i3C Symposium
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Structural behaviour of flexible pavements under seasonal moisture variations and frost/thaw conditions

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Overview

1. **Background**
2. **Full Scale Accelerated Pavement Testing (APT)**

   APT – HVS test results showing moisture dependency on the behaviour on unbound layers and subgrades.
3. **Laboratory Experiments**

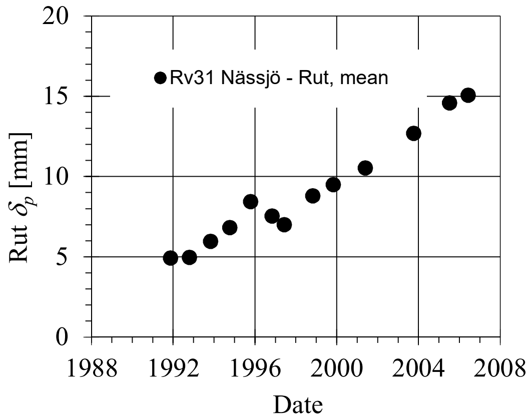
   Stiffness and accumulation of permanent deformation – observed behaviour and modelling.
4. **Full Scale Field Monitoring and Back-Calculation**

   Moisture in pavement structures and its influence on structural response due to heavy traffic loading.
5. **Pavement Design and Performance Prediction**
6. **Summary**

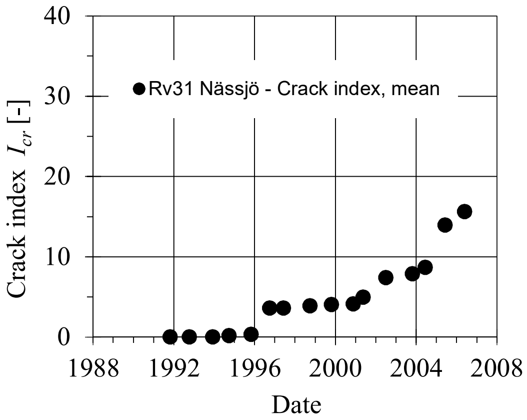
Background #1

Distress mechanisms

Rutting



Fatigue cracking



Studded tyre wear

Frost heave & cracking

Low temperature cracking

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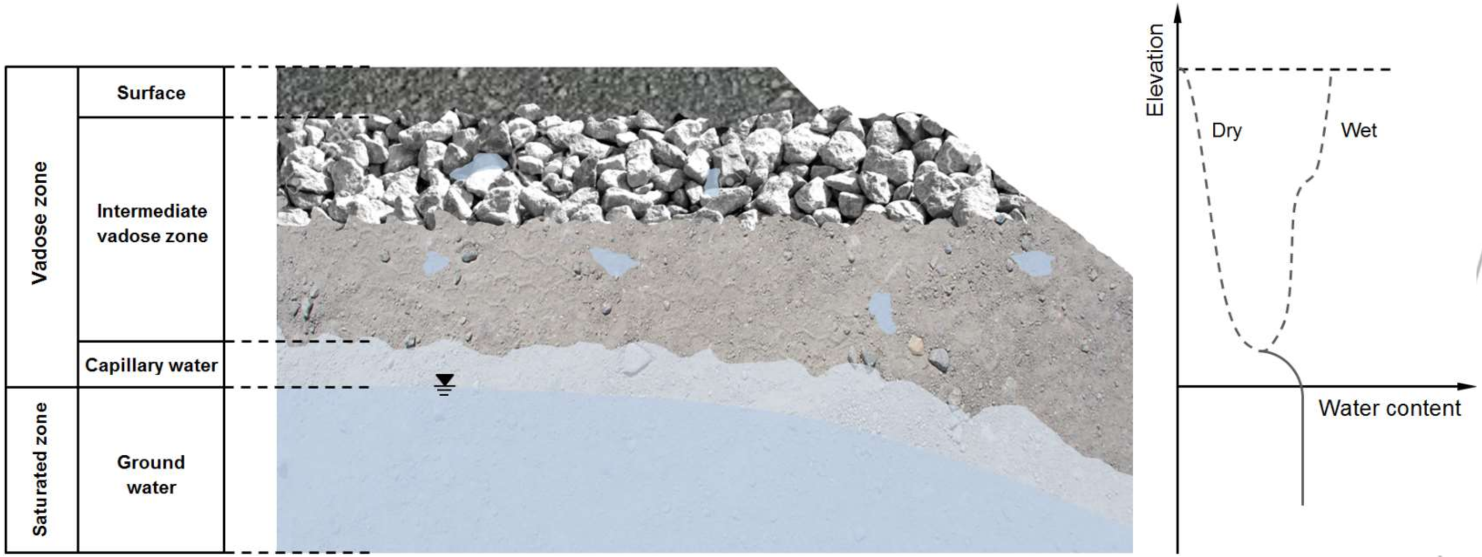
Background #2

Regions of water in pavements

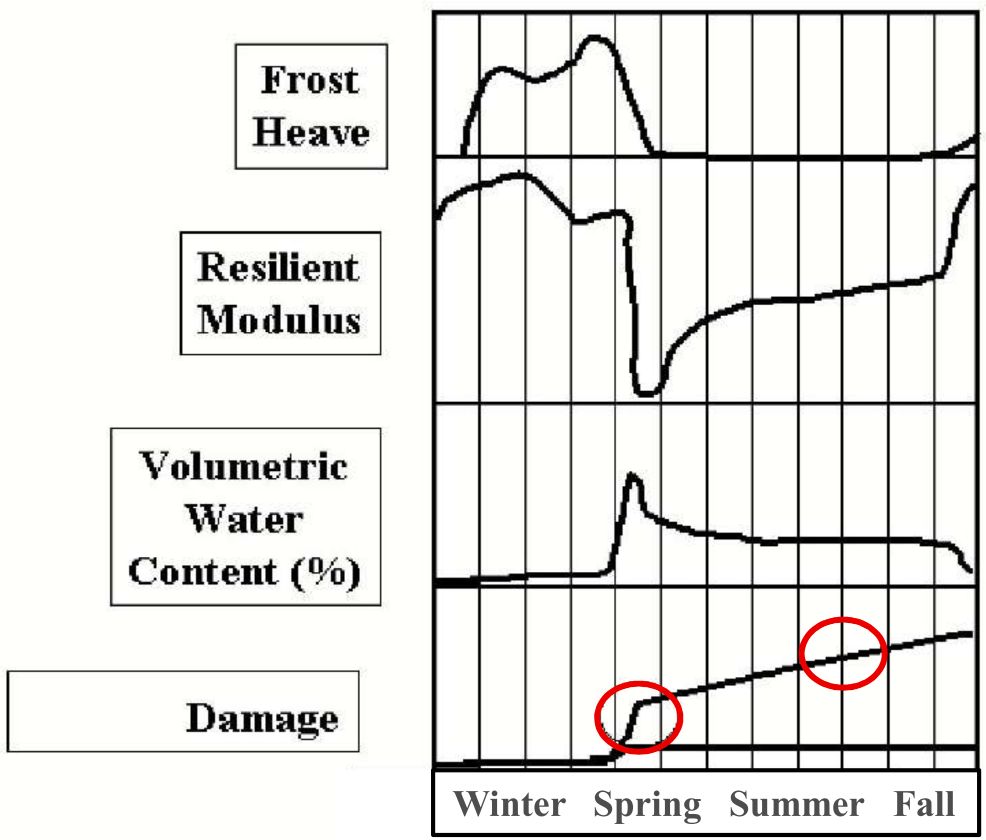


- **Vadose zone:**
  - Surface water
  - Intermediate vadose zone
  - Capillary water

- **Saturated zone**
  - Groundwater

Background #3

Damage accumulation in thin flexible pavements

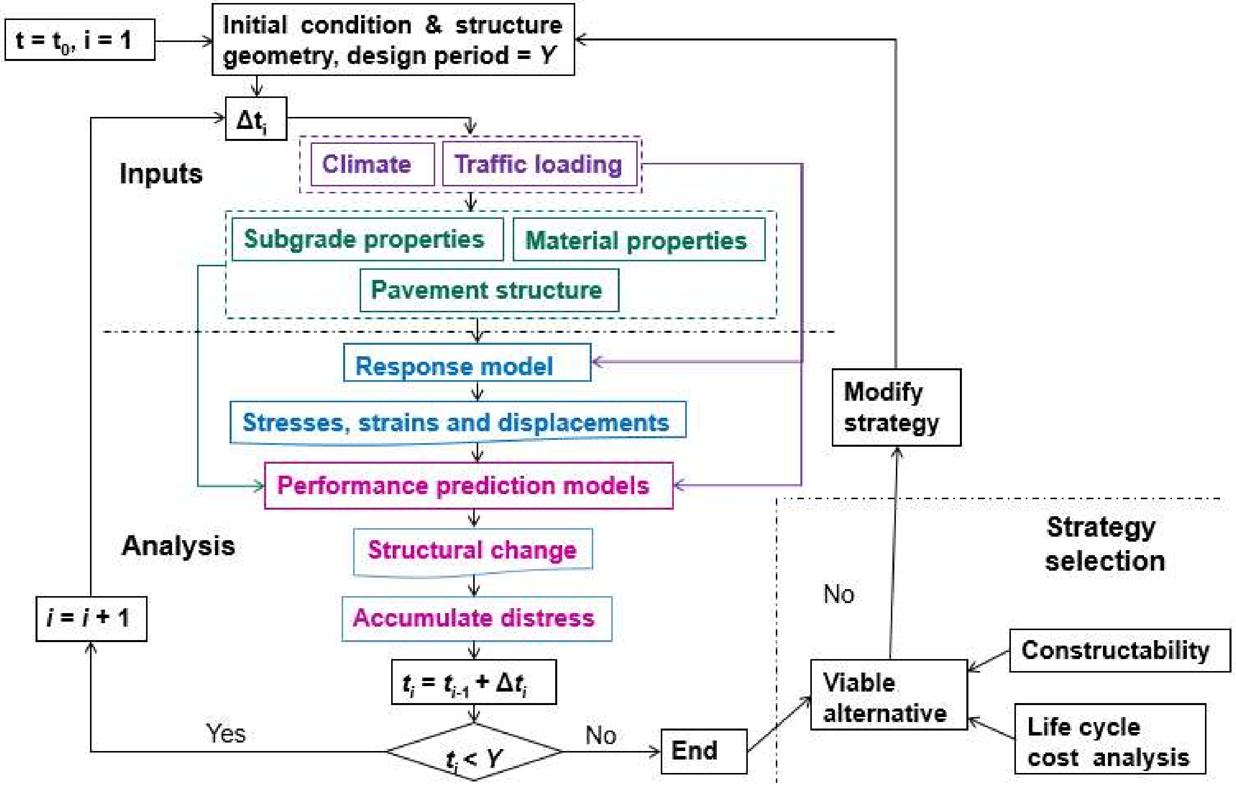


Kestler, M.A. 2003. “Techniques for Extending the Life of Low-Volume Roads in Seasonal Frost Areas”. Transport Research Record 1819, Paper no. LVR8-1150.

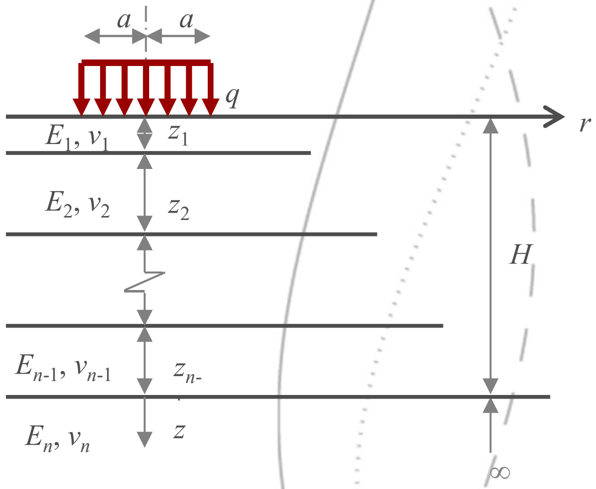
Background #4

M-E design ERAPave PP

Overview

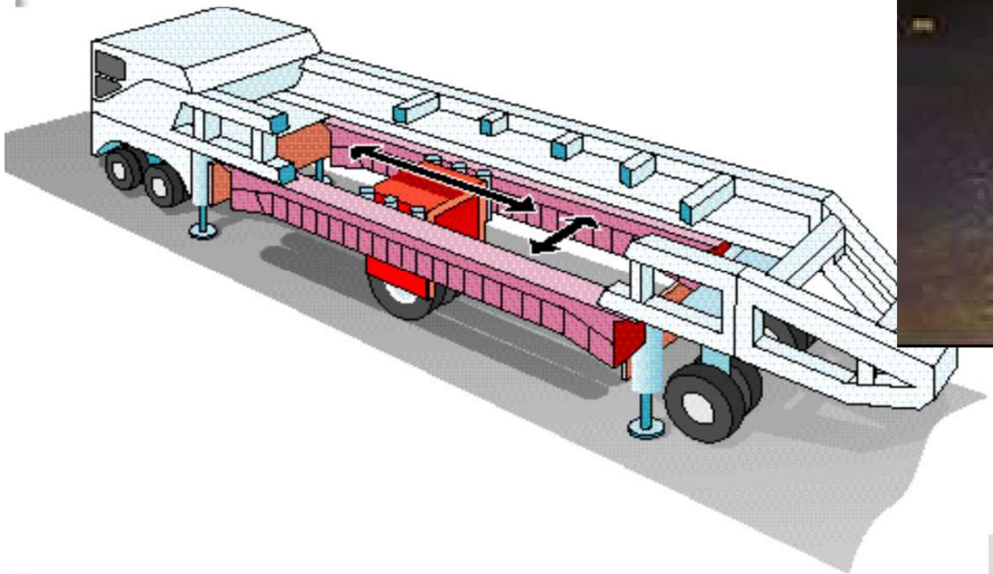


2D Axi sym. MLET



APT Full Scale Testing - HVS equipment

The Heavy Vehicle Simulator (HVS) is a mobile APT test facility.



