

**Enhanced Mechanistic Understanding of
Structural Behaviour of Pavements
- Experiences from Iceland -**



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University of Iceland**

Outline



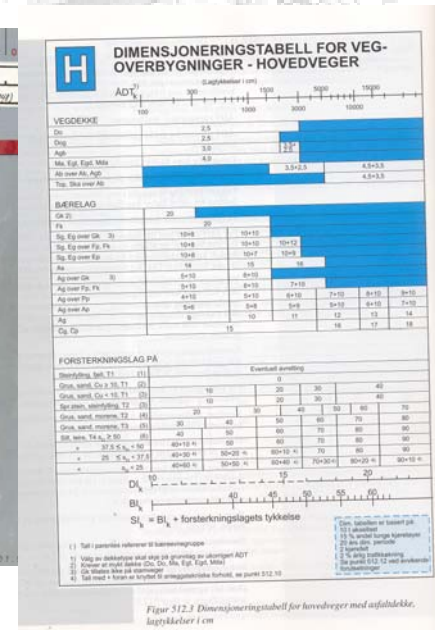
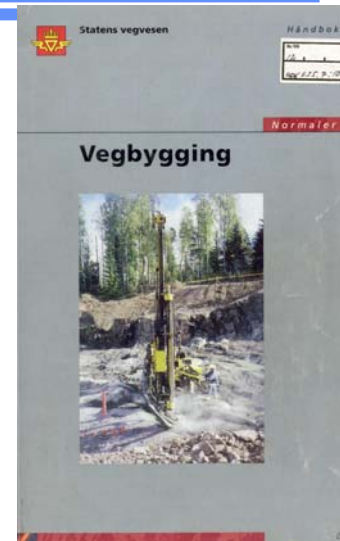
- **Current Design Methods used in Iceland**
- **Mechanistic-Empirical Design Methods**
- **Recent and Ongoing Research Projects:**
 - » **Axle Load Spectrum Analysis**
 - » **Material Characteristics**
 - » **Seasonal Variation of Pavement Response**
 - » **Accelerated Testing of Pavement Structures**
 - » **Response Calculations and Distress Prediction**
- **AASHTO 2002 Design Guide**

Current Design Methods

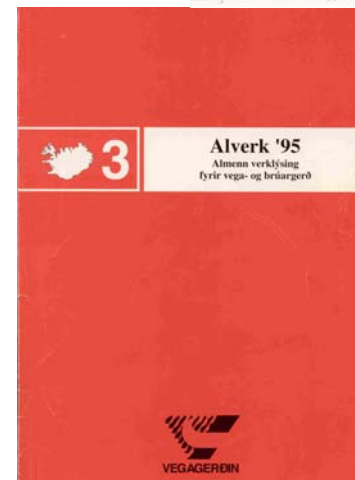
Alverk 95 & Vegbygging Håndbok 018



Empirical design –
AADT
Subgrade
Material Classification



Standard Specification
of Road Structures in Iceland (Alverk 95)



