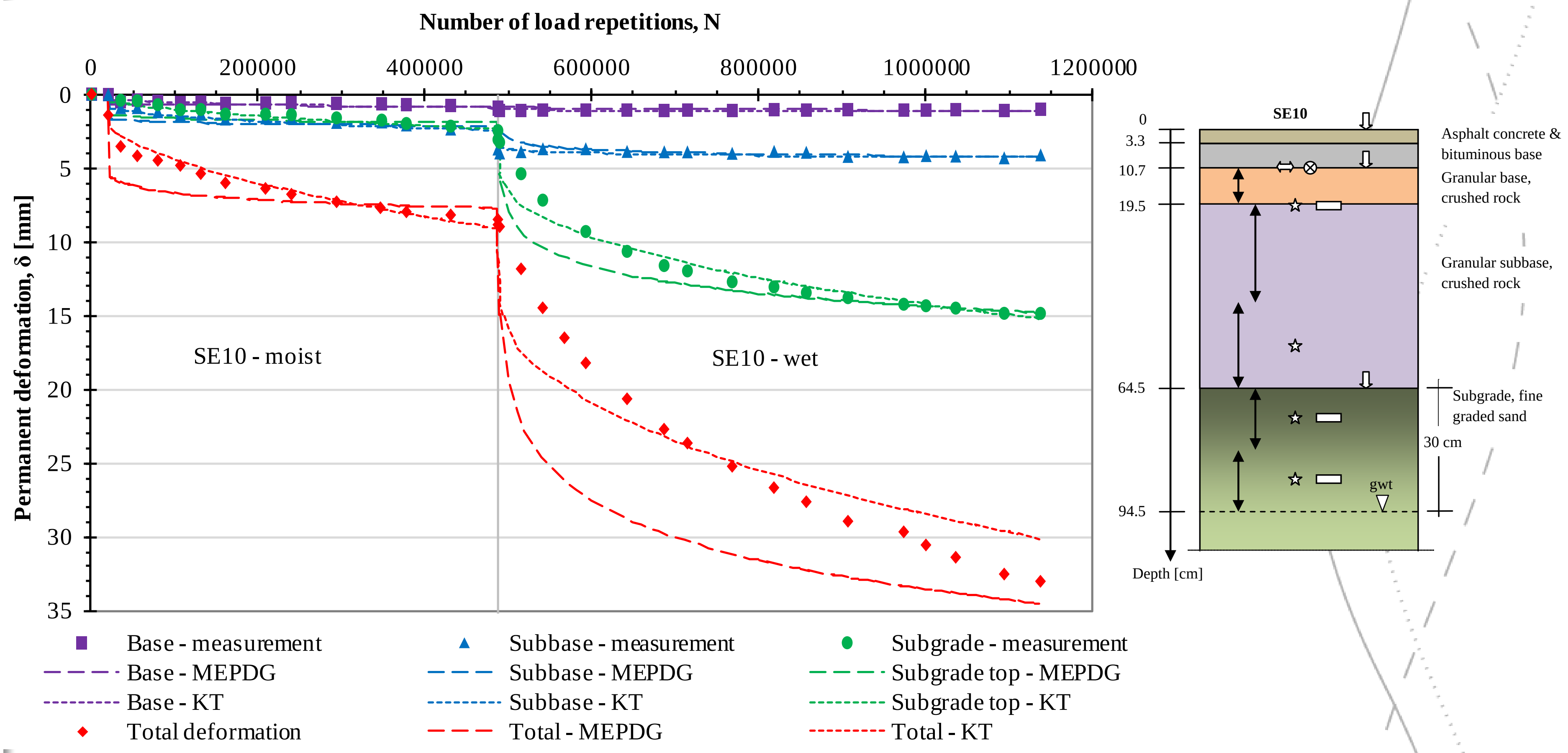
$$N_{eq_j} = \left[\frac{\hat{\varepsilon}_{p_{j-1}}}{\hat{\varepsilon}_{p_j}(N=1)} \right]^{\frac{1}{m}}$$

$$\hat{\varepsilon}_{p_j} = \hat{\varepsilon}_{p_{j-1}} + \hat{\varepsilon}_{p_j}(N=1) \cdot \left[\left(N_{eq_j} + \Delta N \right)^m - N_{eq_j}^m \right]$$

j= j+1

Next j

Accumulation of permanent deformation



Conclusions

The proposed M-E framework seems to adequately predict permanent deformation

MLET response program (ERAPave) that can handle linear or nonlinear elastic materials has been developed

Simple three parameter hardening model can be used to predict the permanent deformation using time hardening scheme to sum up the contributions from different axle load, lateral wander, temperature etc.

Tensile strain at the bottom of the bound layer in combination with Miner´s rule is used for predicting fatigue damage.

Further developments

- Response calculation
  - Visco-elasticity (AC layer)
  - Aging
- Climate model
  - Moisture
  - Frost/thaw
- Performance prediction
  - IRI (Roughness)
  - Low temperature cracking
  - Wear from studded tyres
- Validation / Calibration
  - Real pavement performance
    - rut, fatigue, low temperature cracking, IRI

Further developments cont.

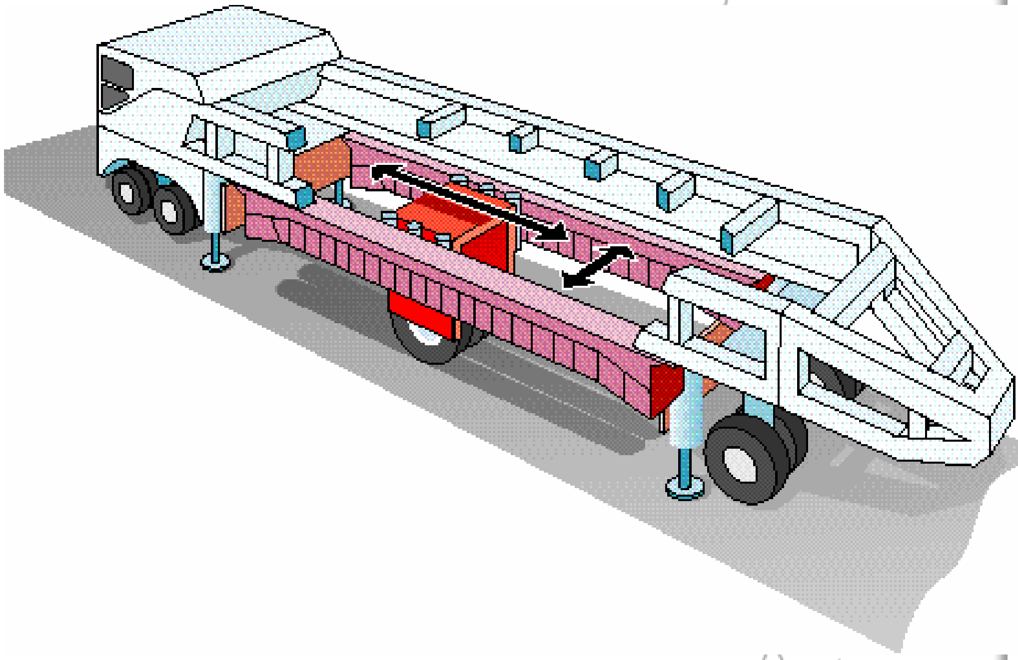
- Full scale testing
  - Heavy Vehicle Simulator (HVS)
  - Instrumented test road structures

- Field testing & monitoring
  - Falling Weight Deflectometer (FWD)
  - Monitoring program (temperature and moisture)

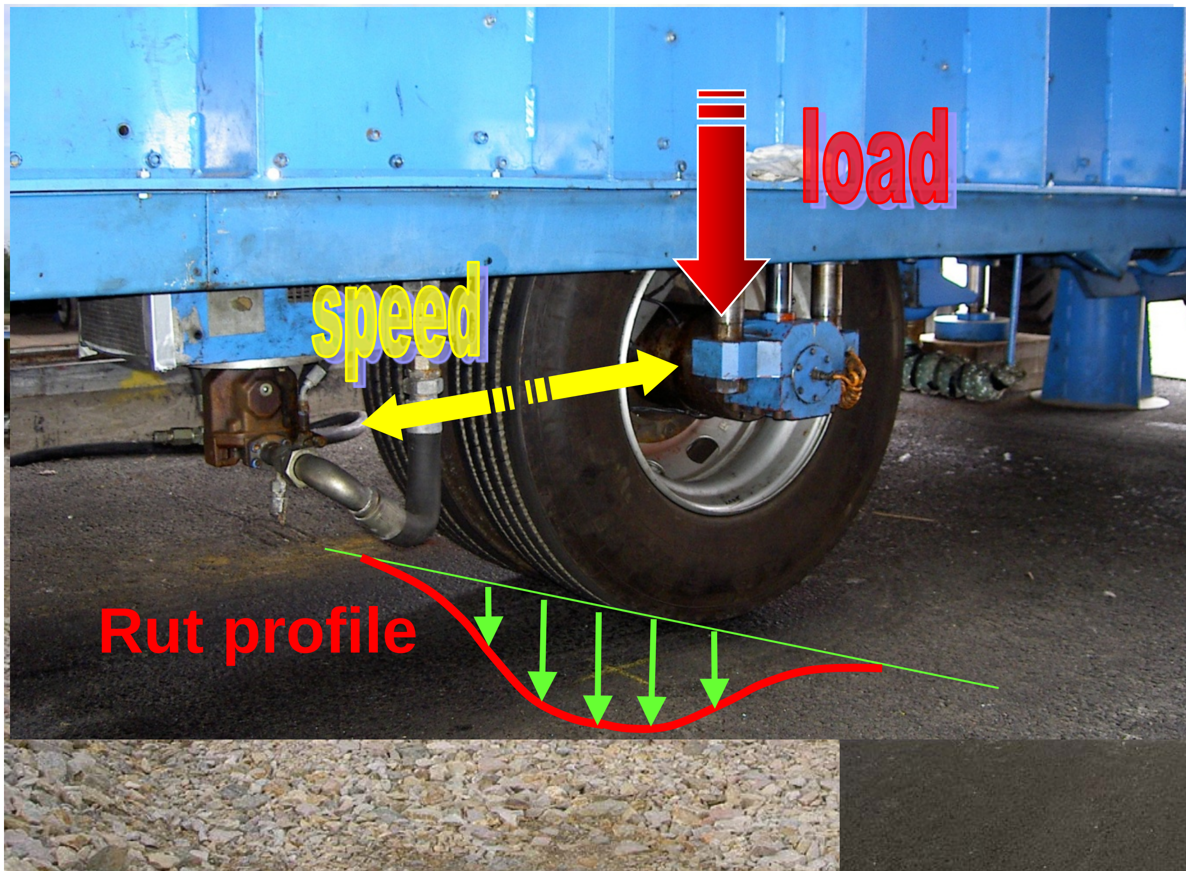
- Laboratory testing
  - Extra Large Wheel Tracking (ELWT) test
  - Repeated Load Triaxial (RLT) tests

Heavy vehicle simulator (HVS)

- For accelerated testing of road structures
- Can simulate one year's heavy traffic in just one week.
- Control of load, speed, temperature, tyre pressure, lateral position and direction of loading.