Construction of a test object #1

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Construction of a test object #2

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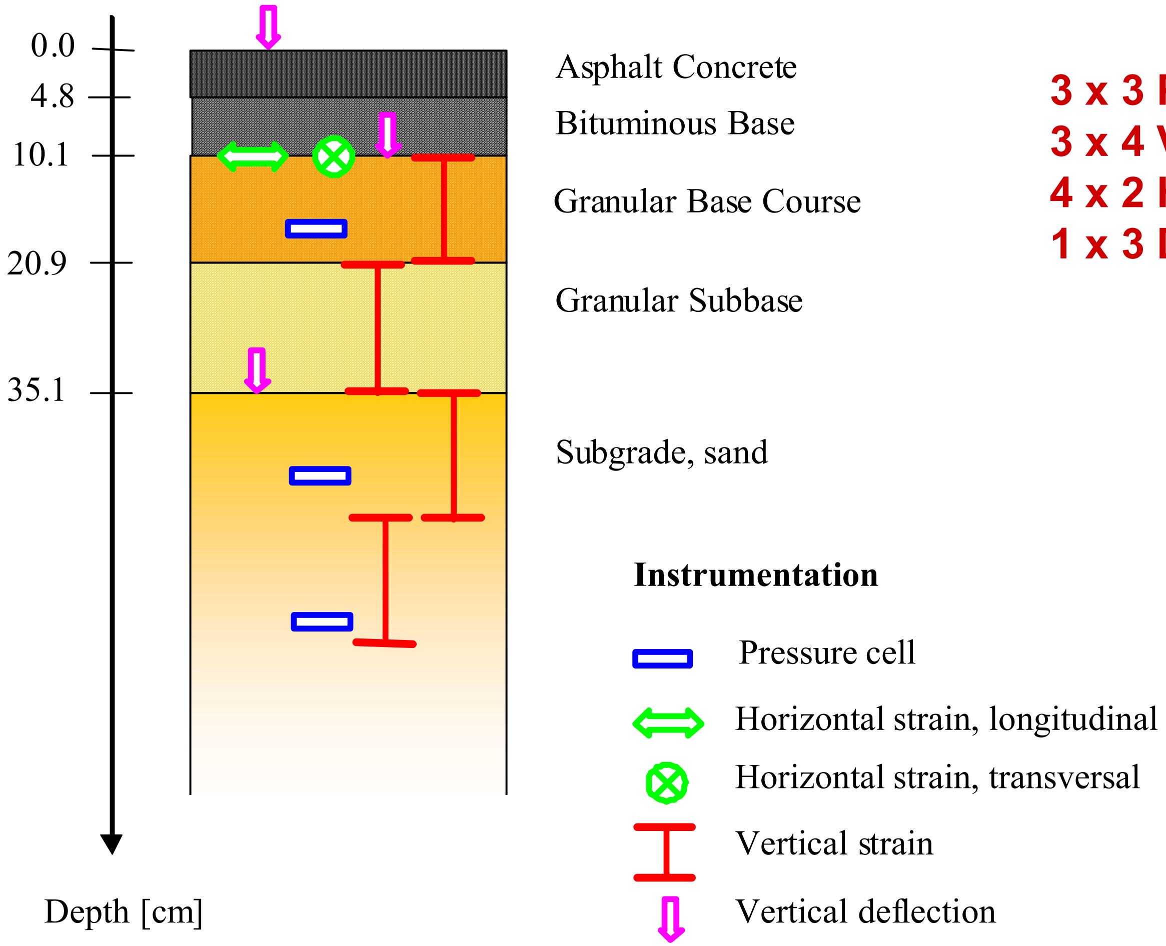
Construction of a test object #3

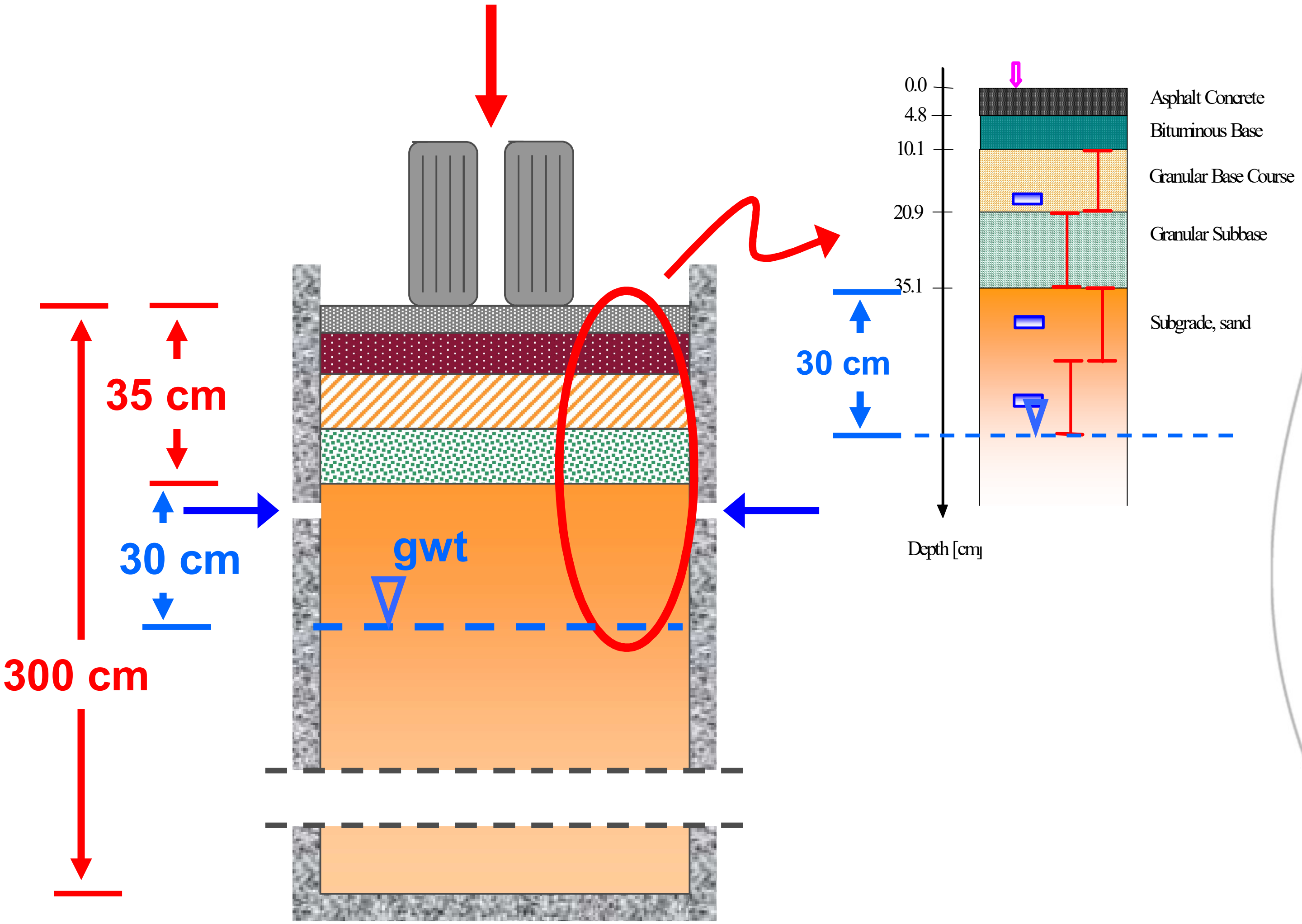
Construction of a test object #5

Instrumented test structure

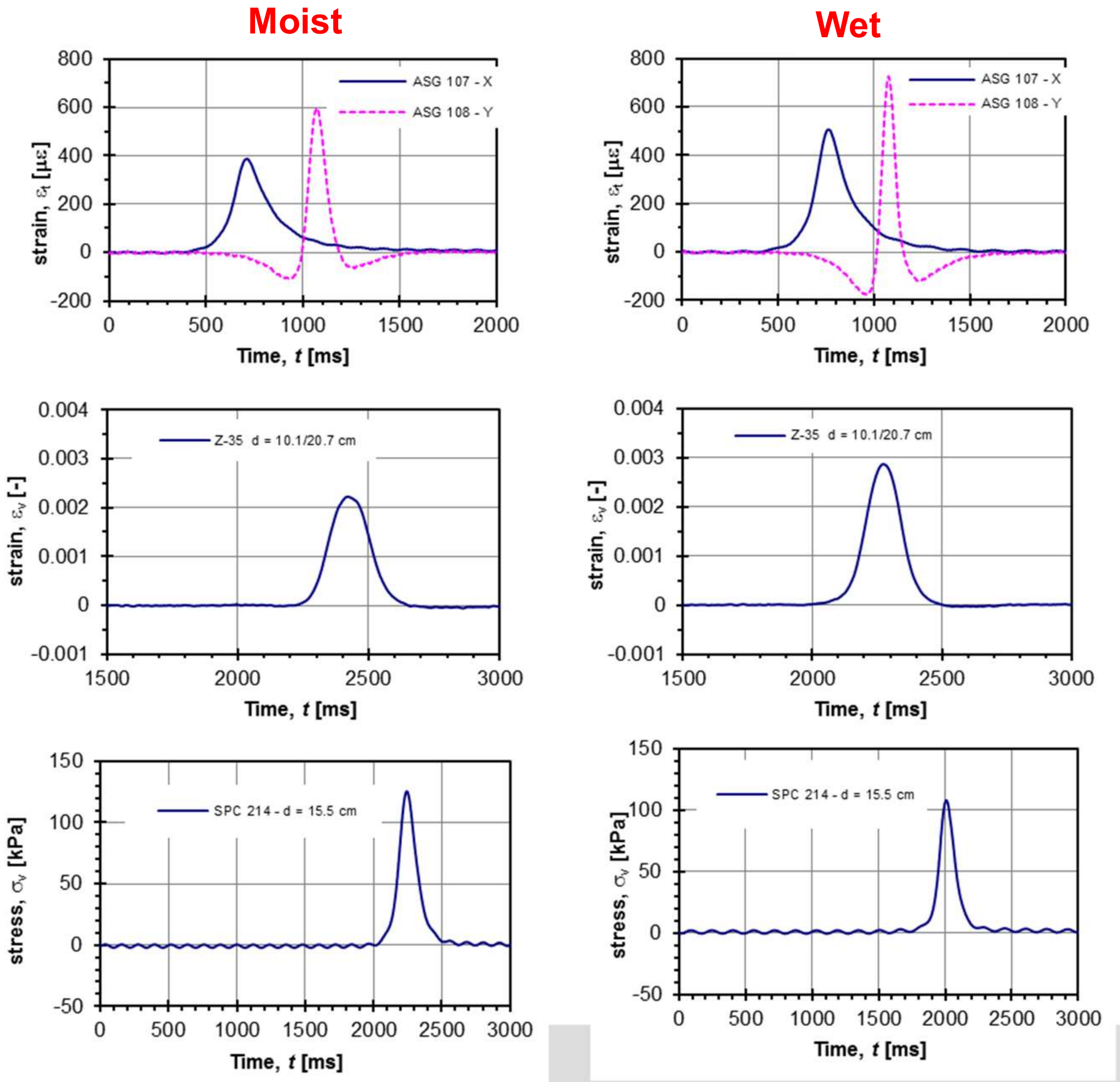


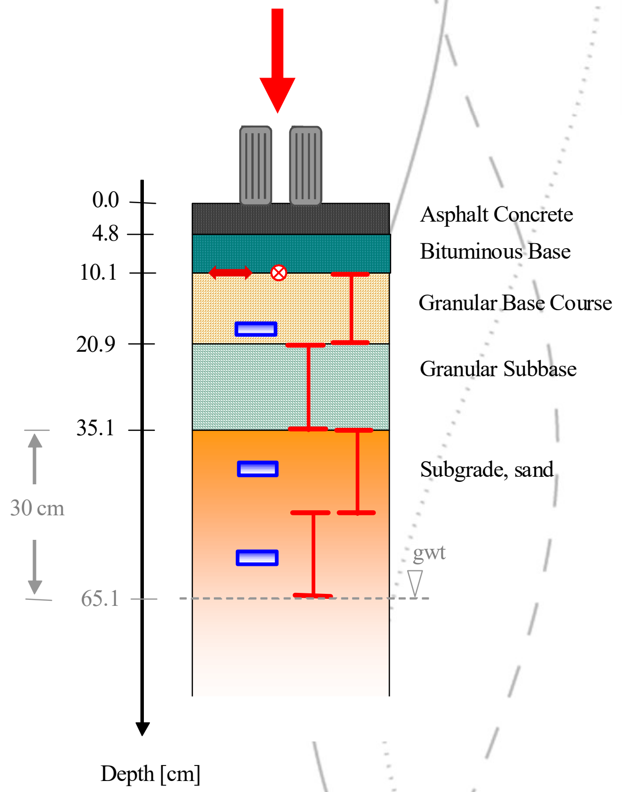
3 x 3 Pressure cells
3 x 4 Vertical strain gauges
4 x 2 Horizontal strains gauges
1 x 3 Deflection sensors