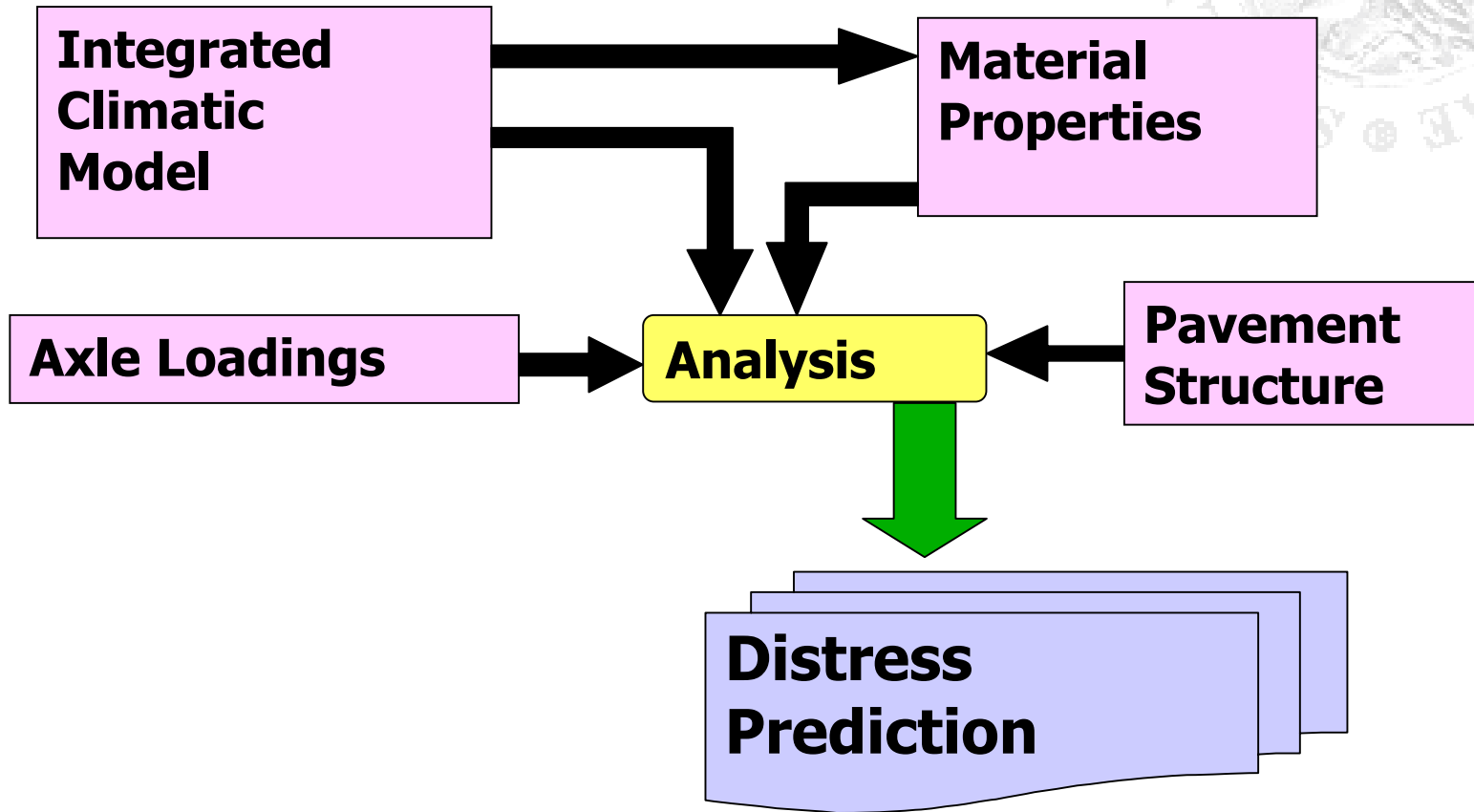
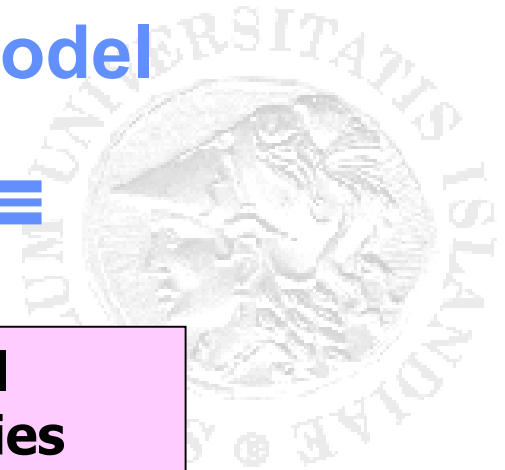
Mechanistic – Empirical Design Method