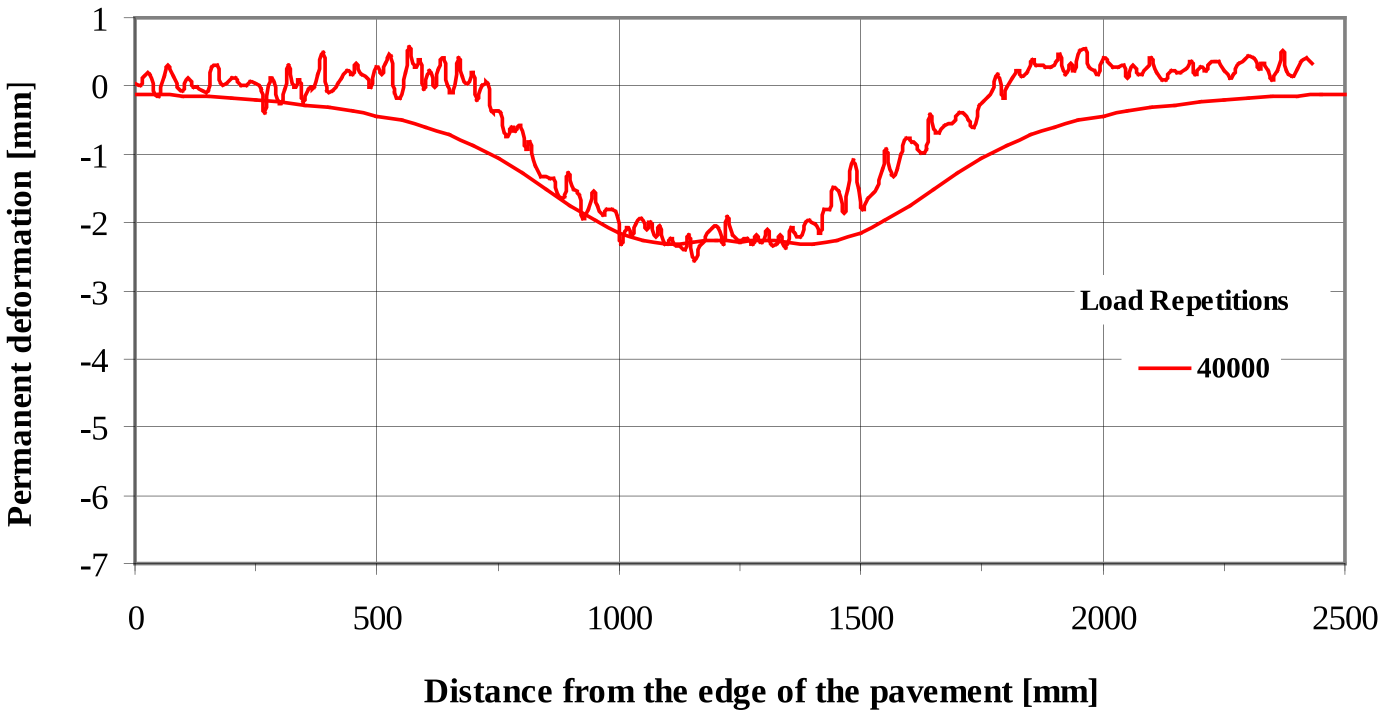


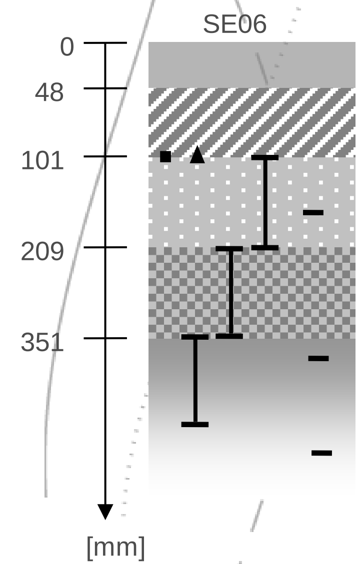
The HVS Nordic cont.



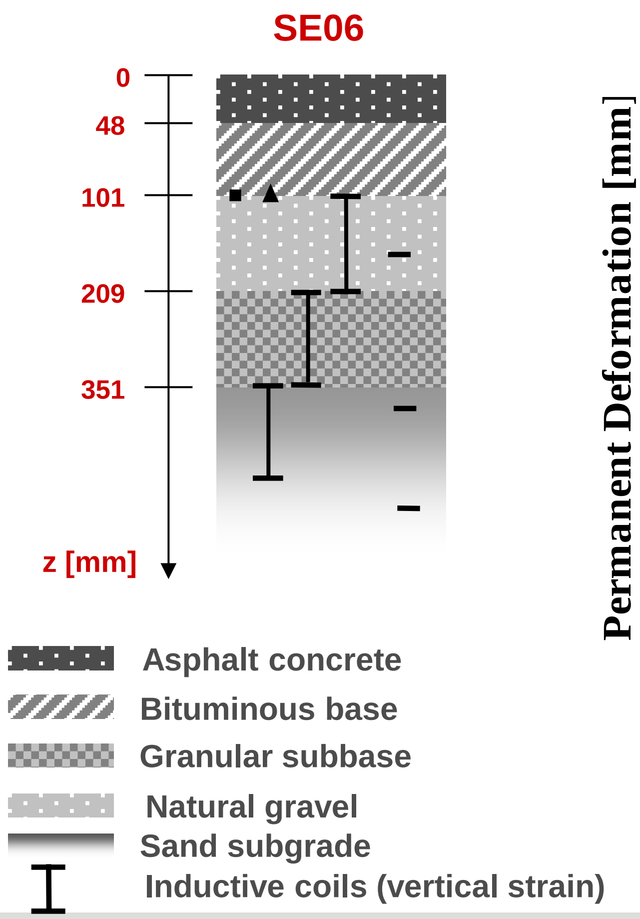
HVS rutting profiles

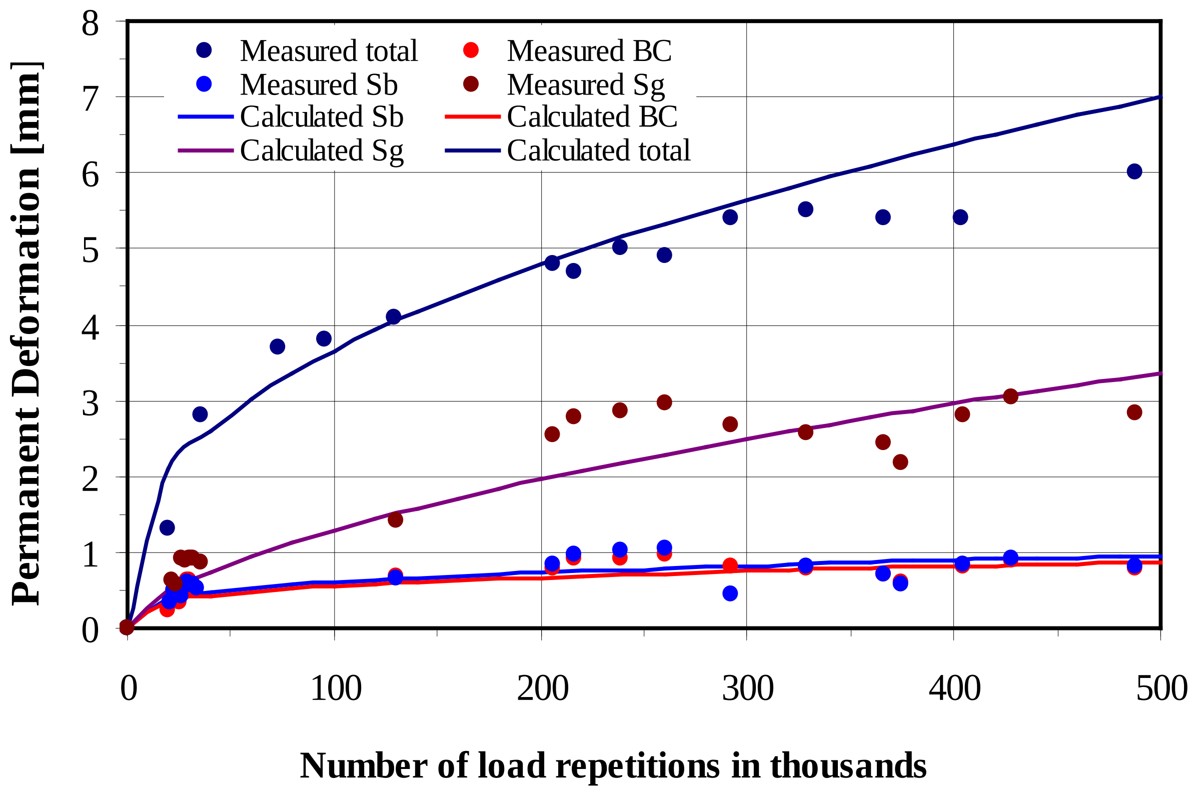
- comparison between measurement and calculation





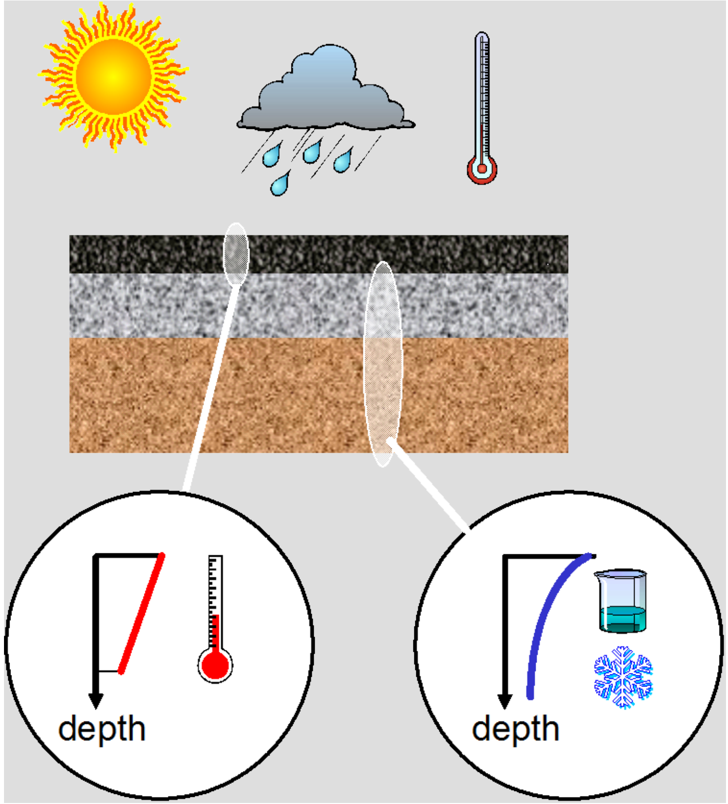
Validation using HVS measurements





Influence of climate on the degradation process

- Temperature
- Moisture (water)
- Freeze/thaw



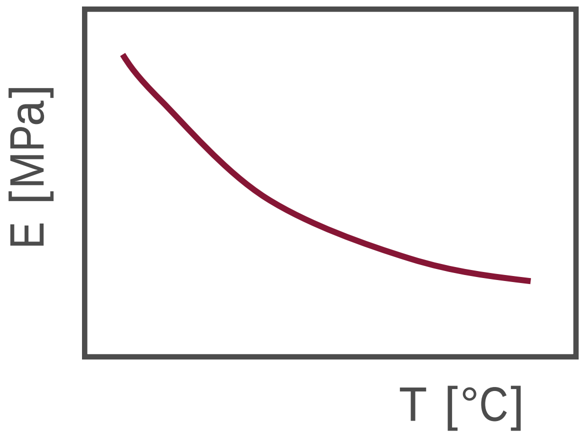
Temperture dependency (AC)