Test procedure

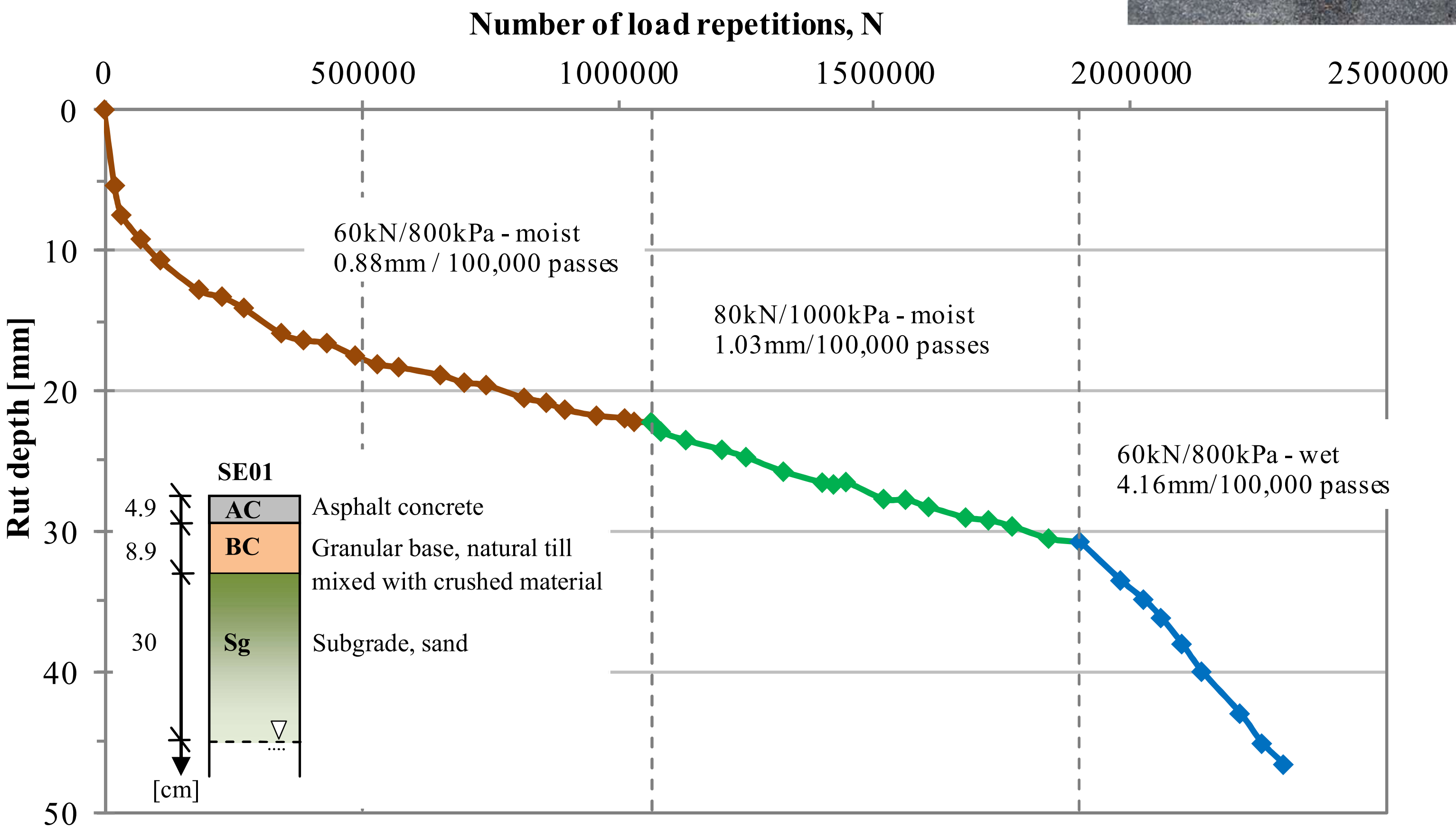


Sensors registration





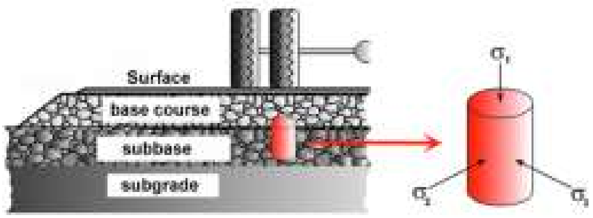
HVS - Influence of water

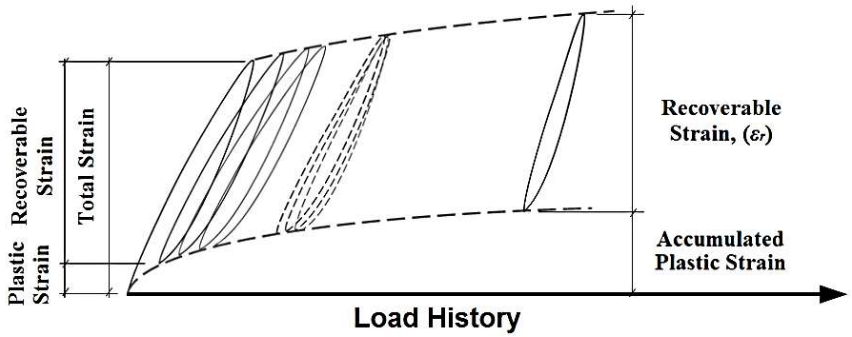


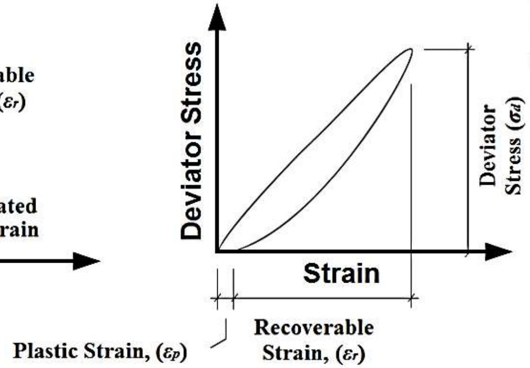
Laboratory experiments

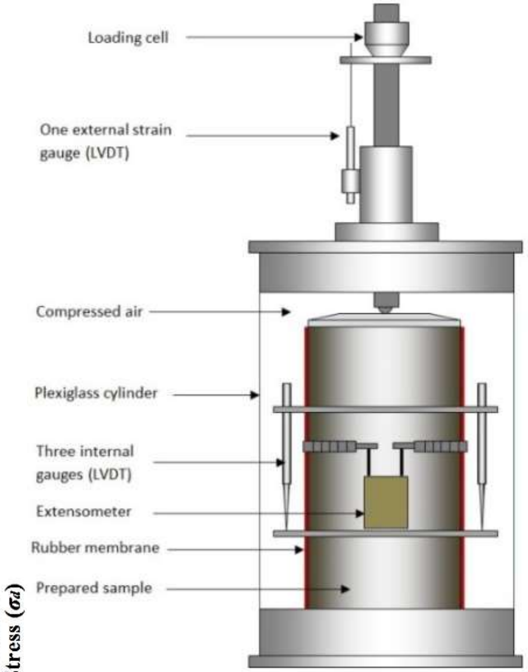
Stiffness and perm. deformation testing

Repeated load triaxial testing



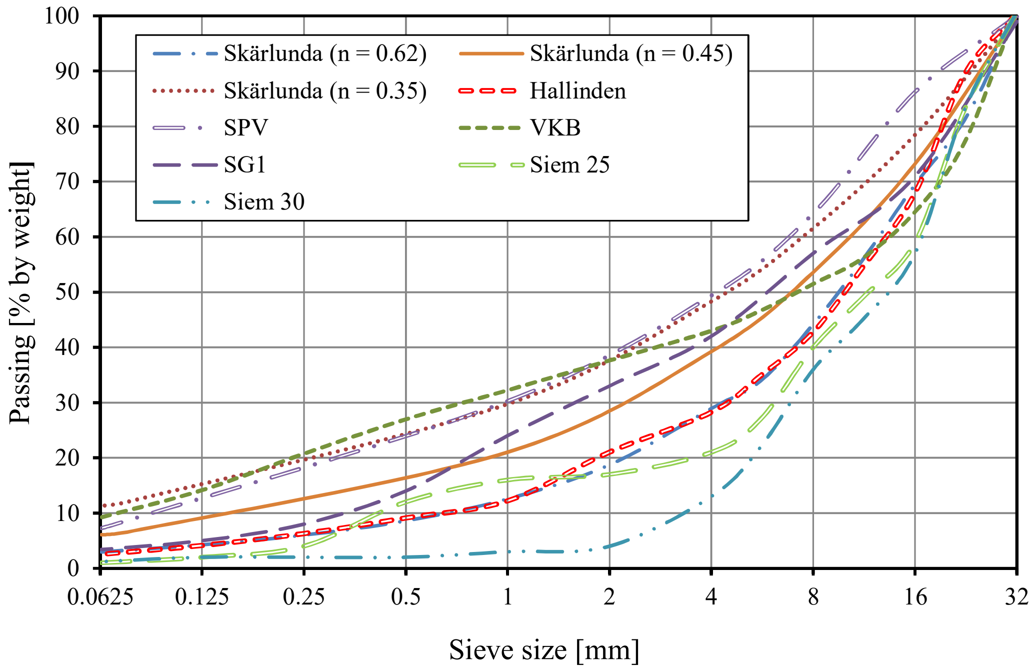


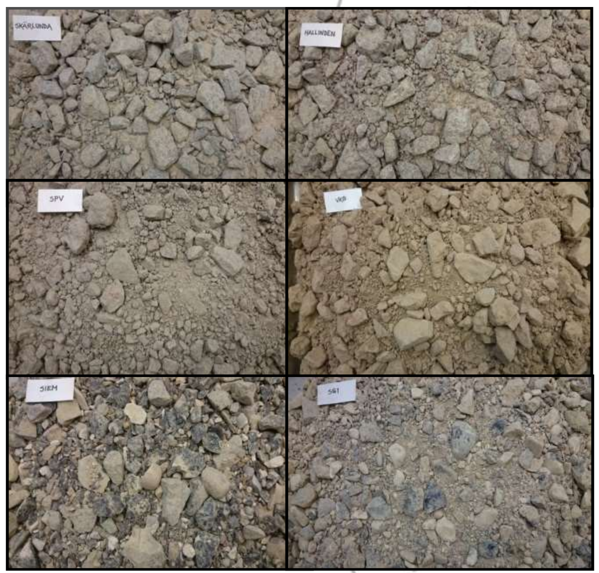




Materials Tested

- Crushed rock aggregates and blends of natural and crushed rock
- Series of moisture contents, degree of compaction, grain size distribution