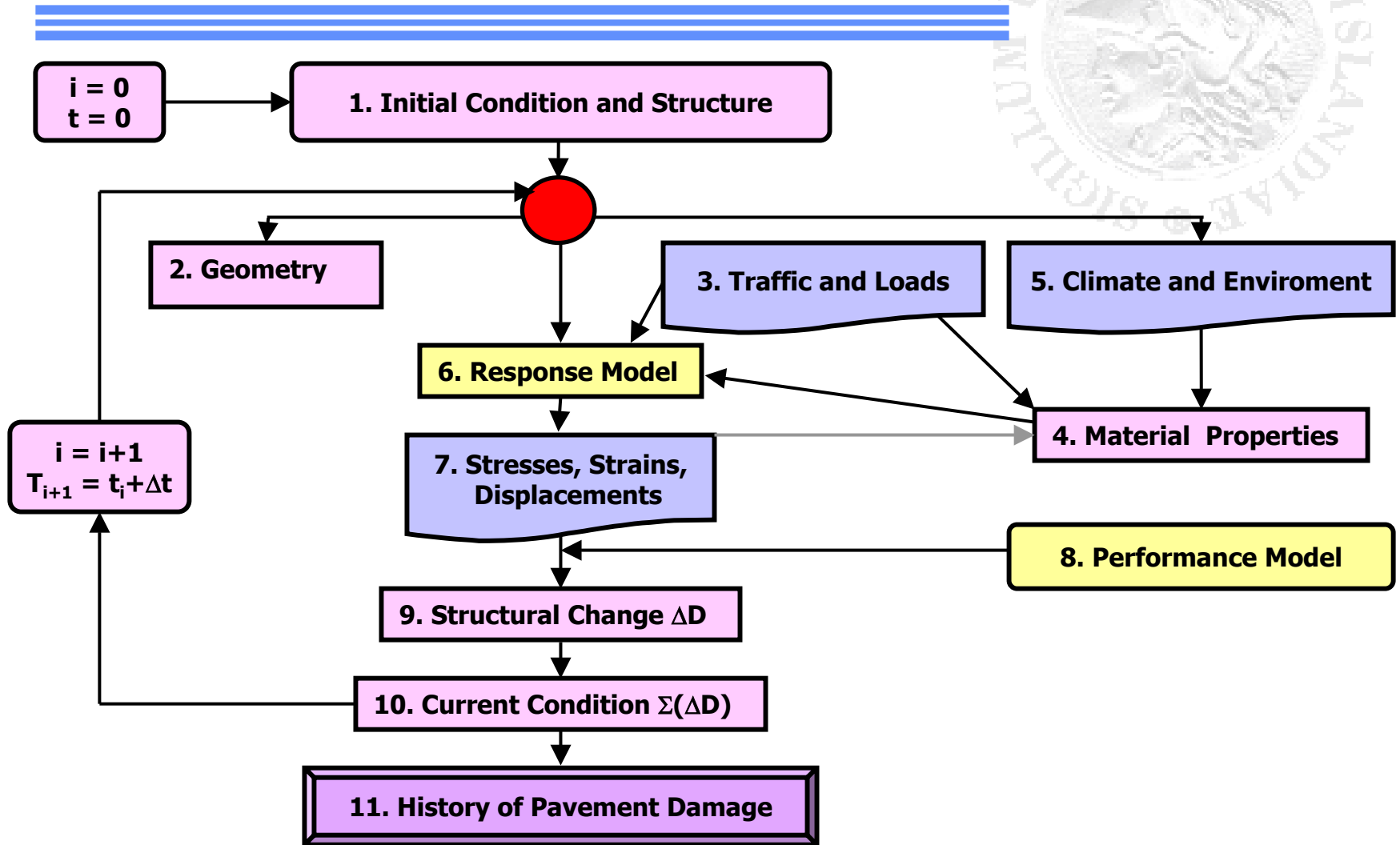
What is a Mechanistic - Empirical Design Method ?

Using a mechanistic-empirical design method is applying the principles of engineering mechanics in evaluating the response of pavement structures to traffic loading and empirical design methods in carrying out distress prediction.