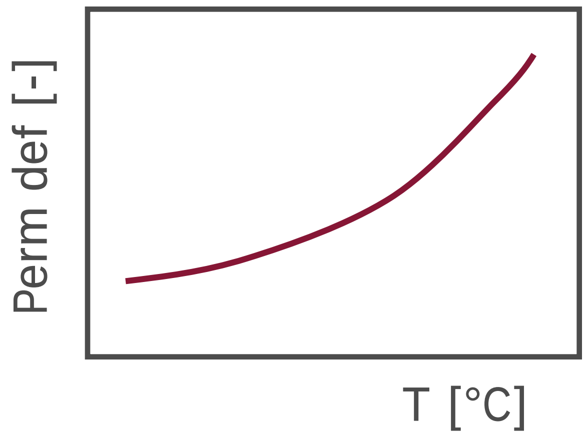
Material properties of Asphalt Concrete are highly temperature dependent:

- Stiffness
- Permanent deformation properties
- Fatigue cracking

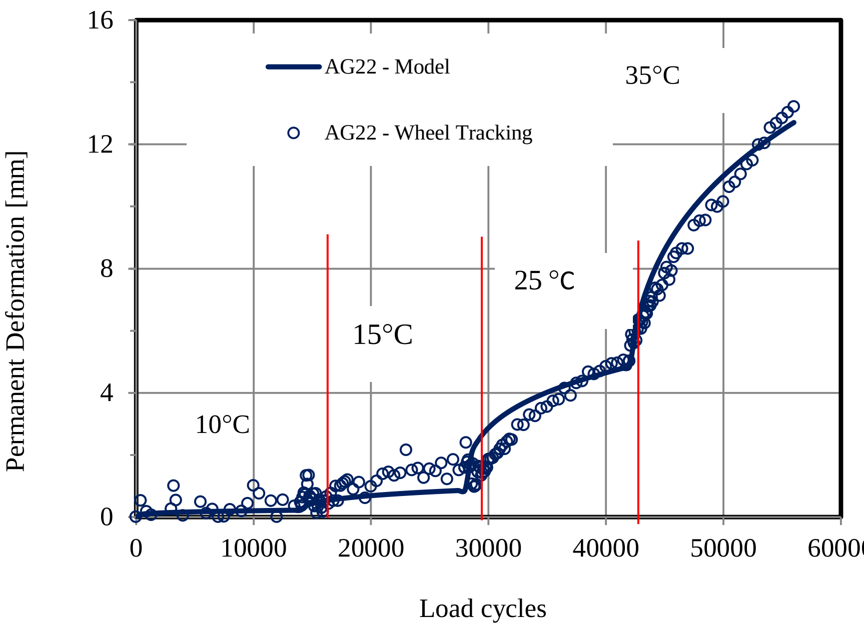
Further:

- Ravelling, bleeding

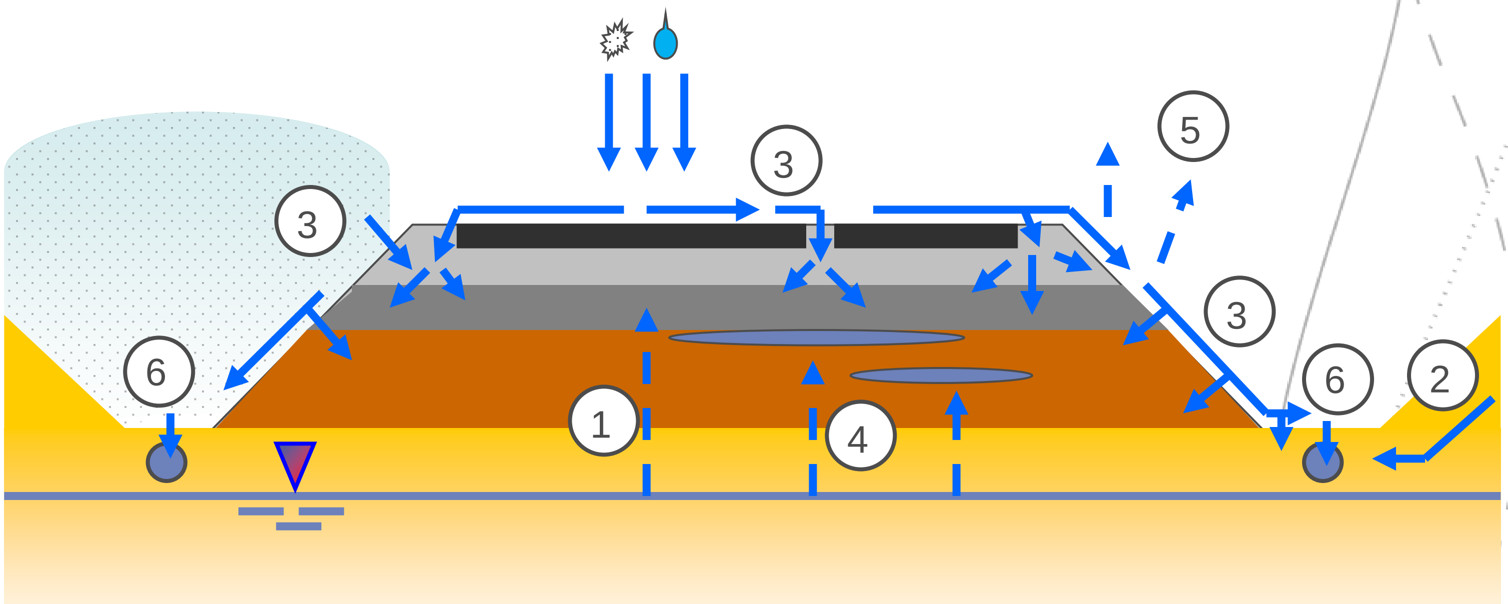




AC
Wheel tracking test: Perm. Def. development



Water (moisture) impact



Water intake

1 Capillary rise

2 Lateral transfer of moisture

3 Infiltration from precipitation

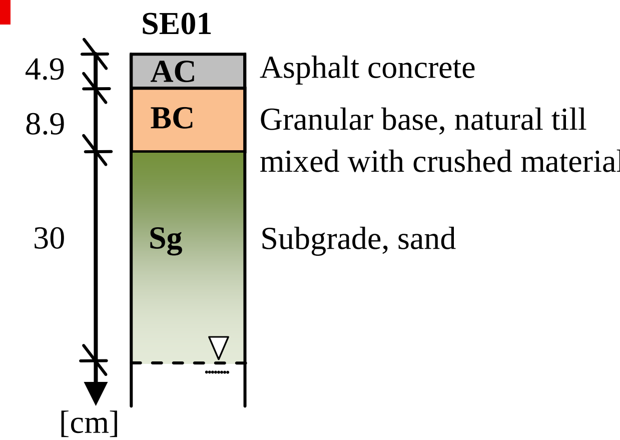
4 Frost action - capillarity

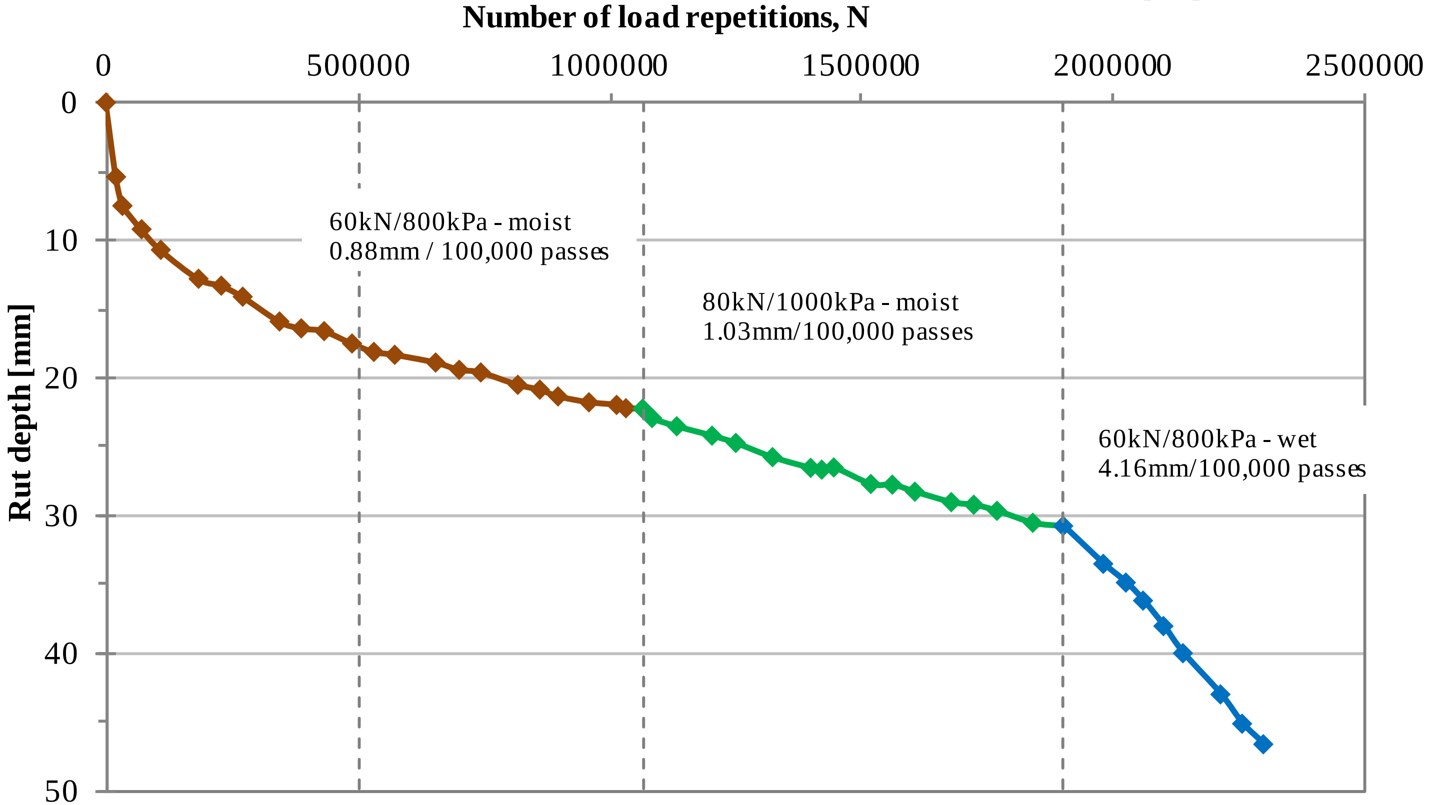
Moisture extraction

5 Evaporation

6 Drainage

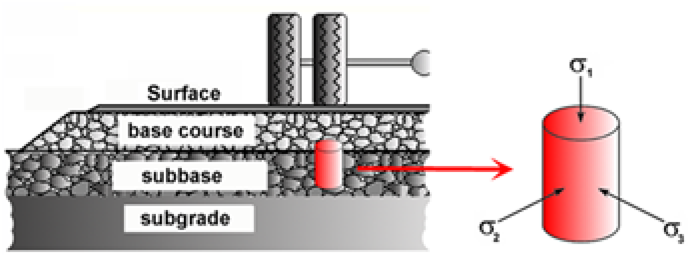
Influence of water

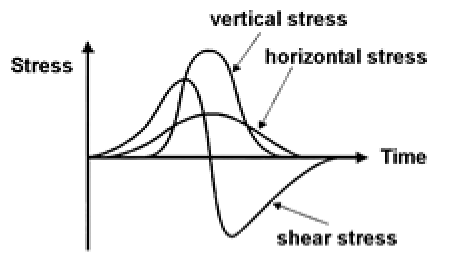


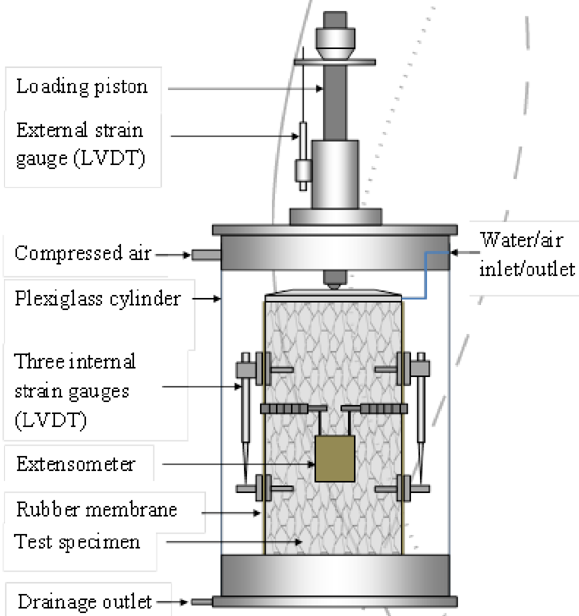


Unbound granular layers

- Repeated-Load Triaxial (RLT) test is used to study the permanent deformation behaviour.
- In RLT test, a cylindrical specimen is subjected to cyclic stresses corresponding to field conditions and the deformations are measured.

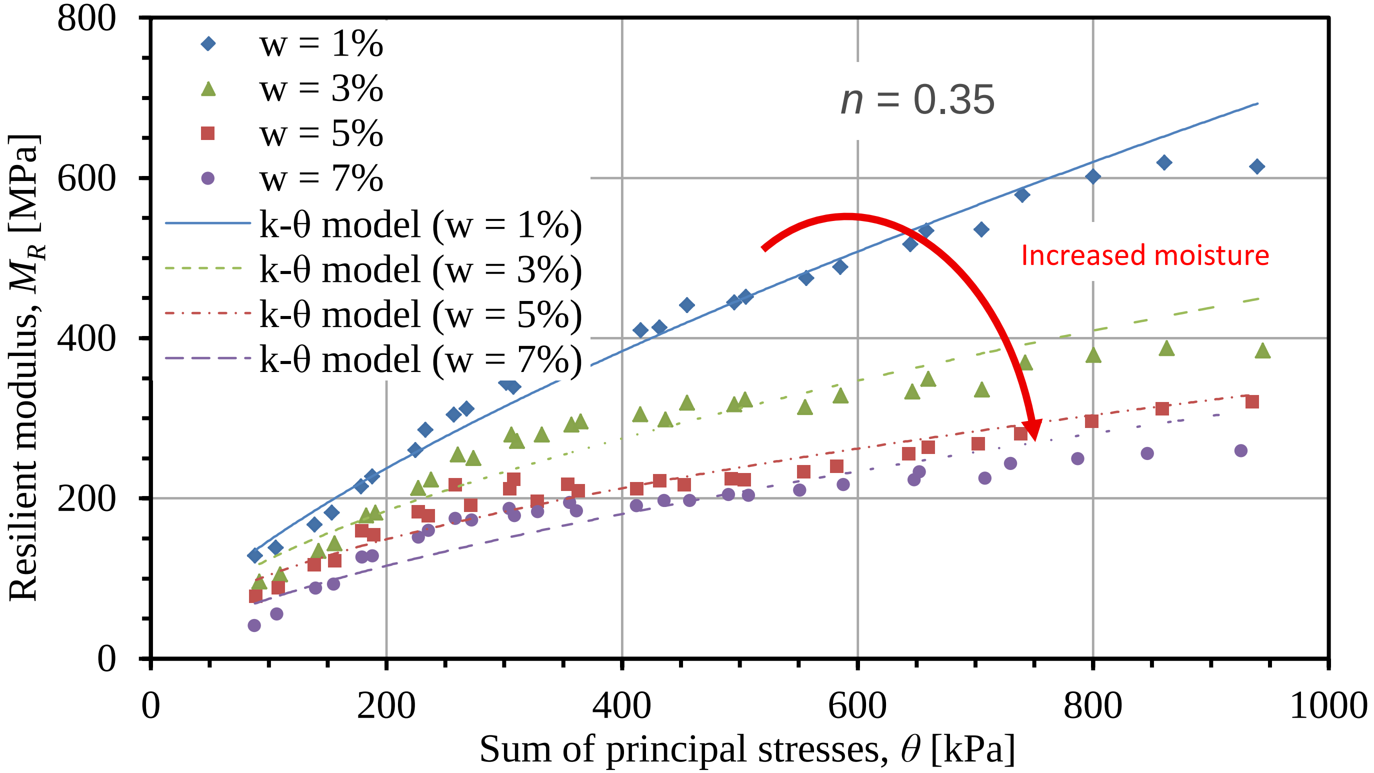






Stiffness vs. moisture content

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

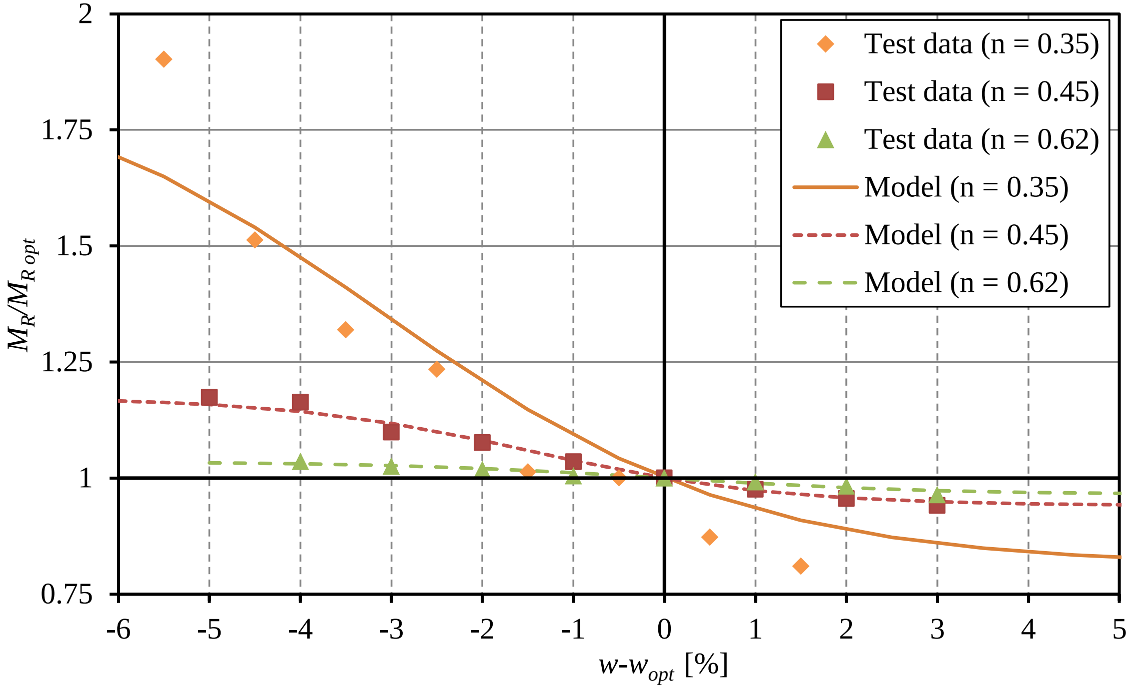


Moisture Impact on the Resilient Behavior

The MEPDG model:

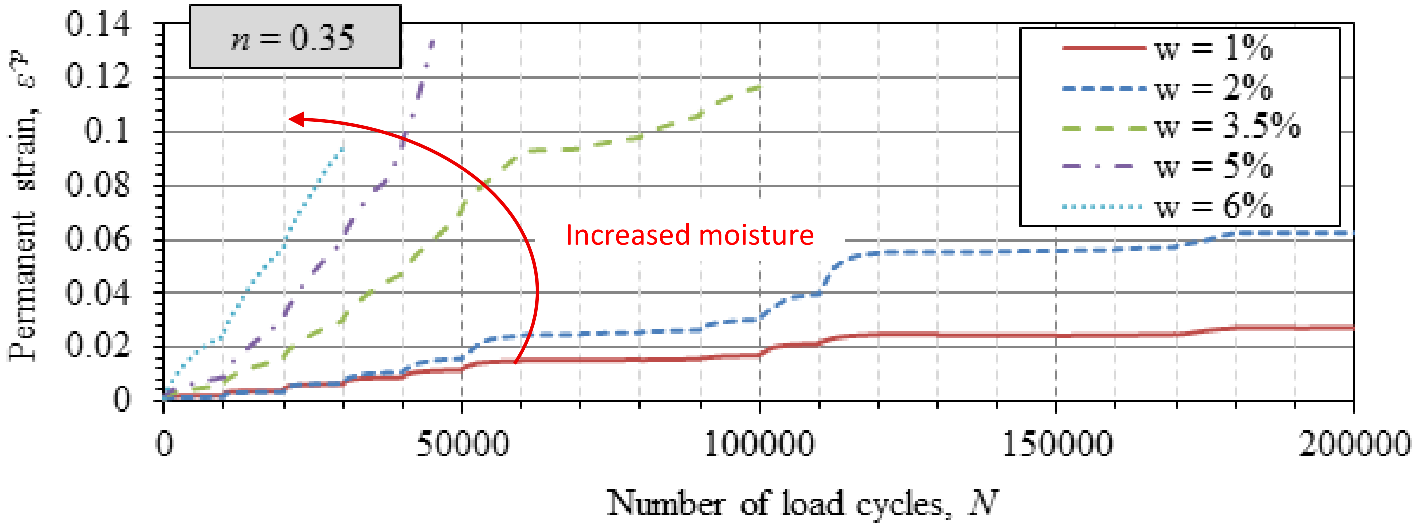
$$\log_{10}\frac{M_R}{M_{Ropt}} = \log_{10} a + \frac{\log_{10} b - \log_{10} a}{1 + EXP(\beta + k_w(w - w_{opt}))}$$