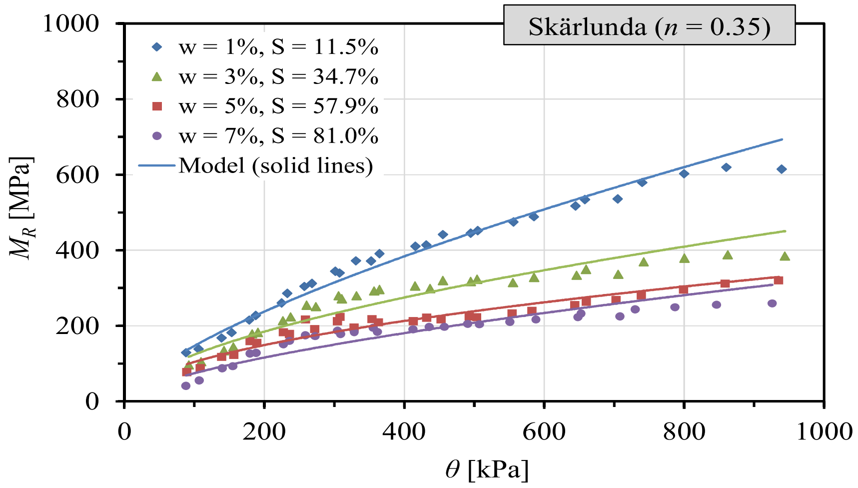


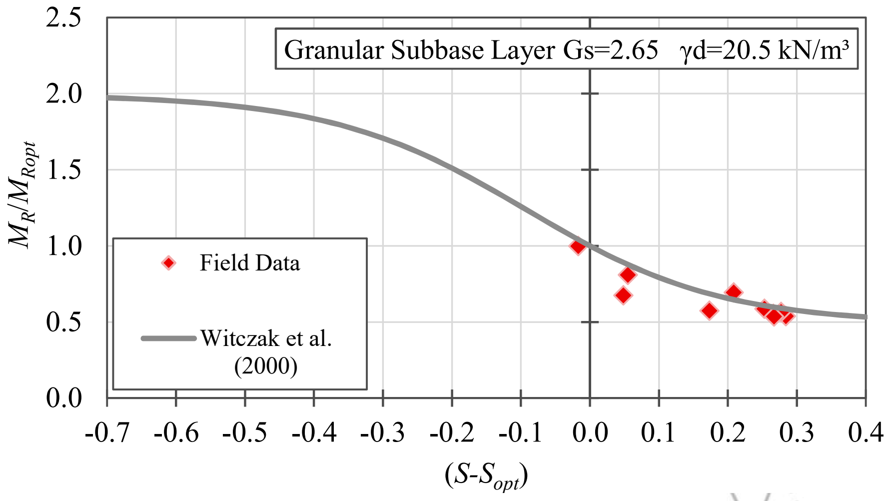
Moisture impact on resilient deformation

- M_R decreased when *w* increased, finer grading more affected
- The *k-θ* model

$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \qquad k_1 = k_1\left(w \; or \; S_r\right)$$

$$\log \frac{M_r}{M_{ropt}} = a + \frac{b-a}{1+\exp(\ln \frac{-b}{a} + k_m (S - S_{opt}))}$$





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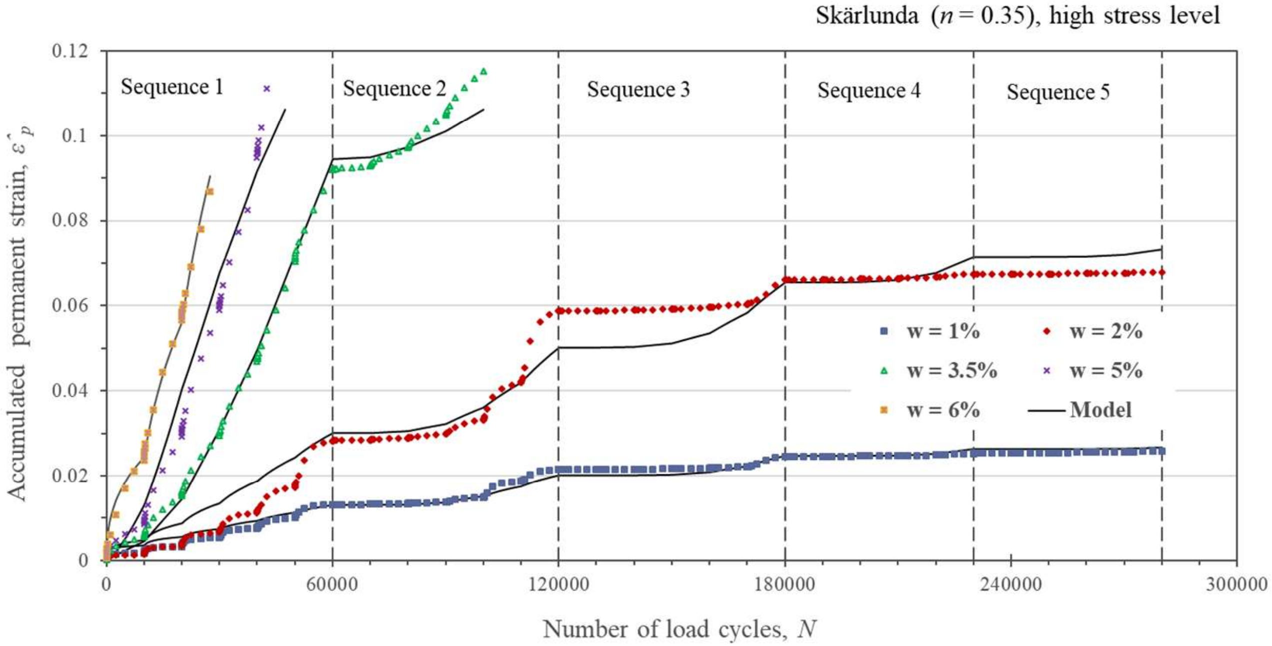
Moisture impact on permanent deformation

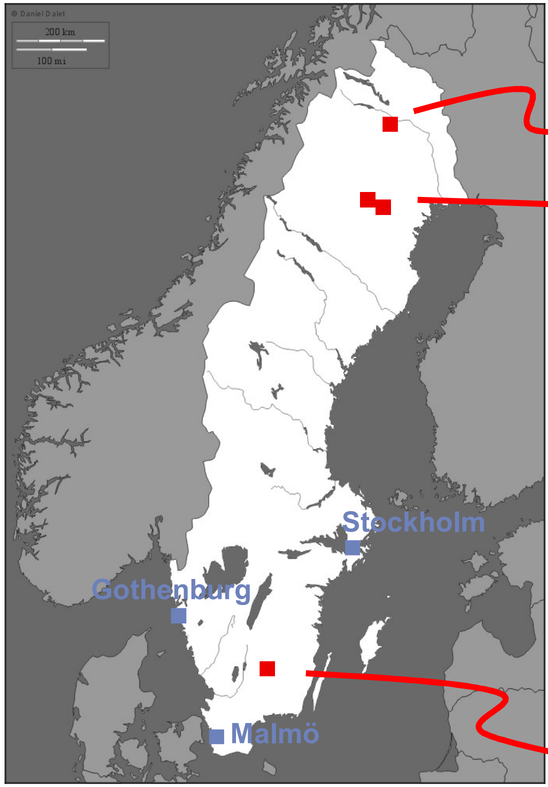
Base course material

Multi Stage (MS) approach

$$\hat{\varepsilon}_p(N) = a\varepsilon_r N^{b\varepsilon_r} \qquad a = a(w\,or\,S_r)$$