Mechanistic Pavement Design Model



Incremental design procedure – Flow diagram



Recent and Ongoing Research Projects

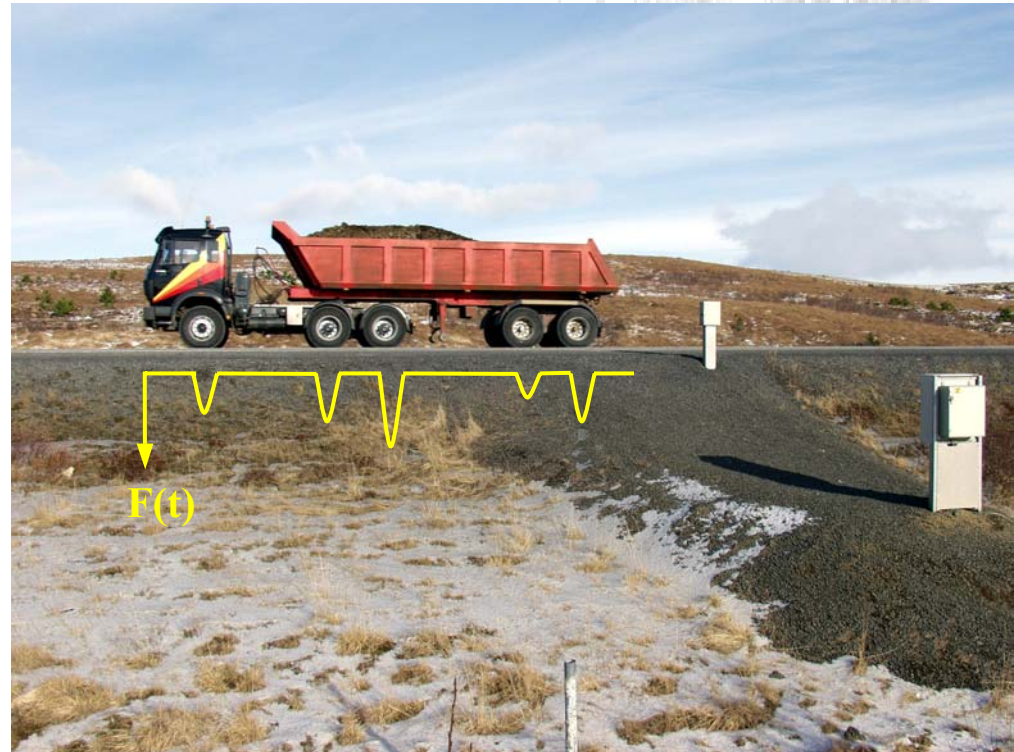


- ***Axle Load Spectrum based on WIM-data***
- ***Material Characteristics***
- ***Seasonal Variation of Material Properties***
- ***Full Scale Testing (APT)***
- ***Response Calculations and Distress Prediction***

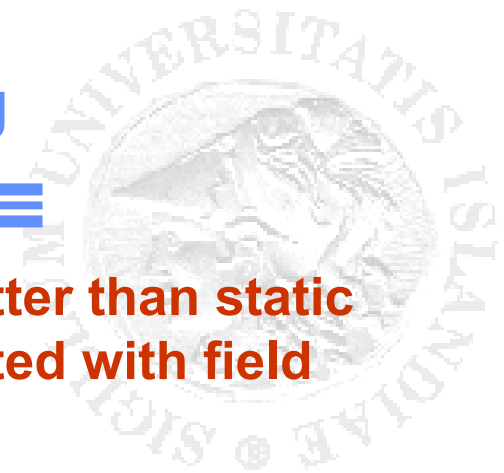
Axle Load Spectrum - *Weigh in Motion*



- **WIM-stations**
provide information on:
Axle loads
Number of load repetitions
Frequency distribution



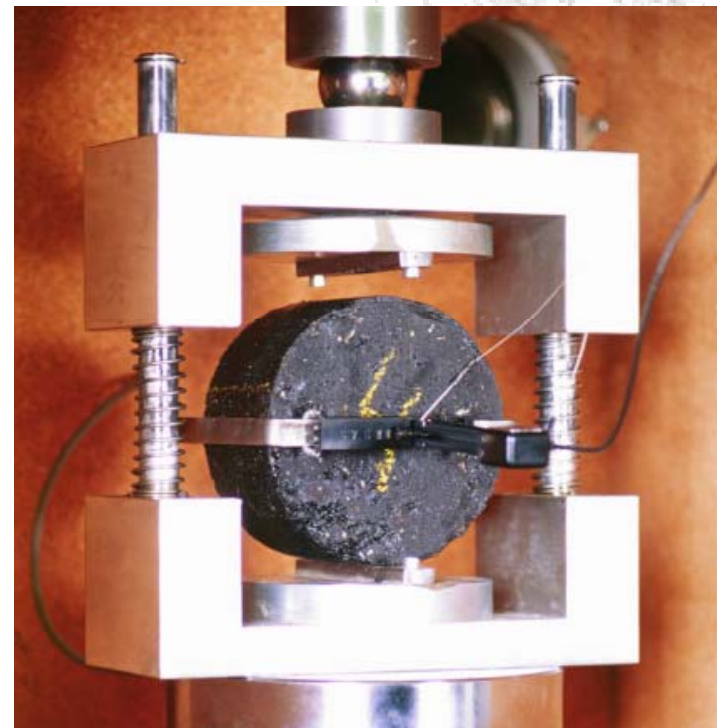
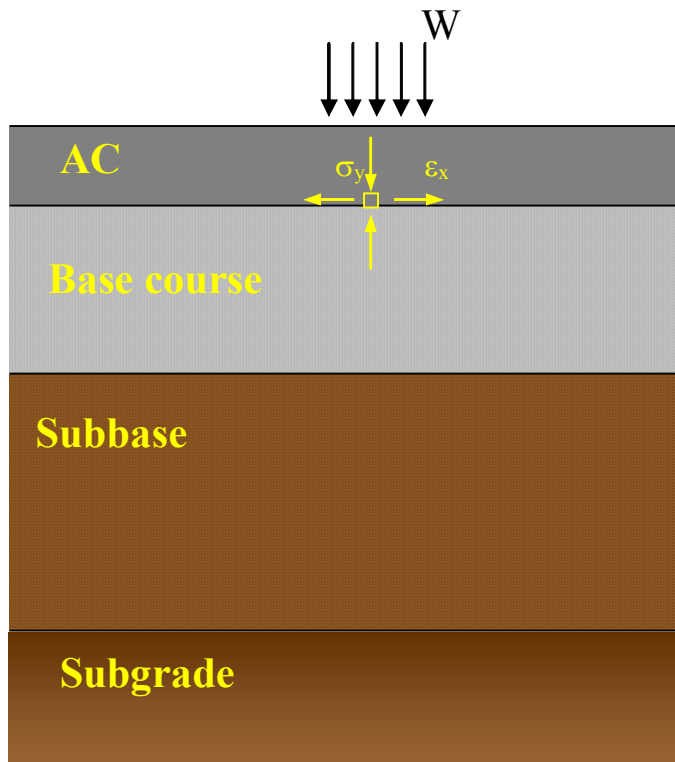
Material Properties - Dynamic testing