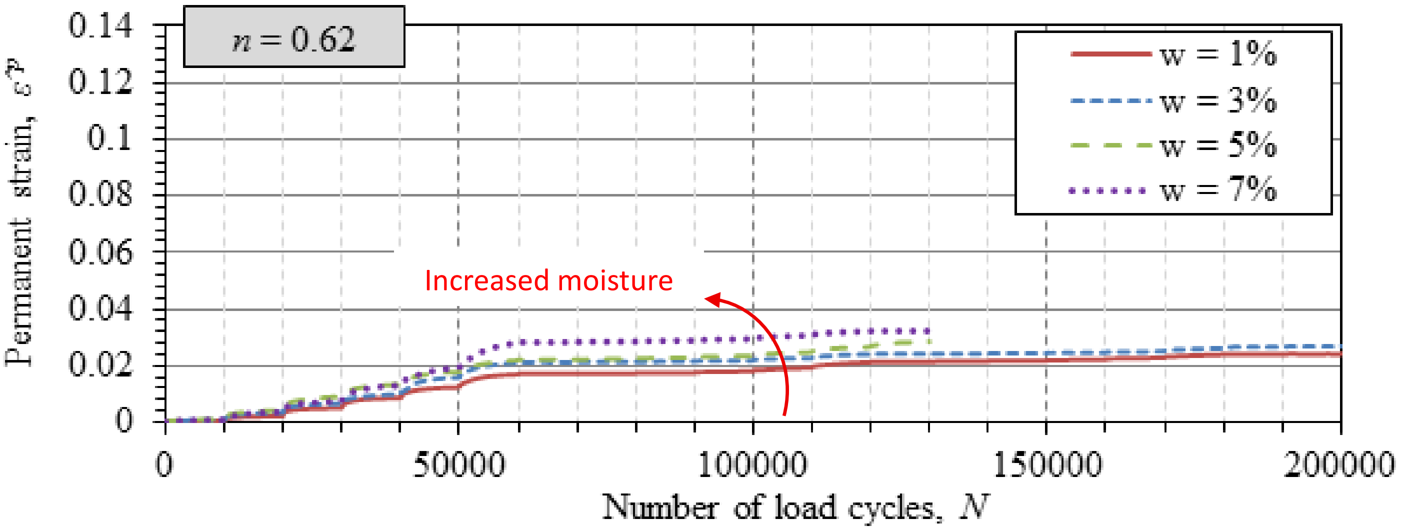
(Andrei, 2003)



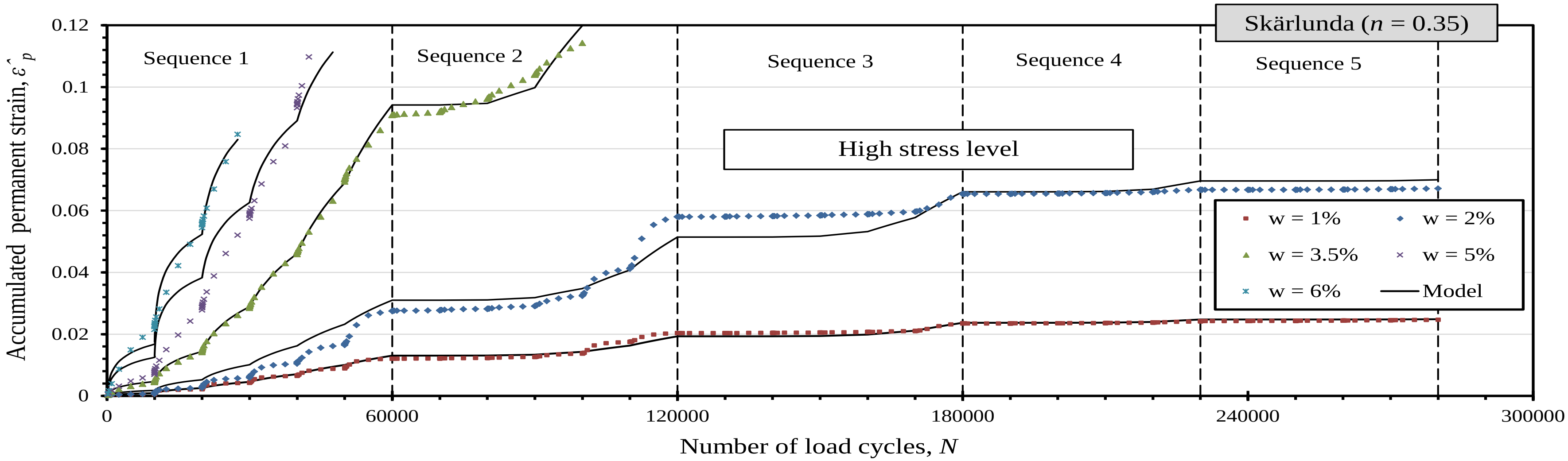
Grading coefficient, *n*	Parameters				R^2
	a	*b*	*β*	k_w	
0.35	0.810	1.902	1.118	49.545	0.887
0.45	0.941	1.174	0.961	74.473	0.984
0.62	0.964	1.036	-0.036	84.842	0.955

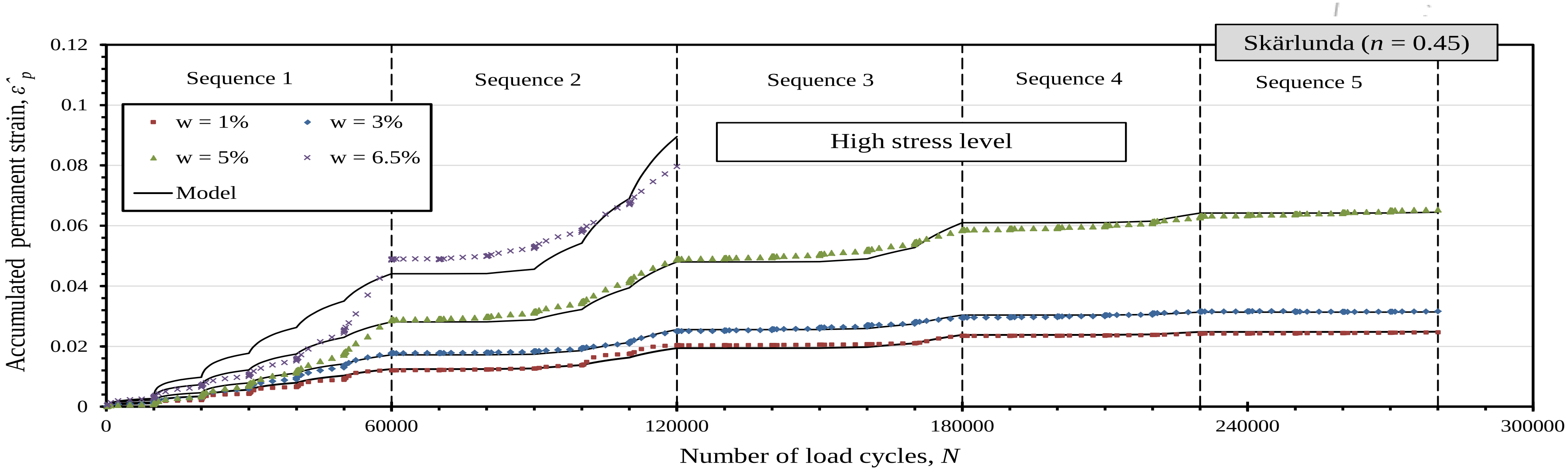
Permanent deformation : Impact of moisture





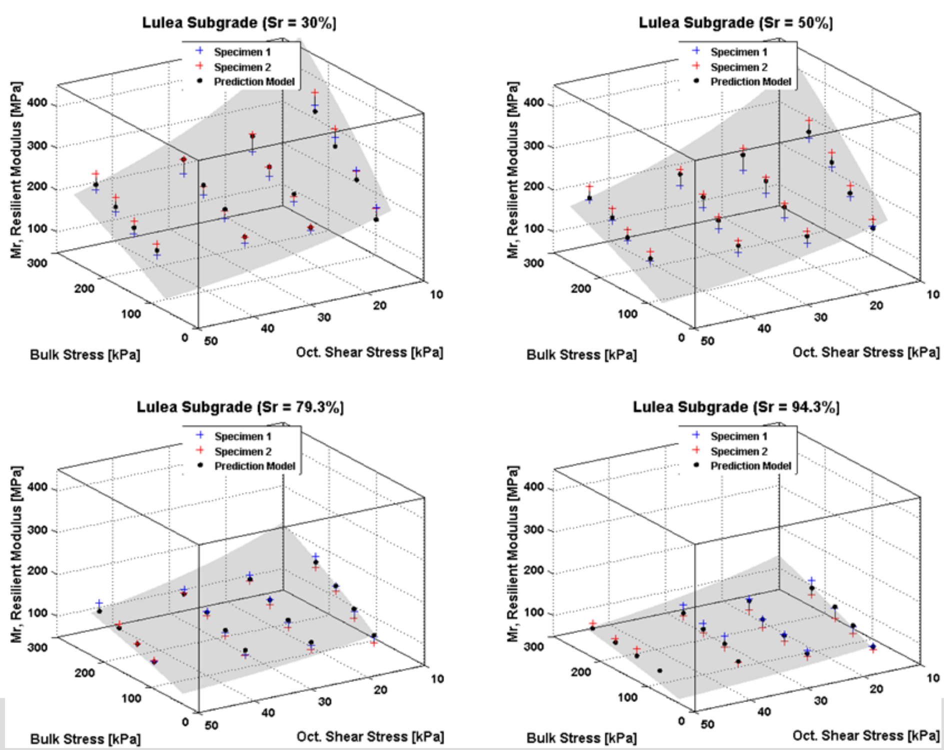
Fitting the model for a range of moisture contents