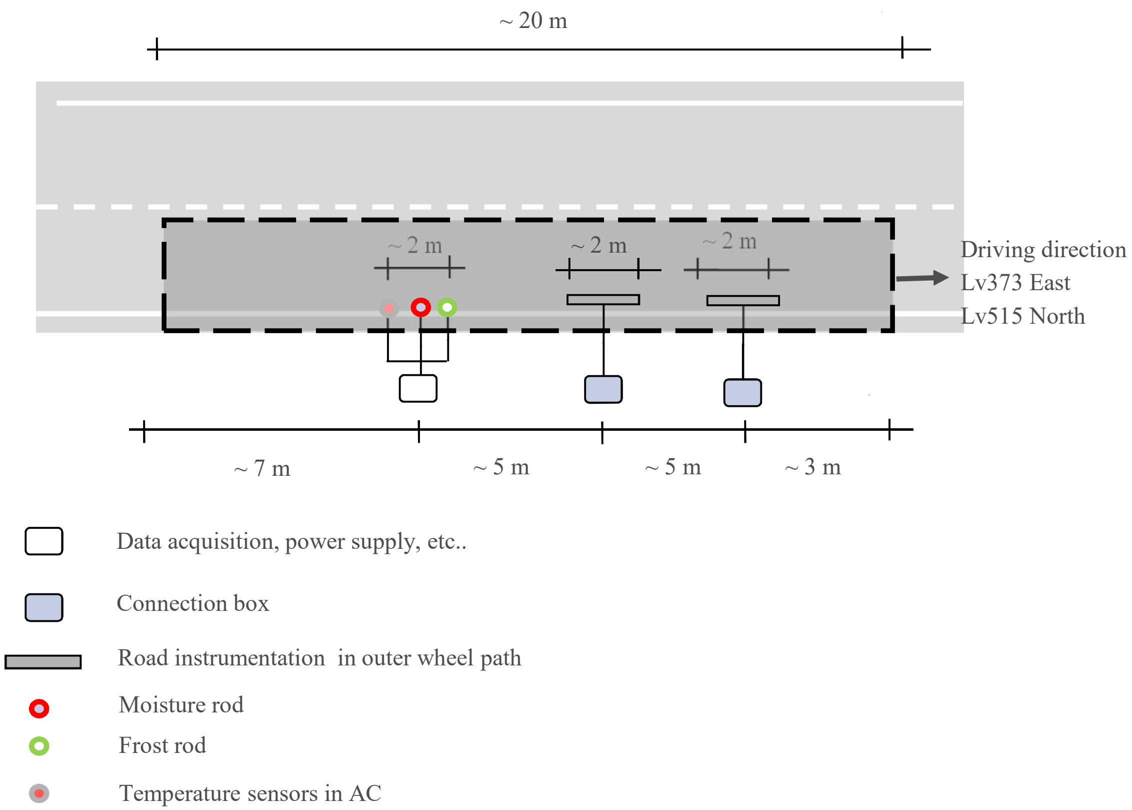


Field Monitoring

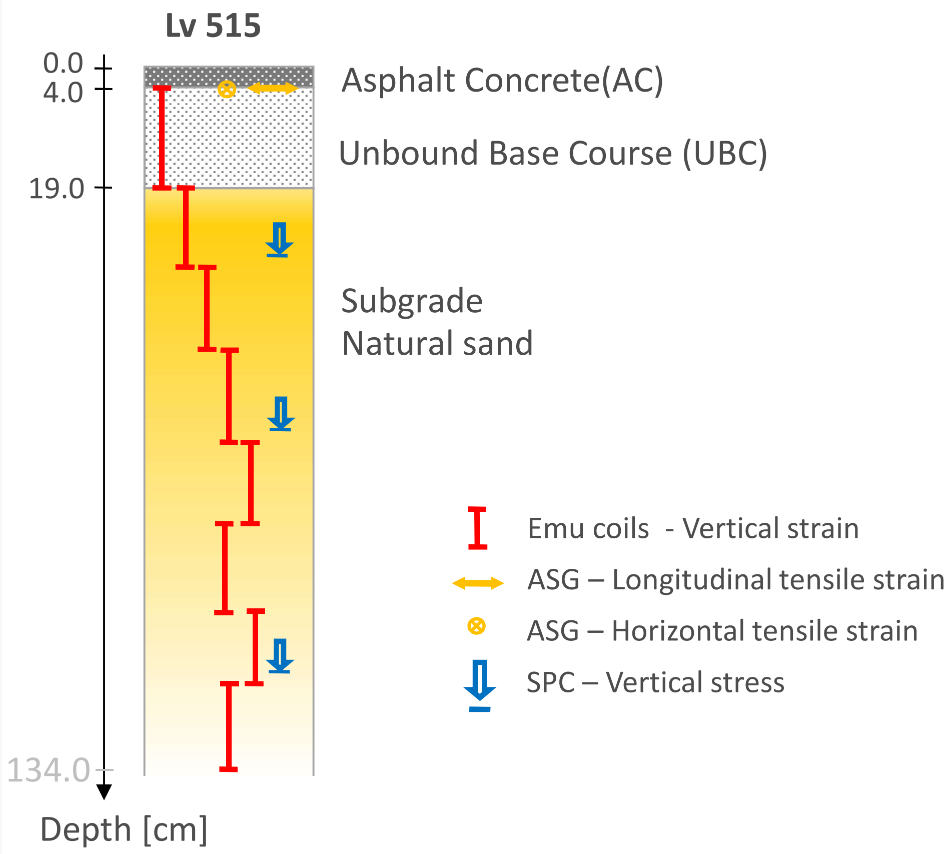


Långträsk

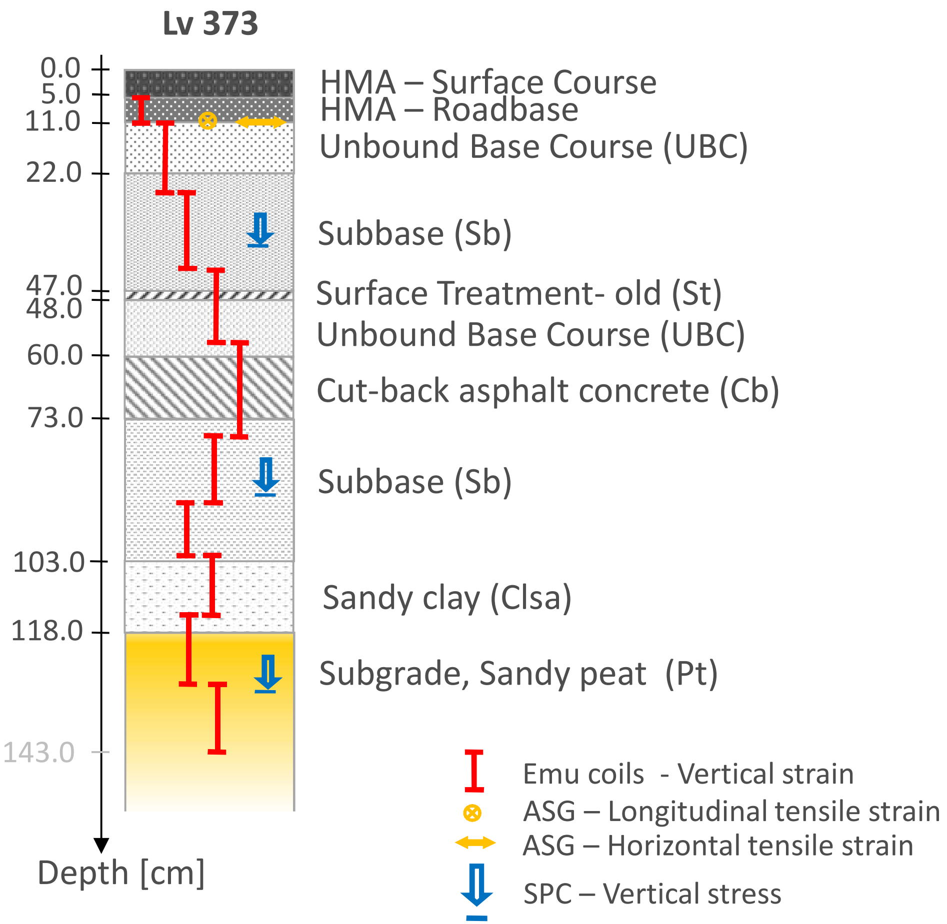
Instrumentation #2



Instrumentation Lv515 - road response sensors



Instrumentation Lv373 - road response sensors



Testing campaigns

4 campaigns

- August 2018
- May 2019
- June 2019
- August 2019

In each campaign

- FWD 30, 50 & 65 kN
- HV1 74 tonnes
- HV2 64 tonnes
- HV3 68 tonnes

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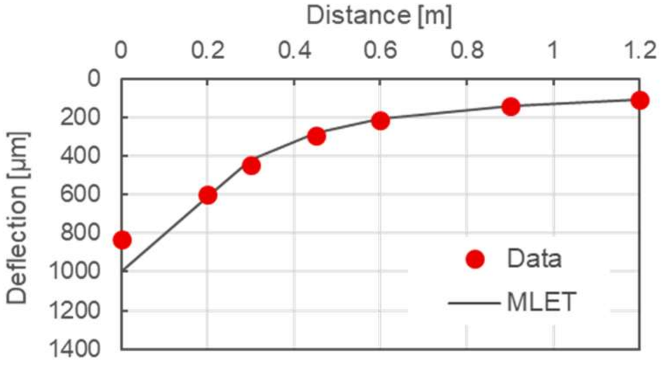
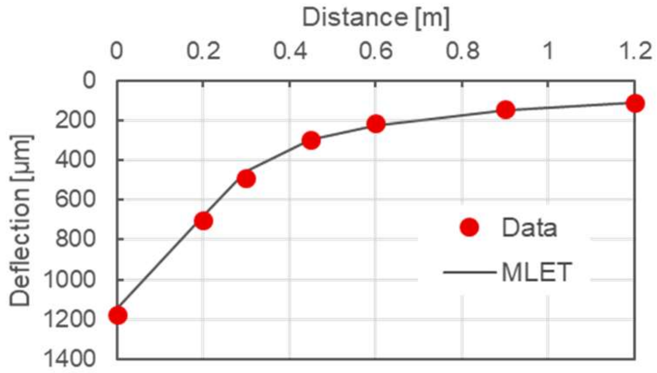
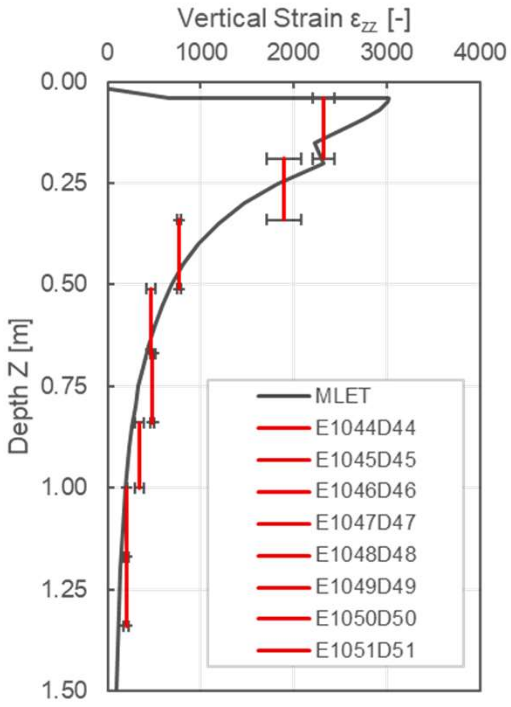
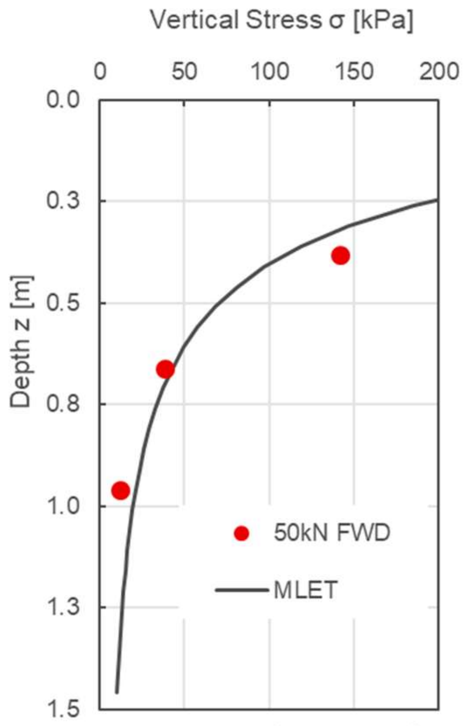
FWD measurements Lv515





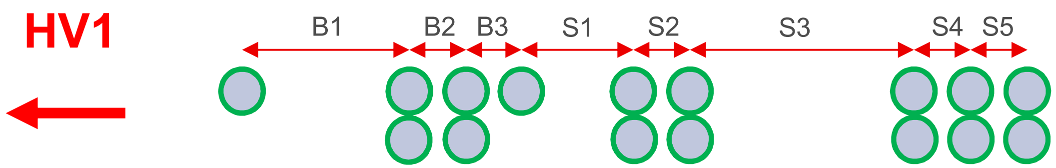




Heavy Vehicle testing – HV1 (60 km/h)

HV1 74 t August 2019 Lv515
1323
S TTS TT TTT

8.60 (840)	=	8.60
8.75 (750) + 7.80 (750) + 6.15 (840)	=	22.70
7.35 (850) + 7.25 (850)	=	14.60
8.95 (850) + 9.30 (850) + 9.25 (850)	=	27.50
		73.40 t



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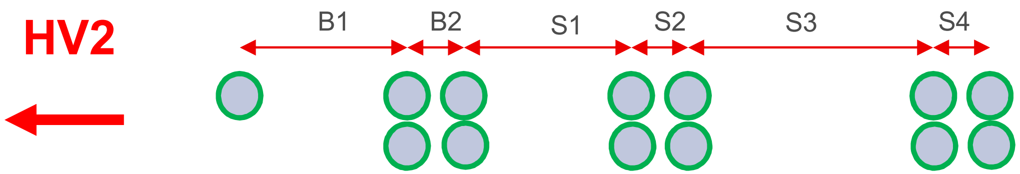
Heavy Vehicle testing – HV2 (60 km/h)

HV2 64 t August 2019 Lv515
1222
S TT TT TT

7.80 (940)	=	7.80
10.75 (660) + 9.90 (670)	=	20.65
7.10 (780) + 7.40 (770)	=	14.50
10.10 (810) + 10.30 (800)	=	20.40
		63.35 t



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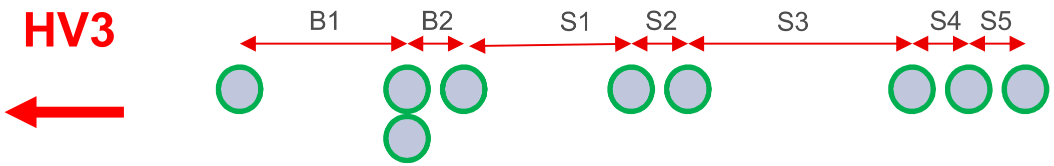
Heavy Vehicle testing – HV3 (60 km/h)

HV3 68 t   August 2019 Lv515
1223
S TS SS SSS

9.40 (880) = 9.40
12.05 (800) + 7.75 (800) = 19.80
8.85 (810) + 9.90 (890) = 18.75
6.65 (850) + 7.35 (880) + 7.40 (850) = 21.40
69.35 t



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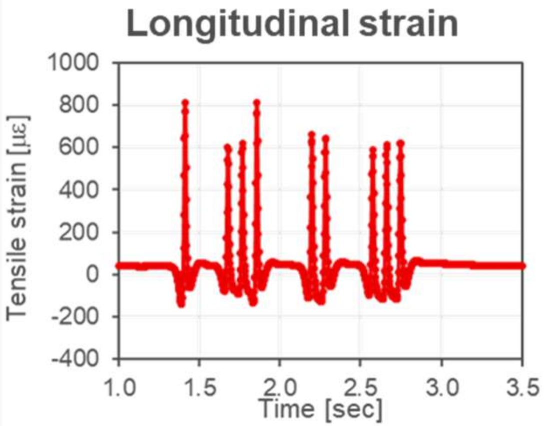
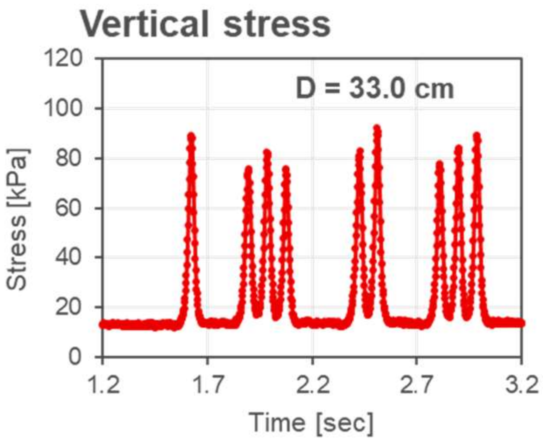
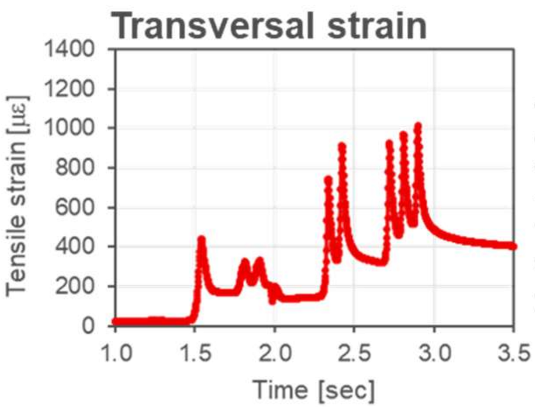
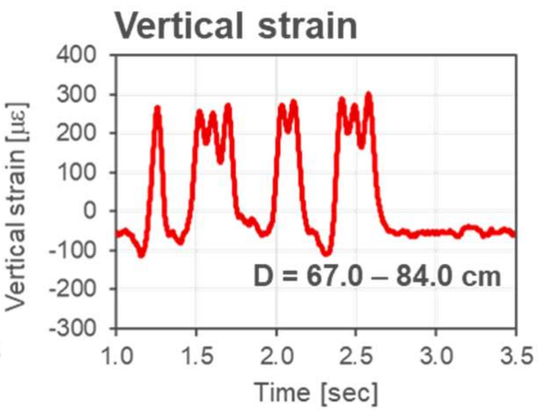
Full scale testing – HV1 74 t: Measured response