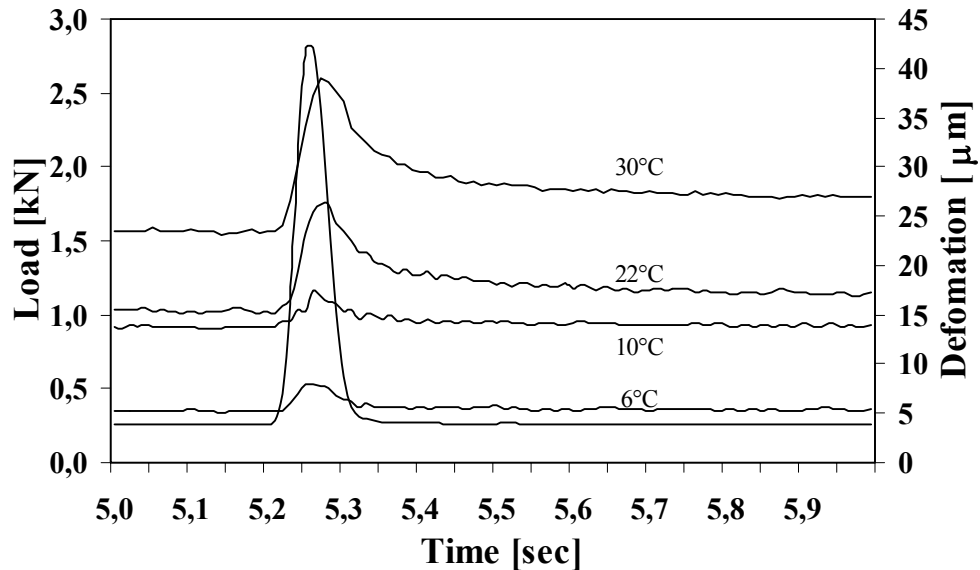
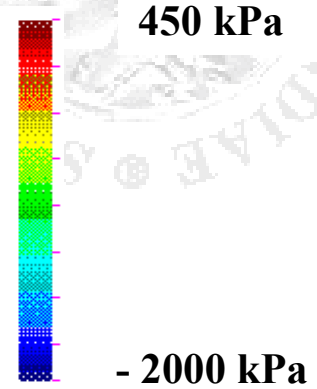
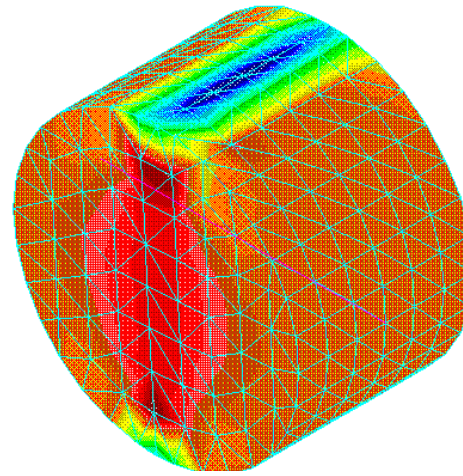
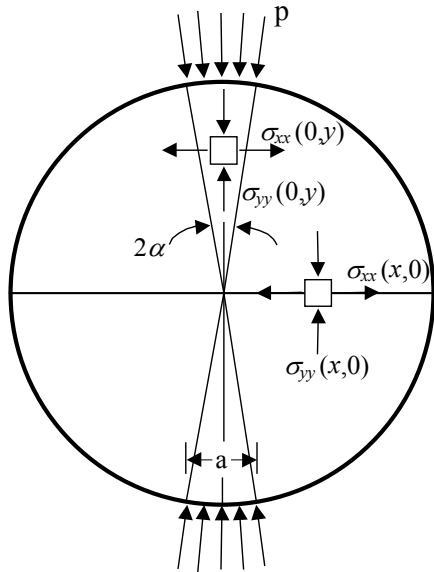
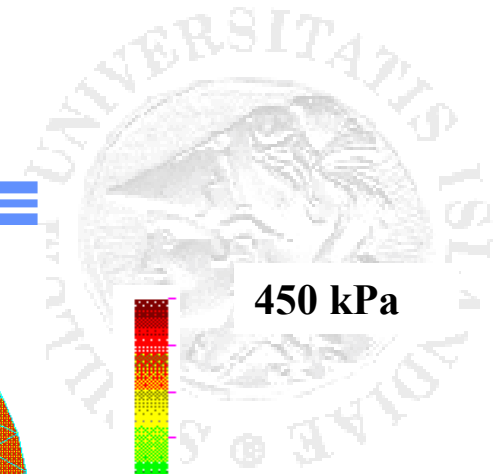
Dynamic testing simulates field conditions better than static testing, therefore a better correlation is expected with field performance.