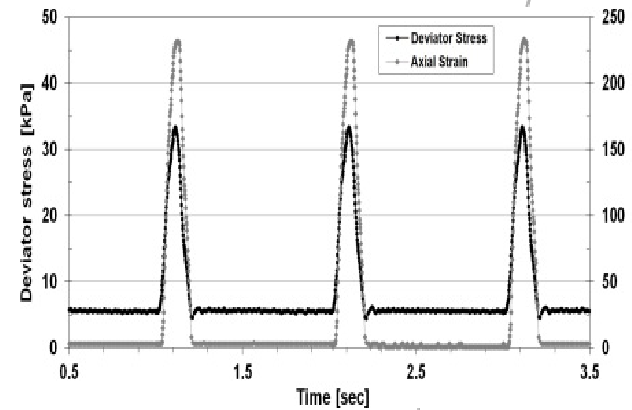


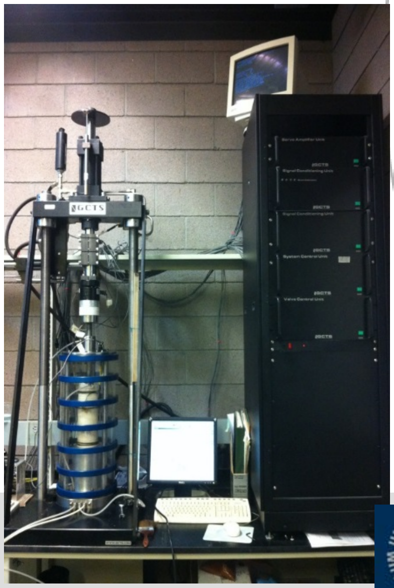


RLT test on subgrades: stiffness

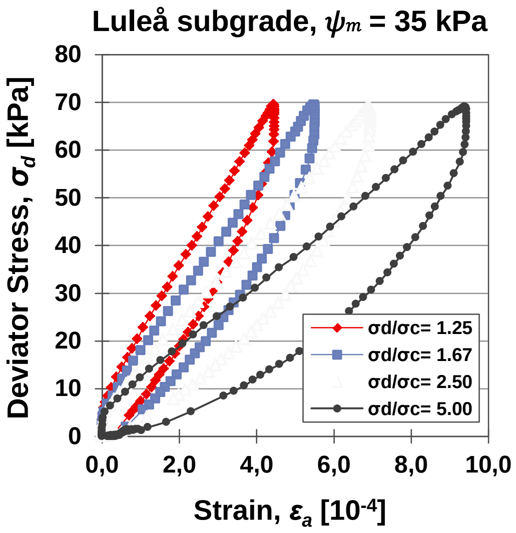
$$M_r = k_{12} \cdot p_a \cdot \left(\frac{\theta - 3\Delta u_{w-sat}}{p_a}\right)^{k_{13}} \left(\frac{\tau_{oct}}{p_a} + 1\right)^{k_{14}} \left(\frac{\psi_m - \Delta\psi_m}{p_a} + 1\right)^{k_{15}}$$

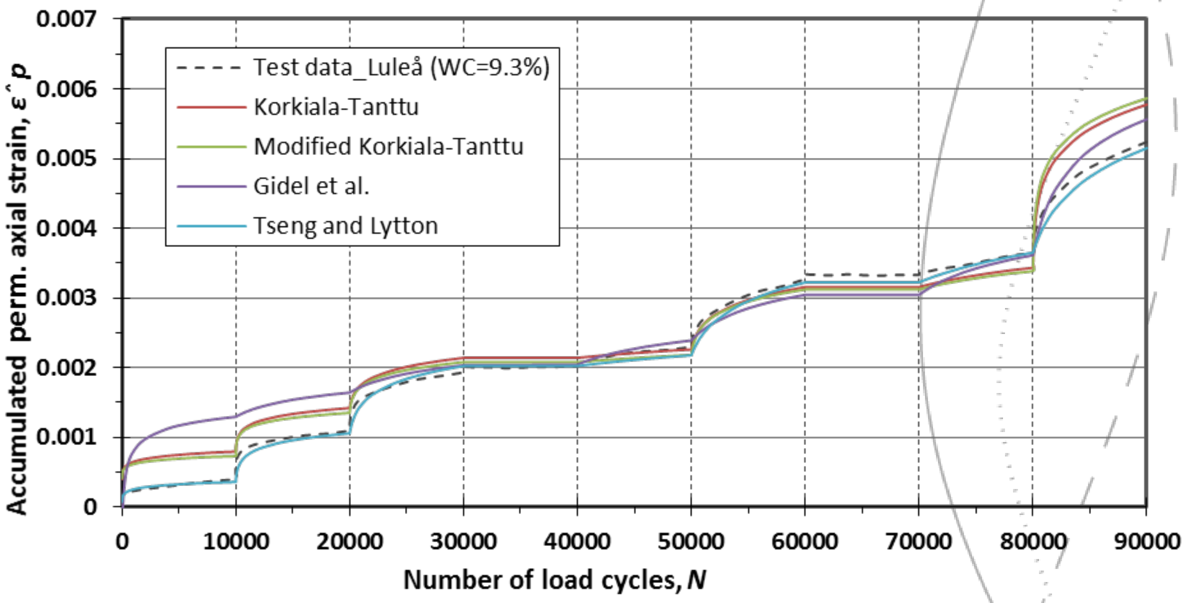






Subgrades: permanent deformation properties





vti

Frost and frost/thaw actions

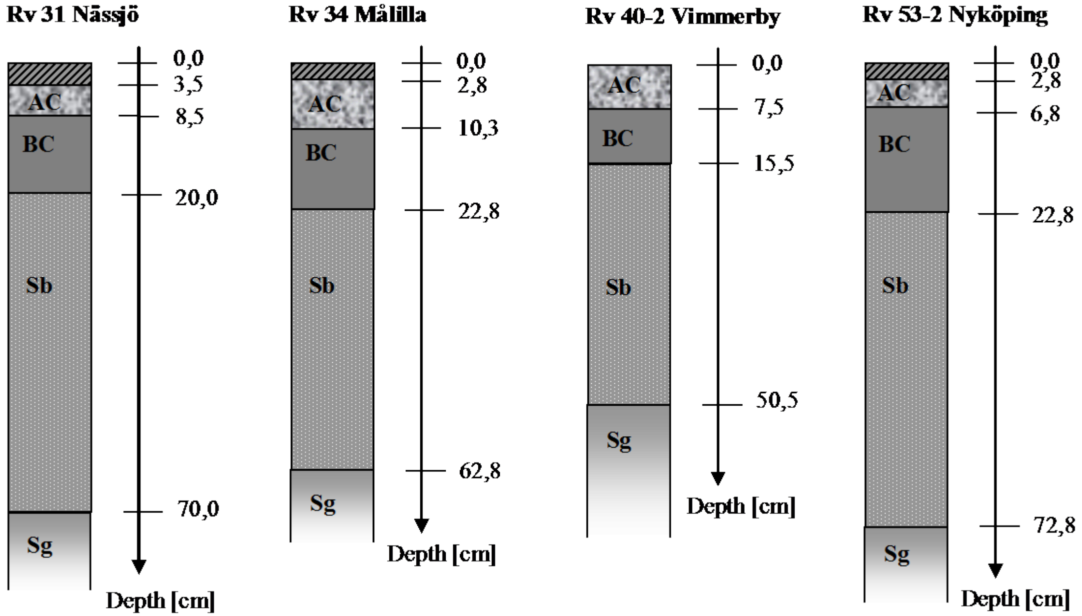
LTPP structures

All four structures belong to the Swedish Long Term Pavement Performance (LTPP) data base

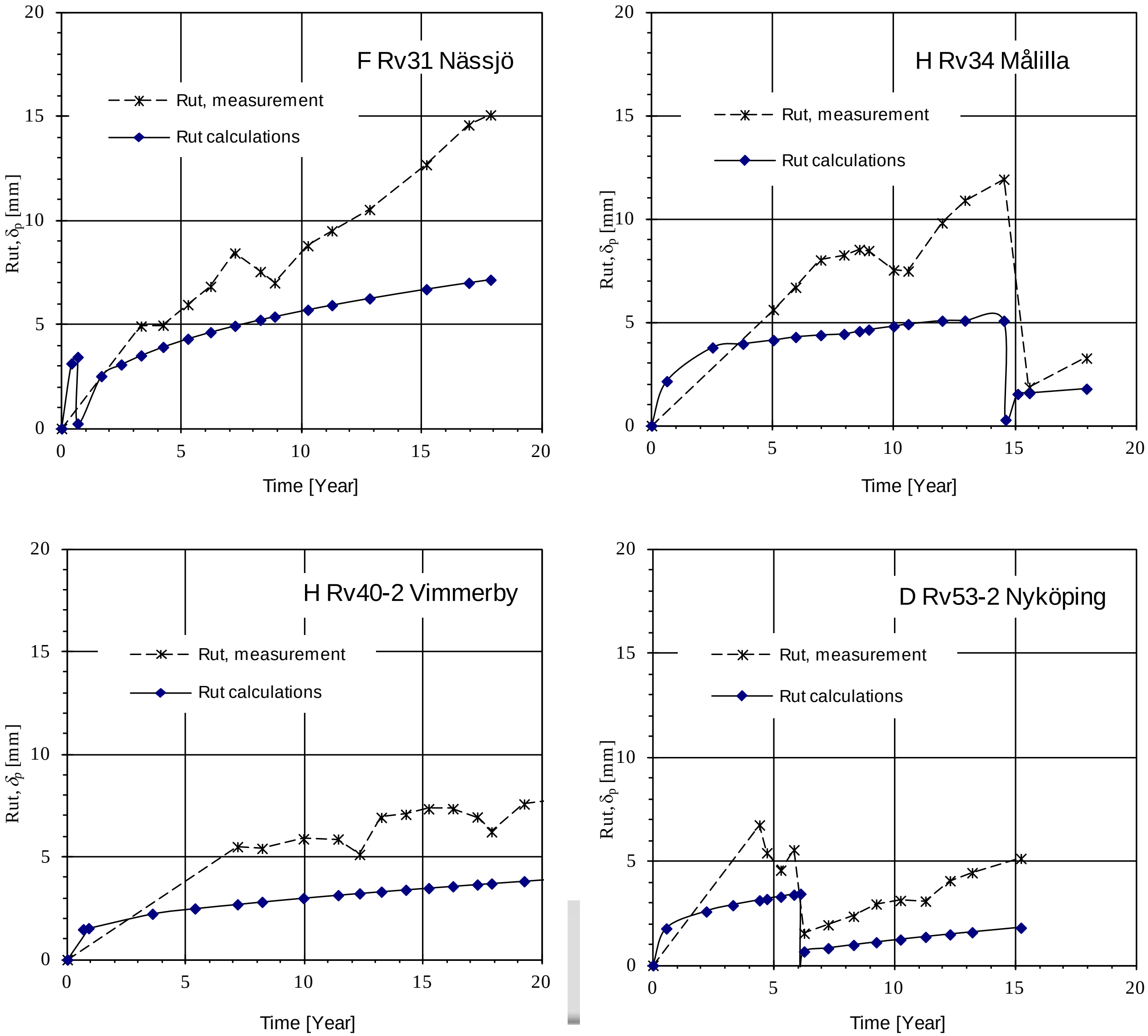
Built in between 1980 and 1988.