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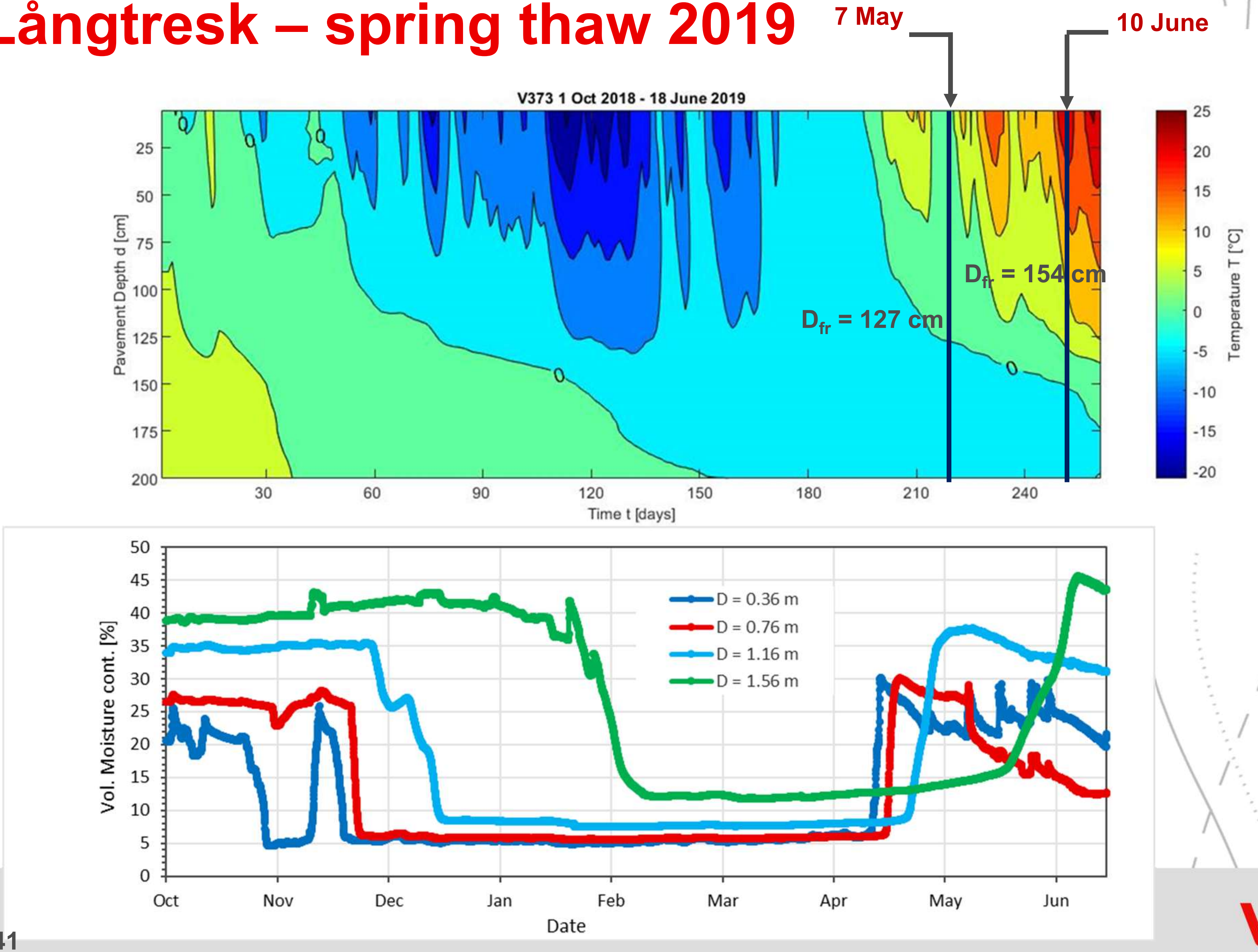
Långtresk – spring thaw 2019



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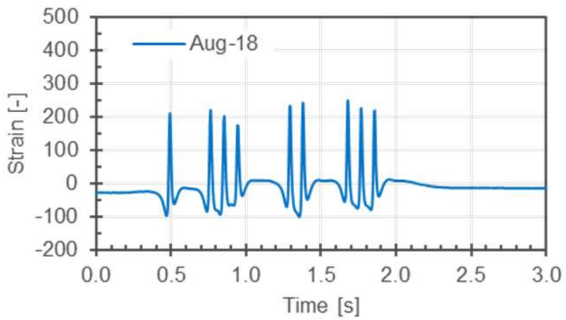
Comparison – Measurements Lv373

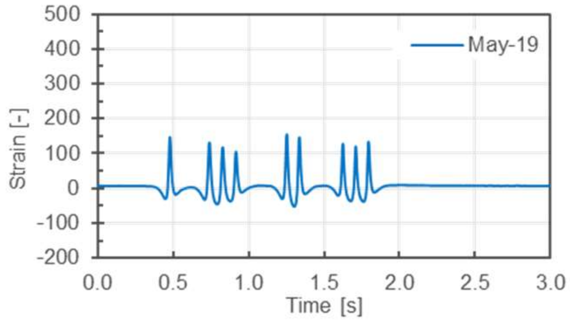
27.08.2018

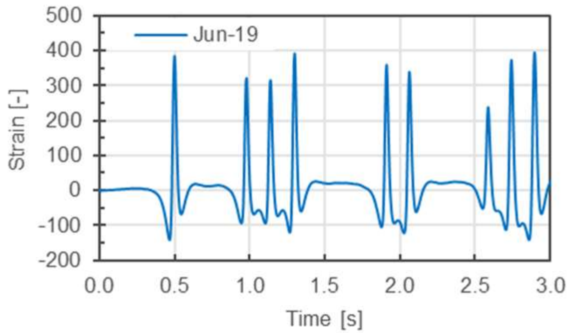
07.05.2019

10.06.2019

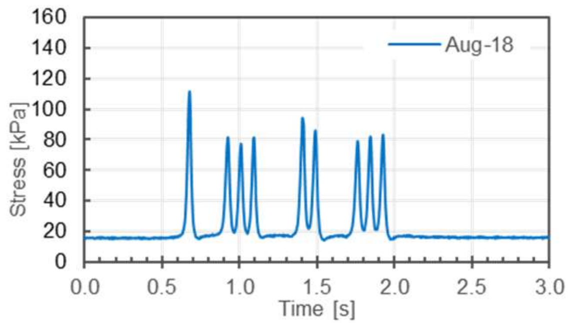
Longitudinal strain:

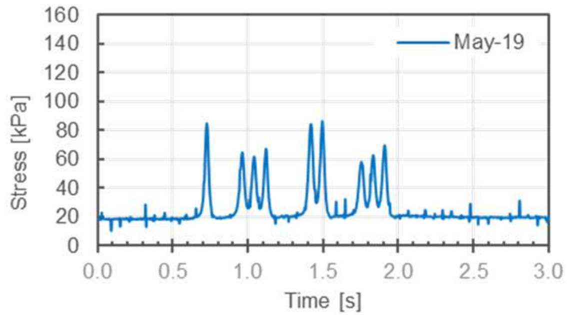


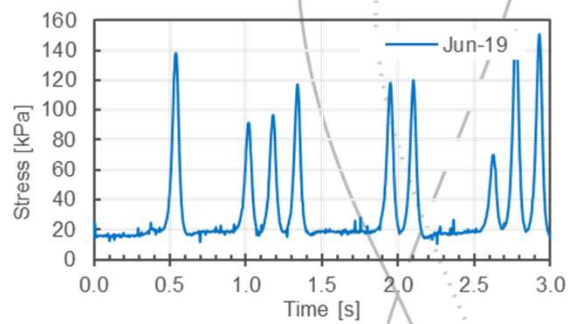




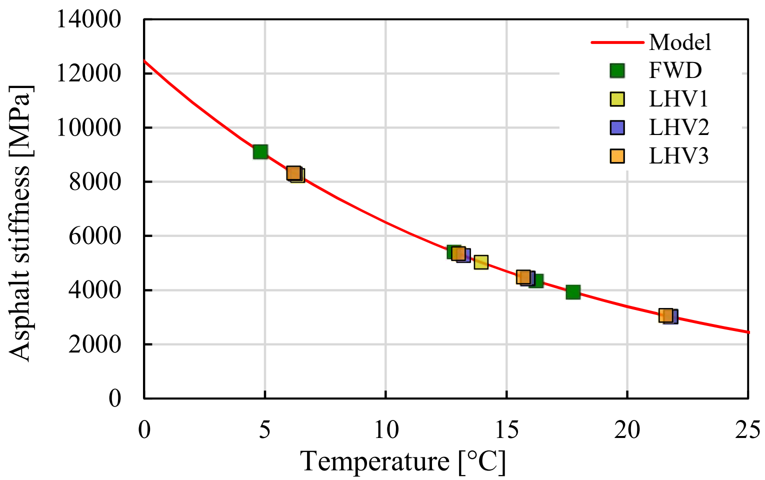
Vertical stress:

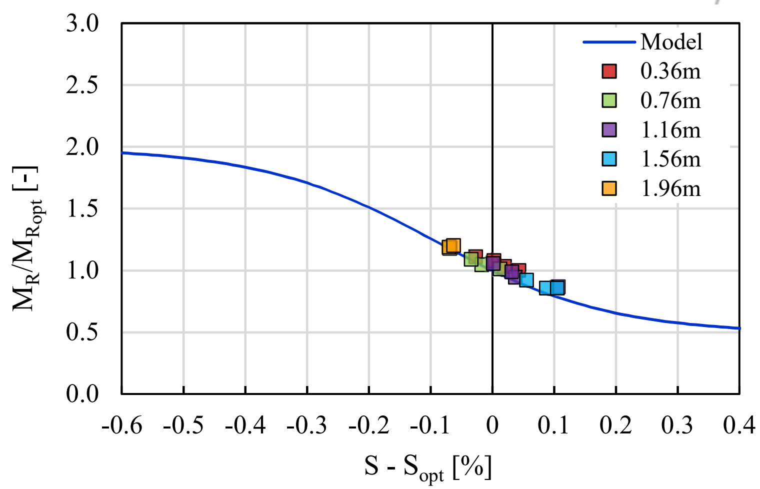






Climate adjustments - Lv515



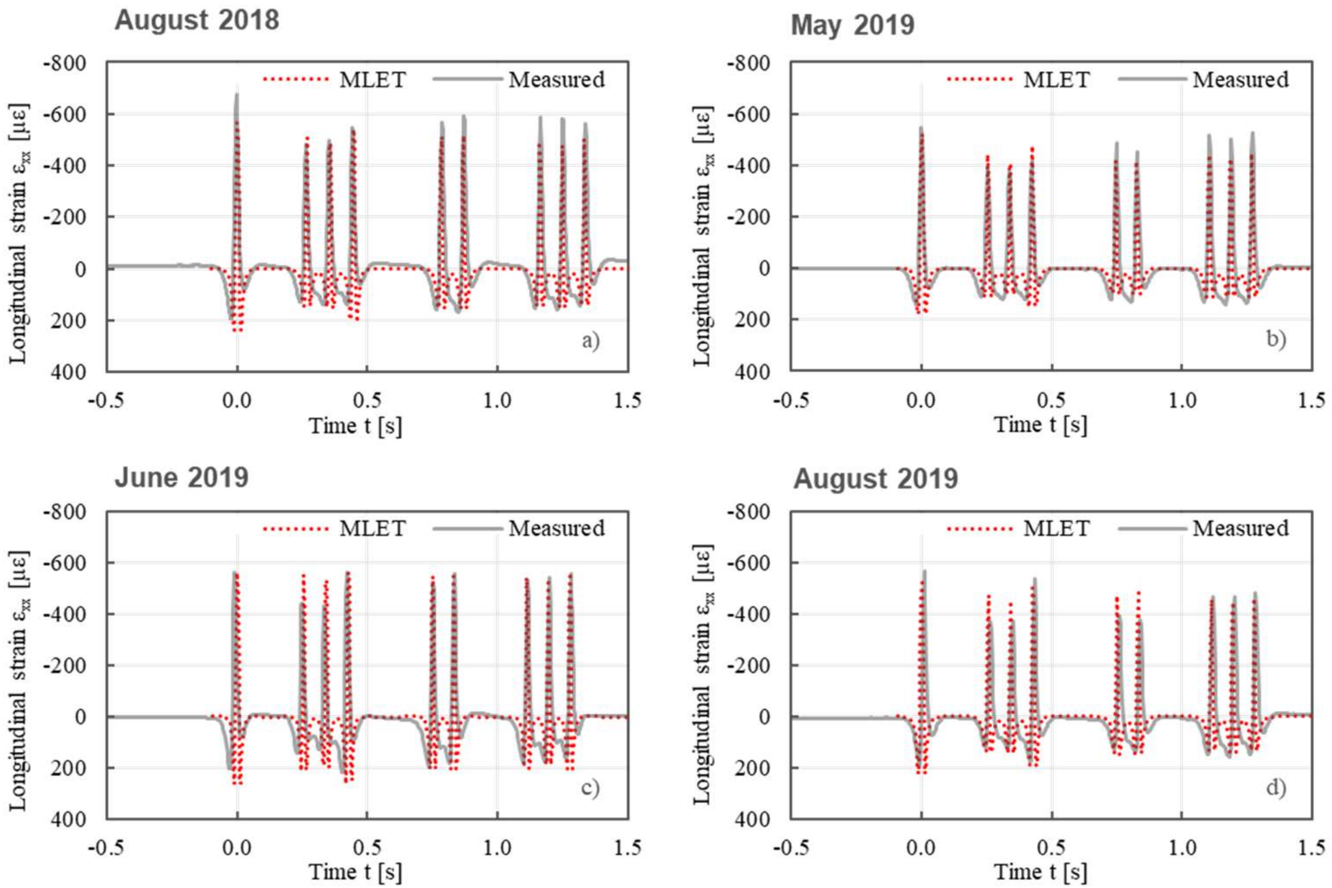


$$E_T = E_{T,ref} \cdot e^{-b(T-T_{ref})},$$

$$\log \frac{M_R}{M_{R,opt}} = a + \frac{b-a}{1+\exp(\beta + k_s(S - S_{opt}))},$$