Layer	Test method	Property
Asphalt Concrete	Indirect tension test Uniaxial compression	Stiffness, Fatigue Creep
Bitumin.stab. Base Course	Indirect tension test Uniaxial compression	Stiffness, Fatigue Creep
Unbound granular materials	Triaxial testing	Stiffness, Permanent Deformation Behaviour

Material Properties Asphalt Concrete



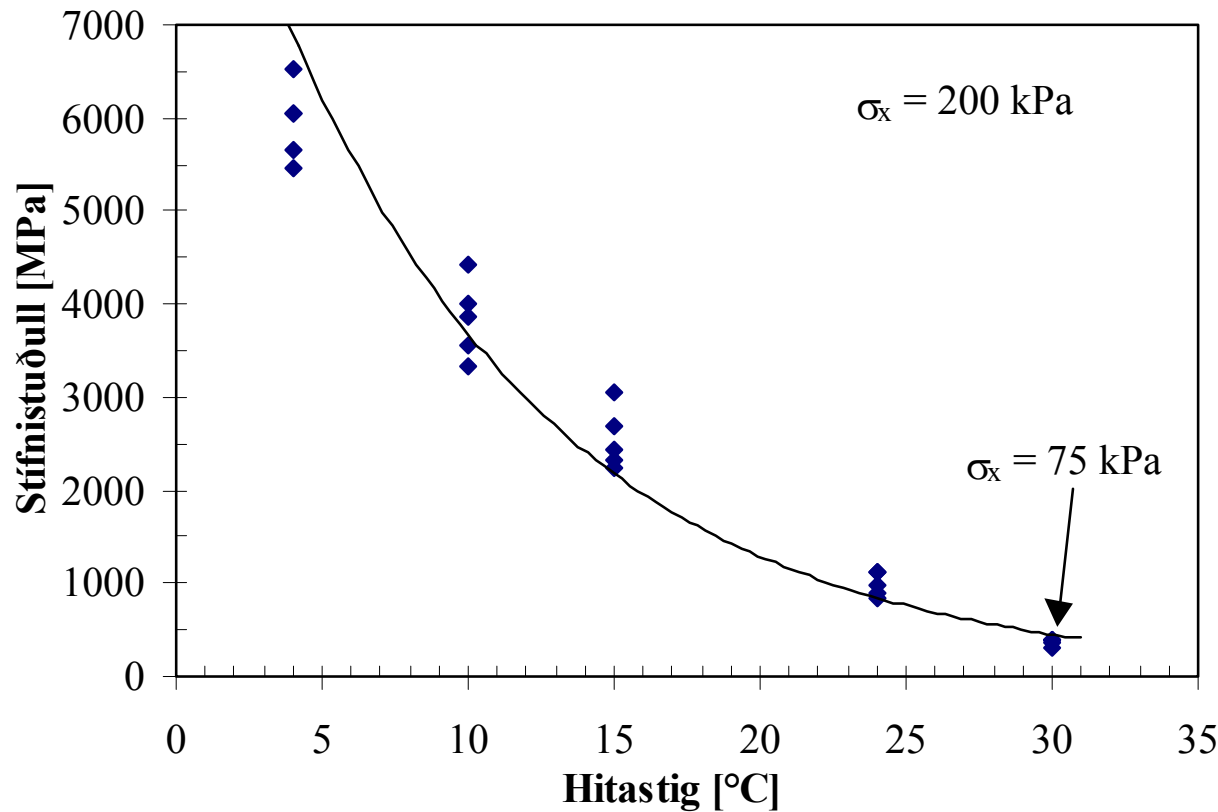