Monitored regularly.

Overlay on three structures



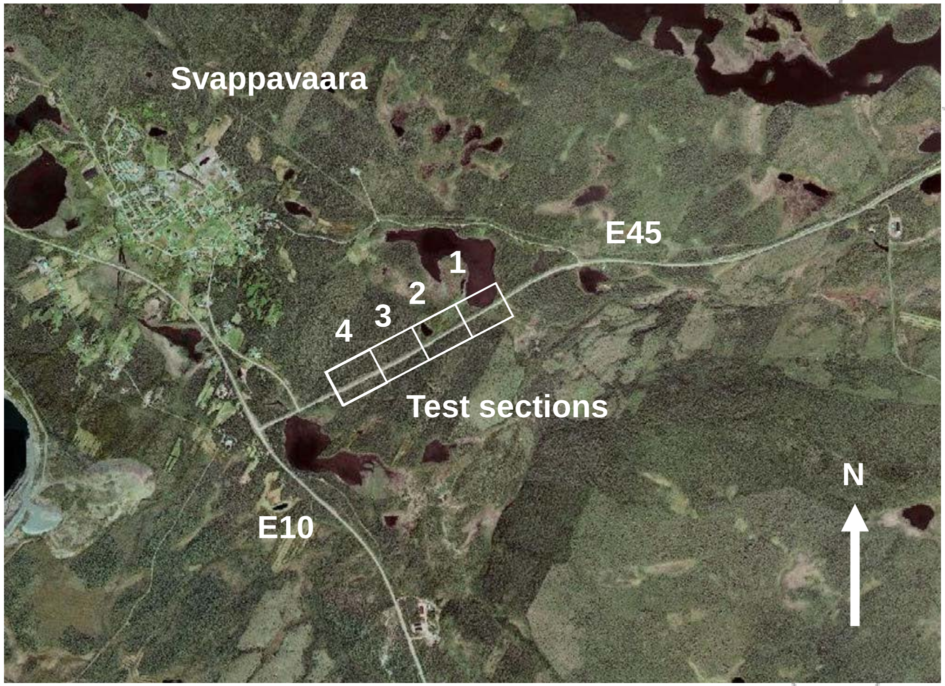
LTPP structures - rutting



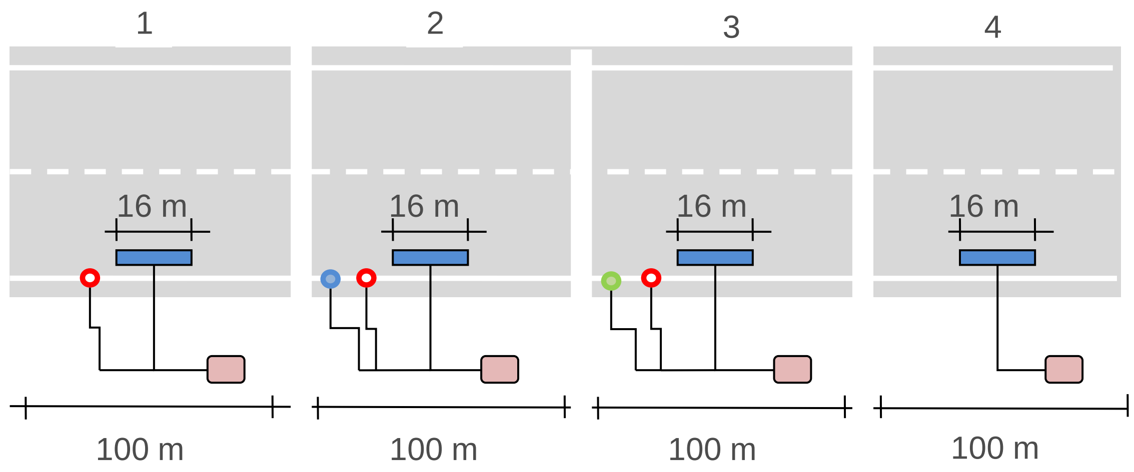
vti

The test sections

Four test sections are located on E45 close to Svappavaara village.



Instrumentation: E45 Svappavaara



Data logger 1, 2, 3 & 4

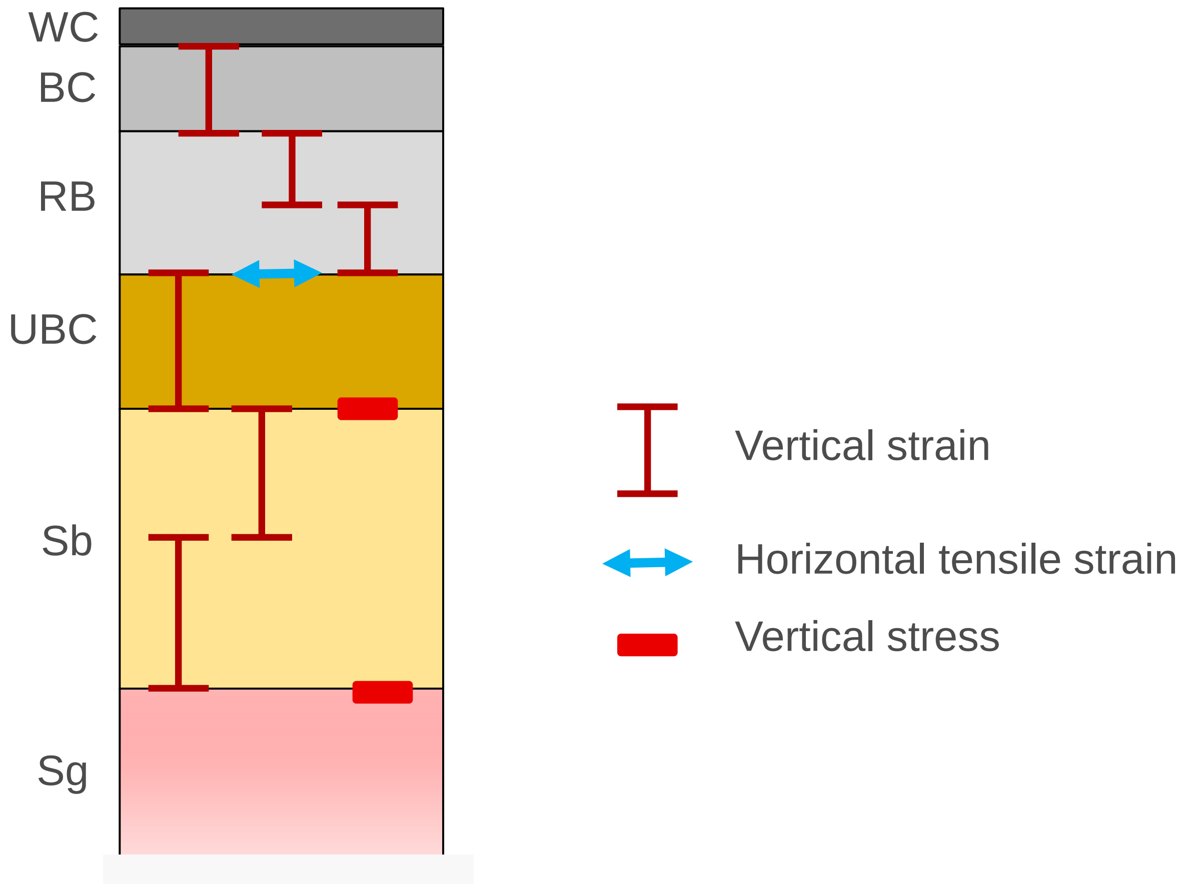
Road sensors instrumentation 1, 2, 3 & 4

Moisture rod 1, 2 & 3

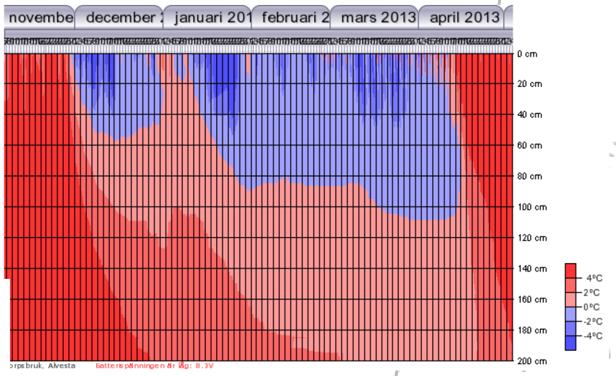
Temperature & frost rod 1 (3)