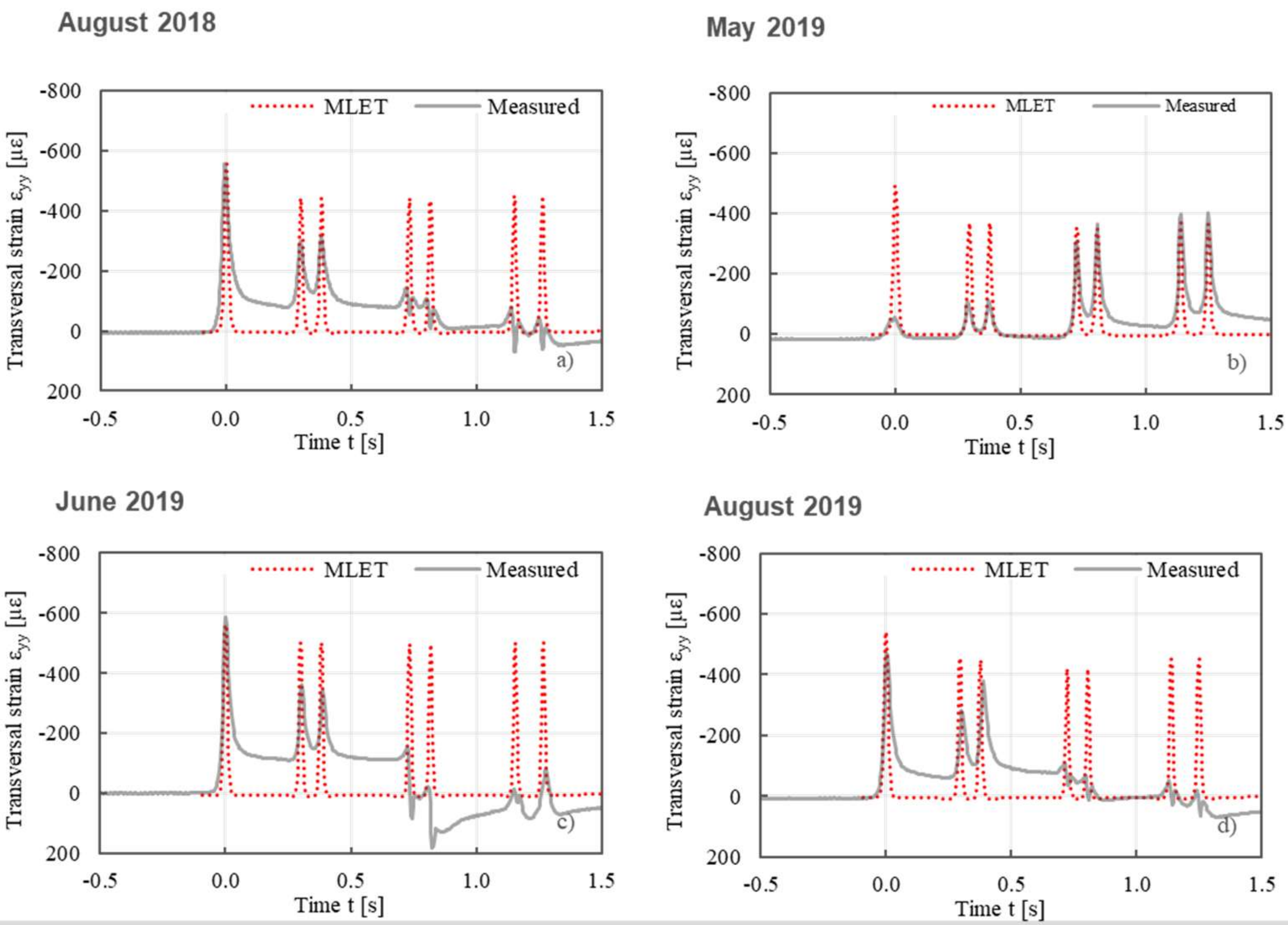
Långtresk – Validation HV1 - 74 ton Lv515

Longitudinal strain



Långtresk – Validation HV2 - 64 ton Lv515

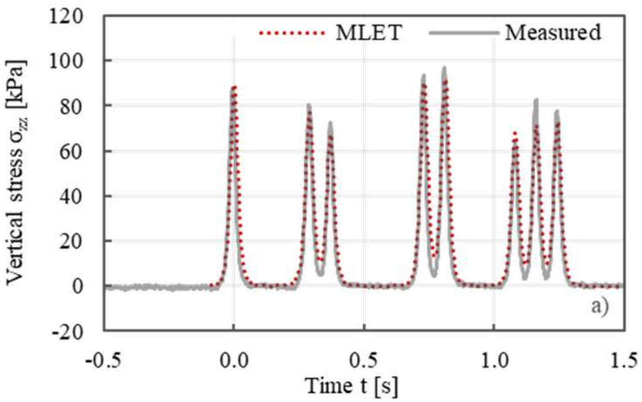
Transversal strain



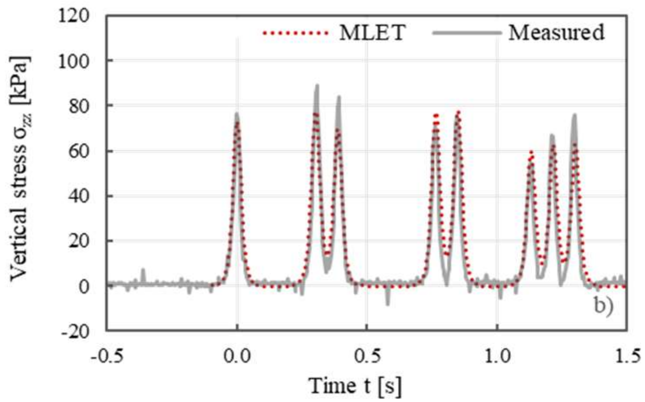
Långtresk – Validation HV3 - 68 ton Lv515