ITT: Testing & FEM calc.: Comparisons



Stiffness as a Function of Temperature

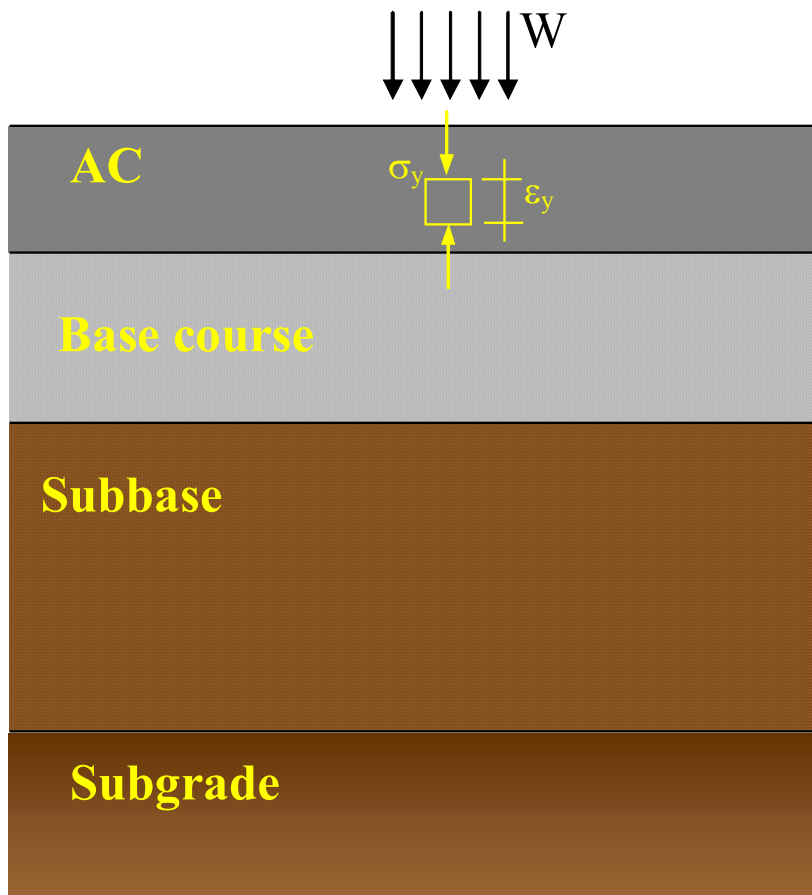


AC: A1-B85



$$M_r = a \cdot e^{-b \cdot T}$$

Uniaxial Compression Test

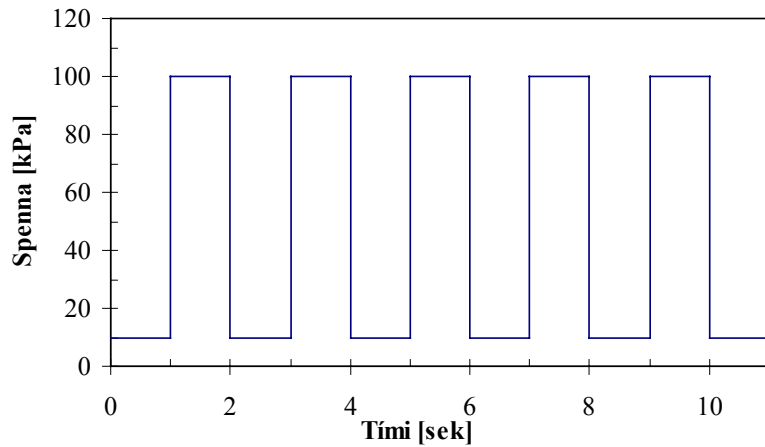


Uniaxial Compression Test - Example

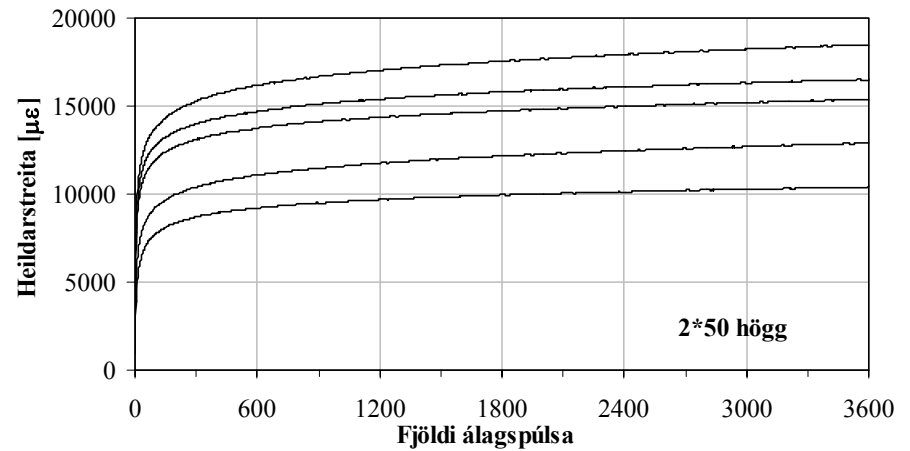


AC: B4-B180

Applied load



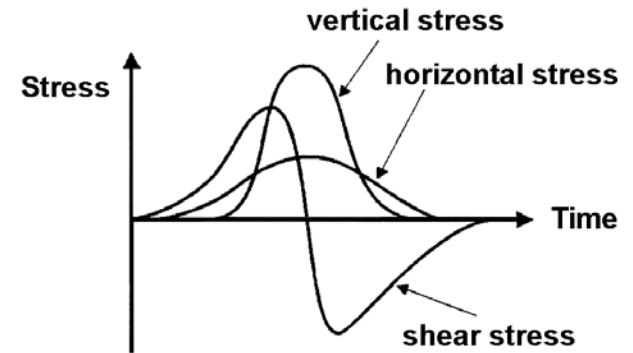