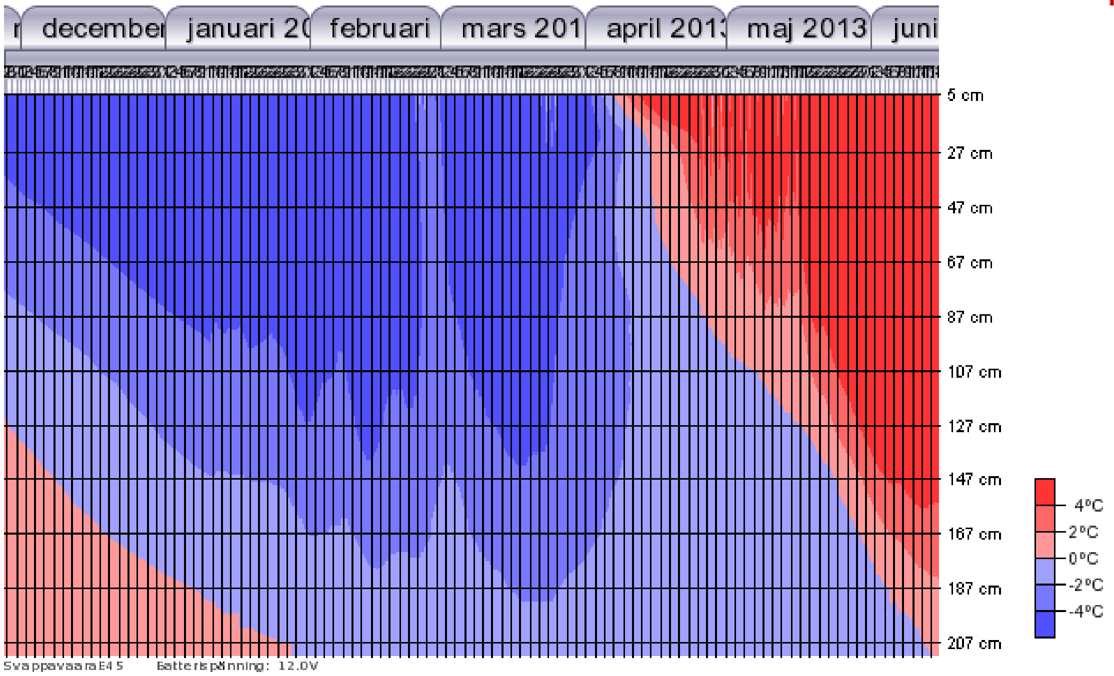
Temperature sensors in AC

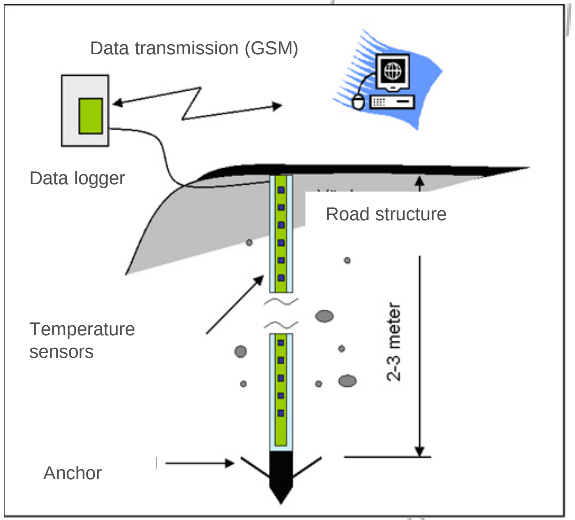
Instrumentation



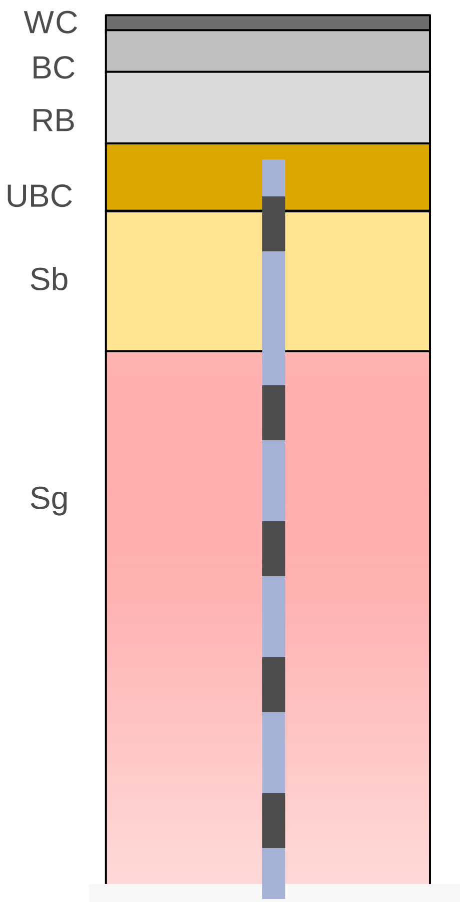
Frost depth penetrations

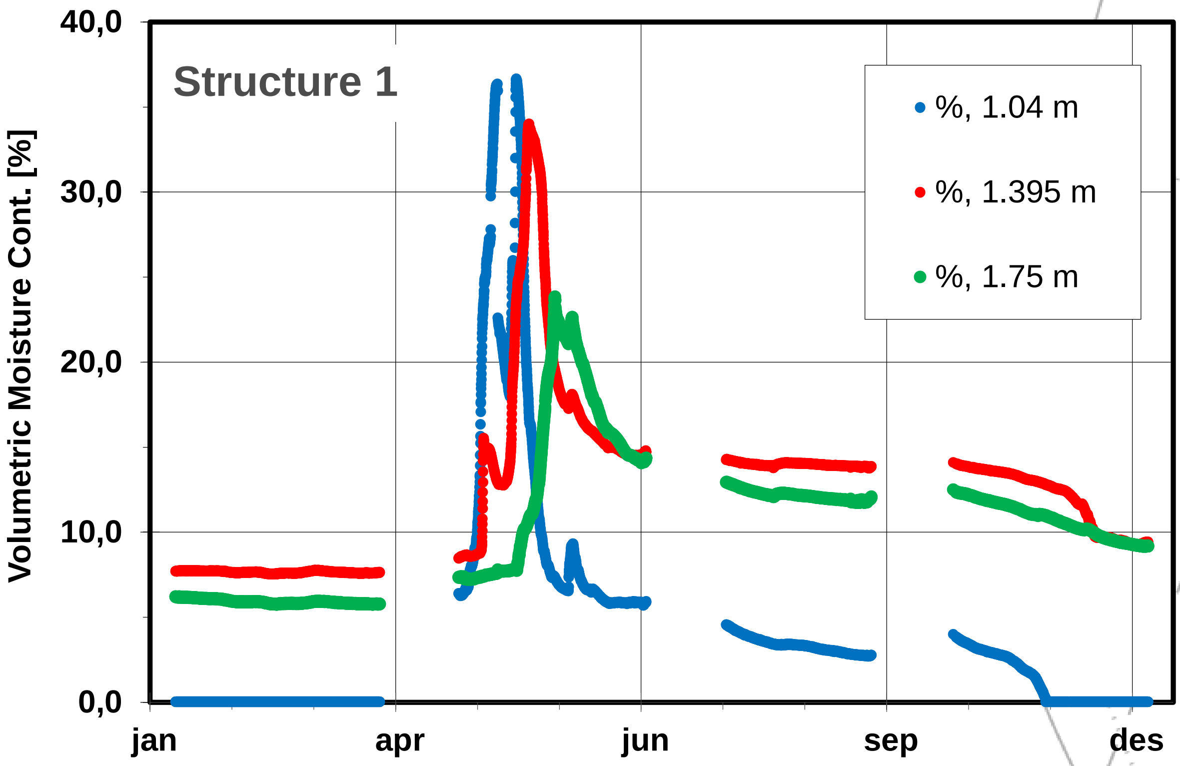






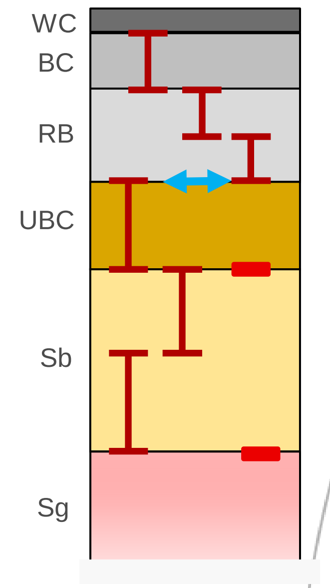
Moisture content (2013)

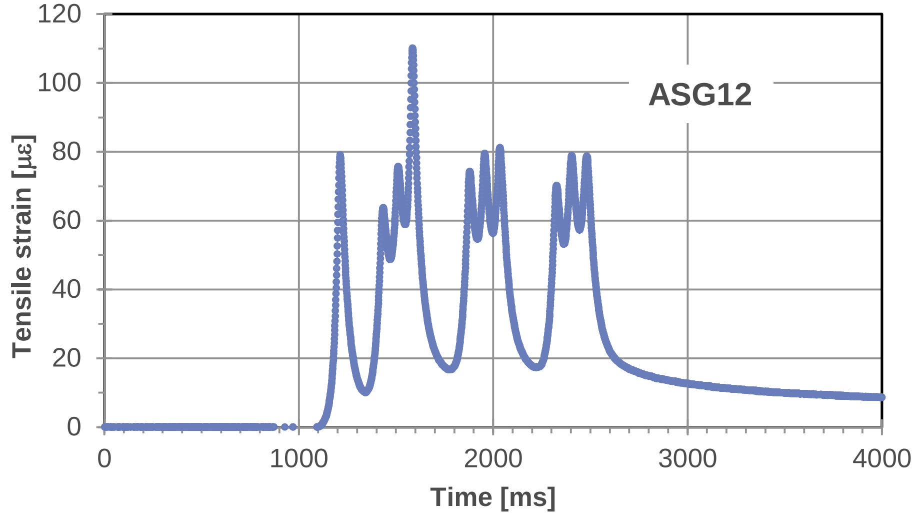


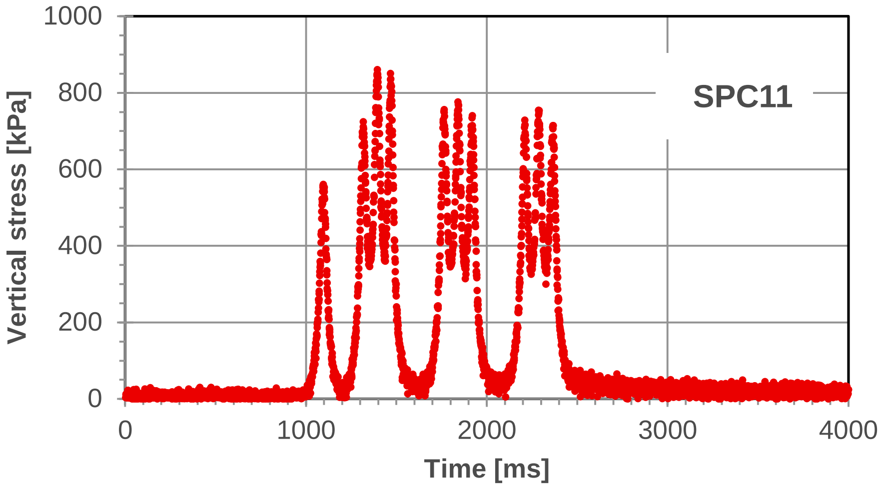


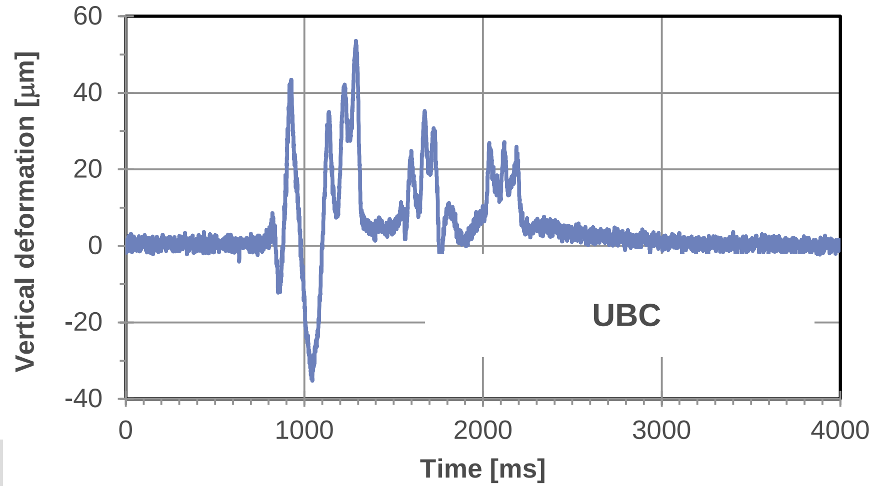
Response measurements

Response measurements









Summary / Conclusions

A new M-E framework for pavement performance predictions is under development in Sweden. At the moment the code can predict rutting and fatigue damage for flexible pavement structures.

Simple explicit models are be used to predict the permanent deformation using time hardening scheme to sum up the contributions from different axle load, lateral wander, temperature etc.

Tensile strain at the bottom of the bound layer in combination with Miner´s rule is used for predicting fatigue damage.

Enhanced climate model is under development where ambient temperature and moisture will be included.

Further distress modes are also under development.

Validation & calibration process is further needed.