Vertical stress

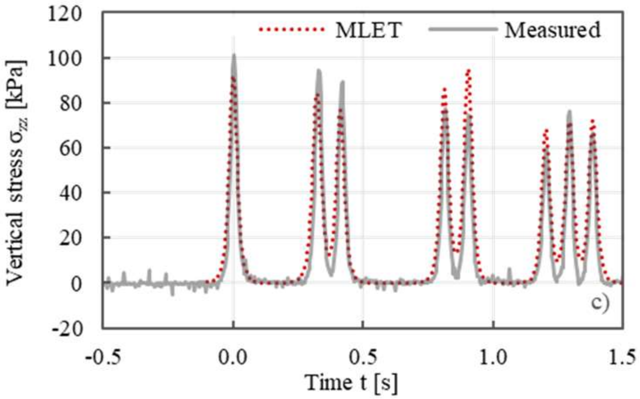
August 2018



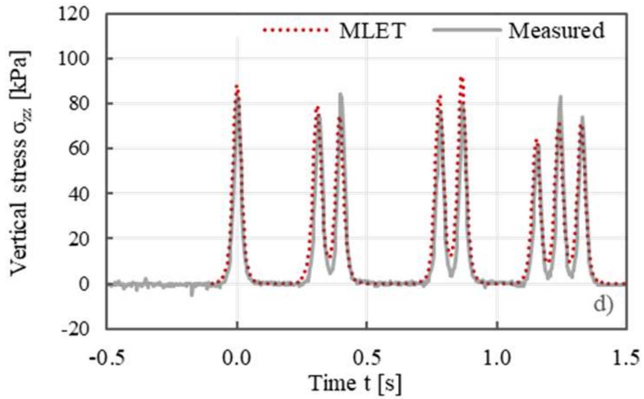
May 2019



June 2019

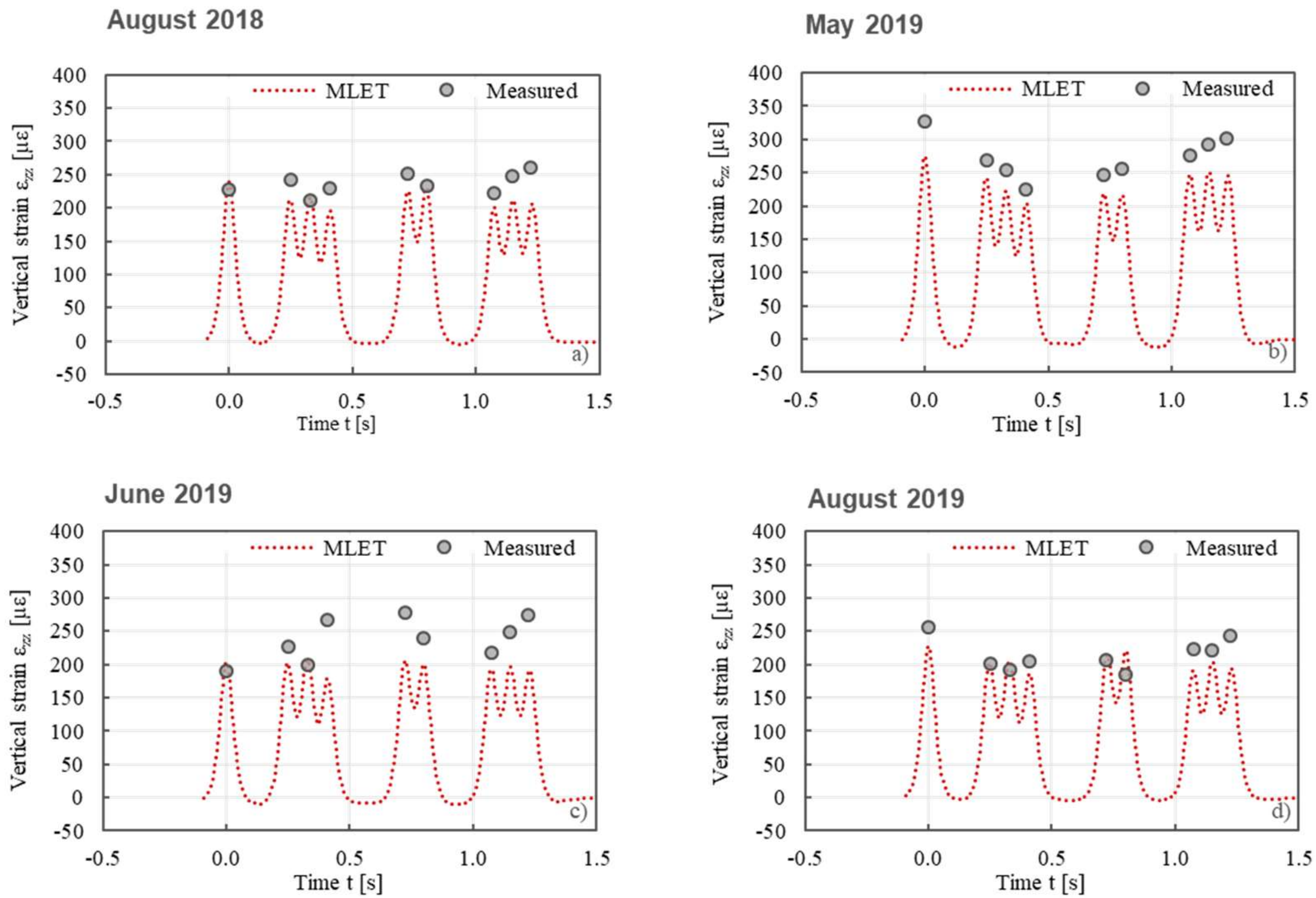


August 2019



Långtresk – Validation HV1 - 74 ton Lv515

Vertical strain



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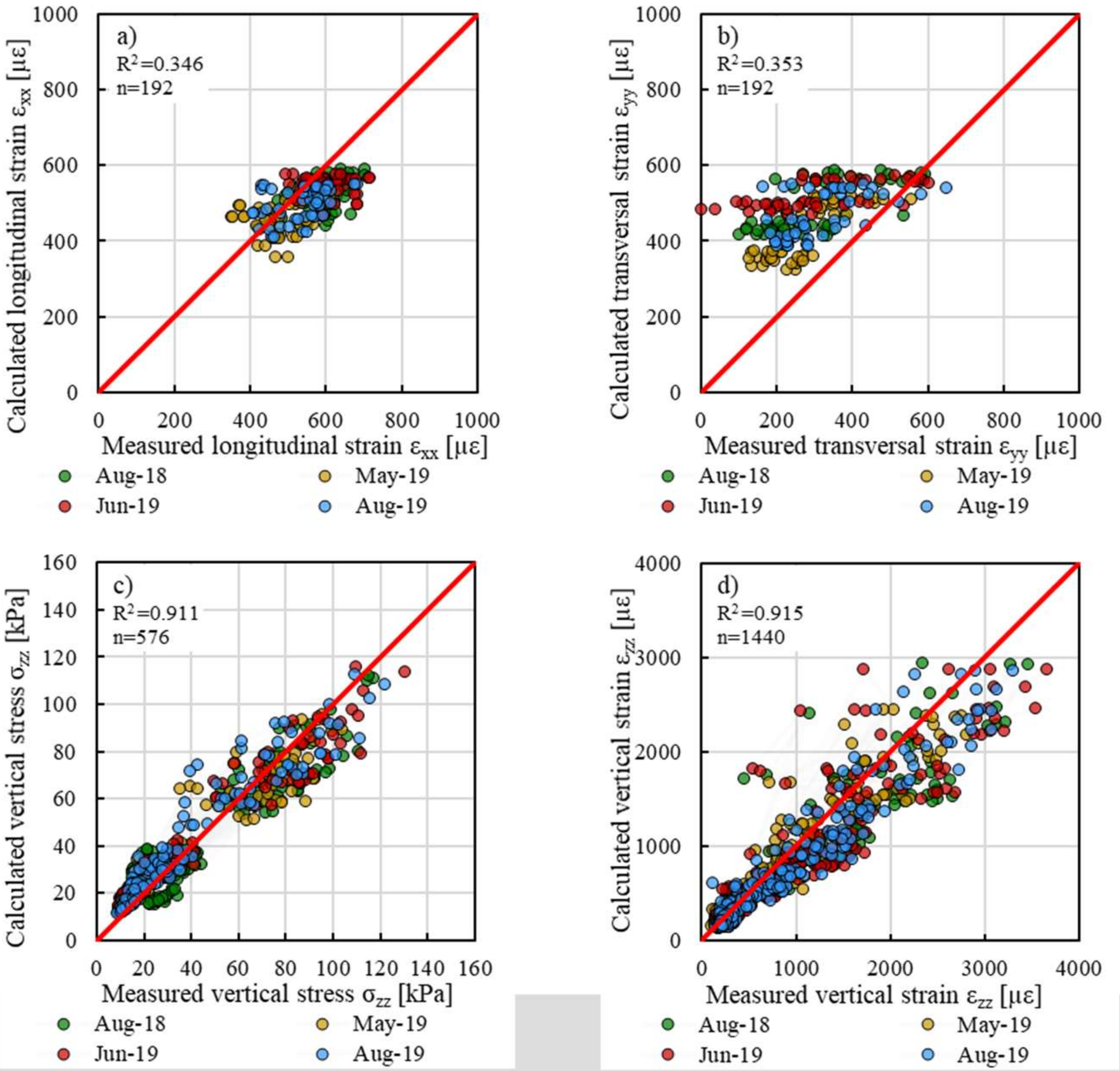
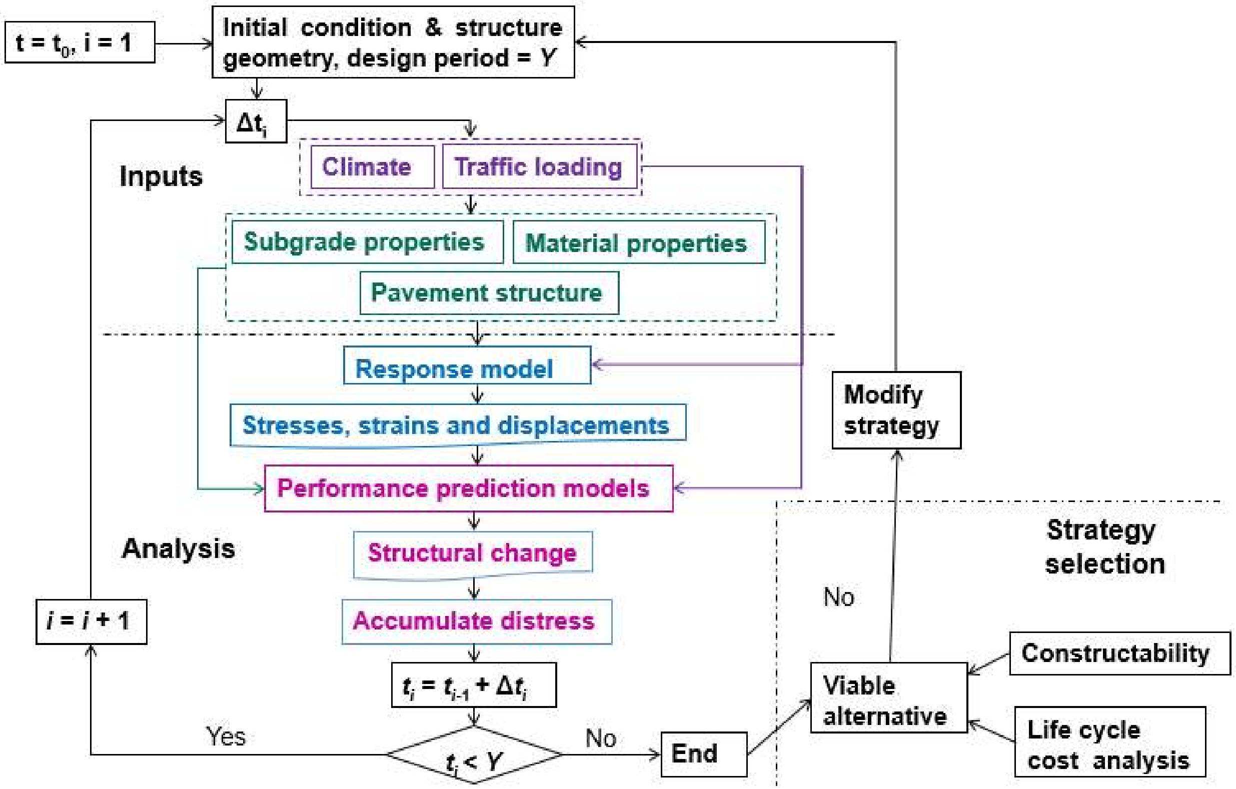
Validation: Calculation against measurements



Lv515

M-E design ERAPave PP

Overview of the M-E design and performance approach



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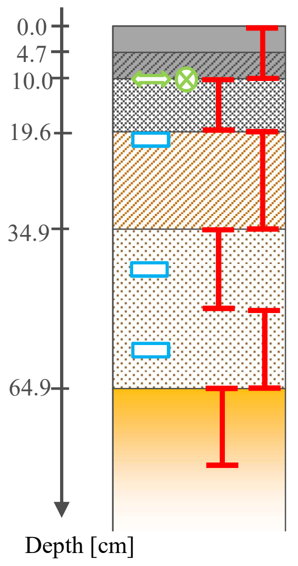
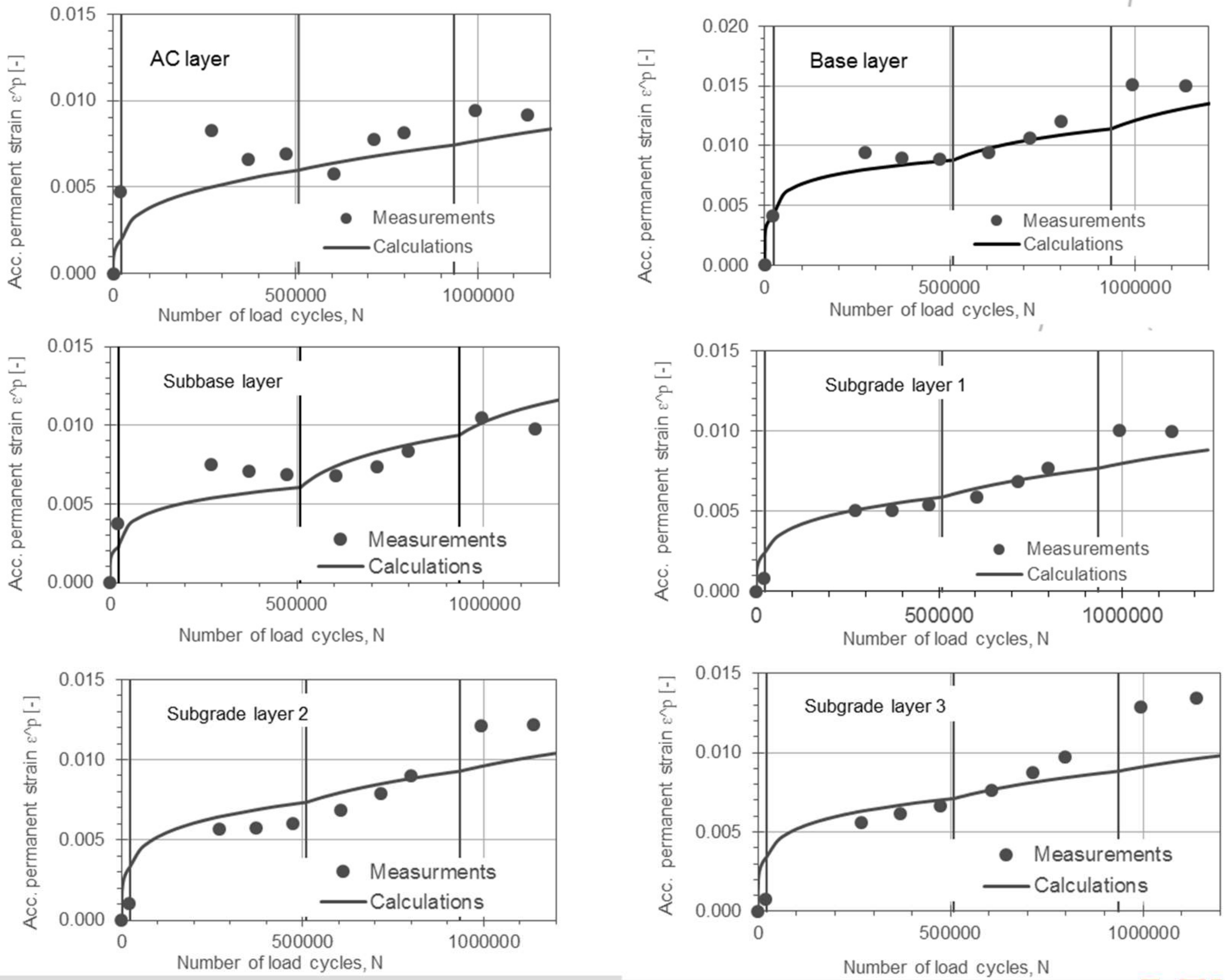
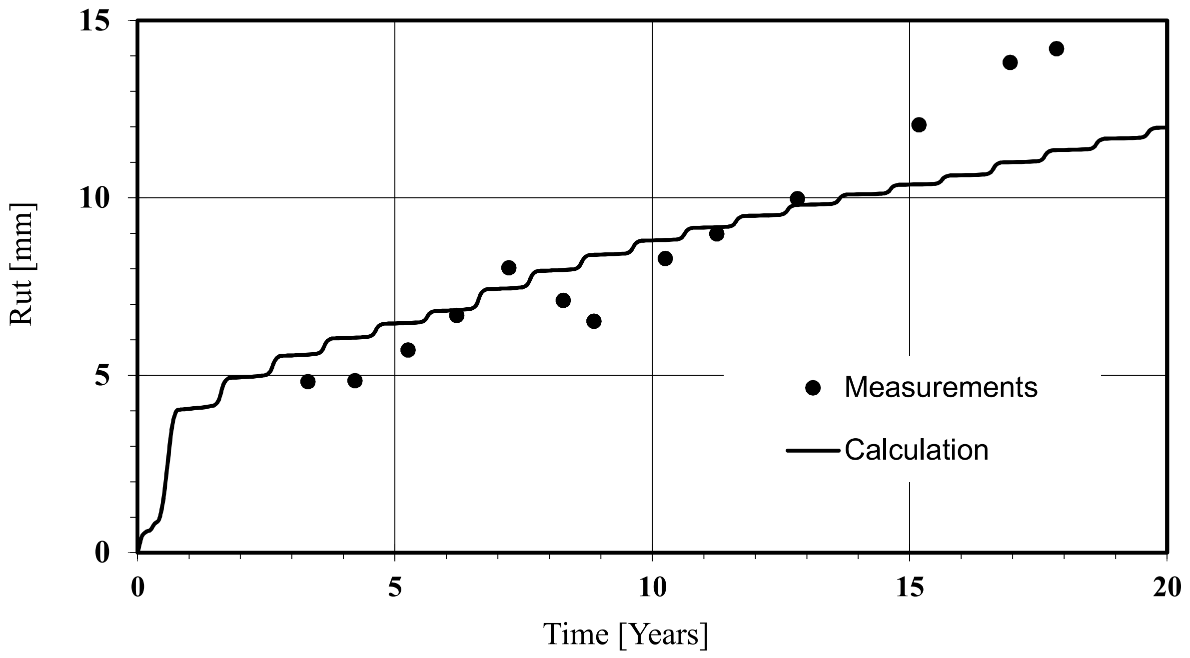
Calibration & Validation – APT testing





LTPP road – Permanent deformation prediction
Validation / Calibration



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Conclusions

Moisture content within the pavement structure changes due to climate condition. Moisture has a great impact on pavement unbound layers behaviour. This is true regarding:

- Stiffness characteristics
- Permanent deformation behaviour

This is evident from:

- Full-scale APT using an HVS in a climate controlled environment
- Controlled laboratory RLT tests
- Field monitoring programs using FWD to mimic the heavy axle loading

During spring thaw large increase in moisture content in UGM is frequently observed that affects the structural behaviour of the pavement structure. By updating the stiffness properties of the UGM layers with moisture content better agreement is gained between observations and calculations.

M-E based design and performance prediction scheme for thin pavements in seasonal areas is under development in Sweden.

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