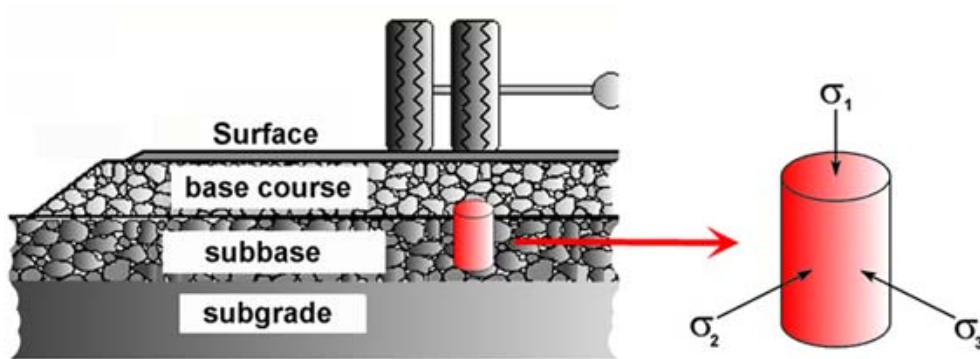
Accumulated strain



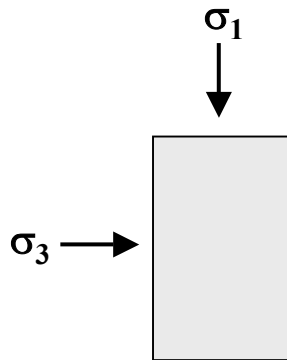
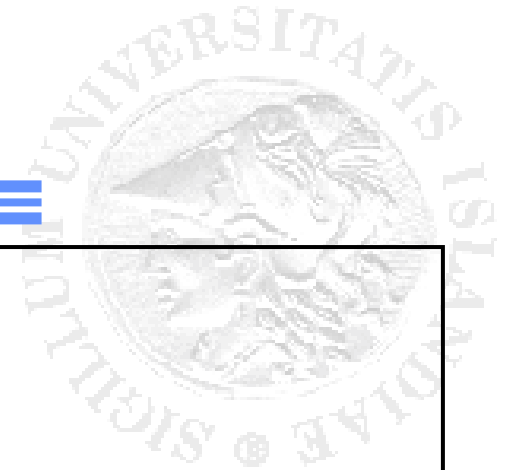
Unbound Granular Materials



- » Stiffness - M_r , ν (nonlinear behaviour).
- » Permanent deformation behaviour



Stresses in RLTT



Before / after:

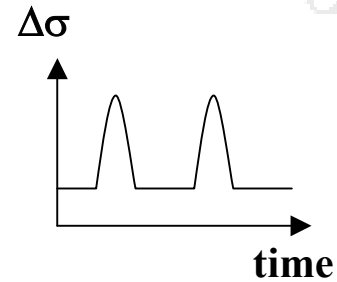
$$\sigma_1 = \sigma_v$$

$$\sigma_3 = \sigma_h$$

During loading

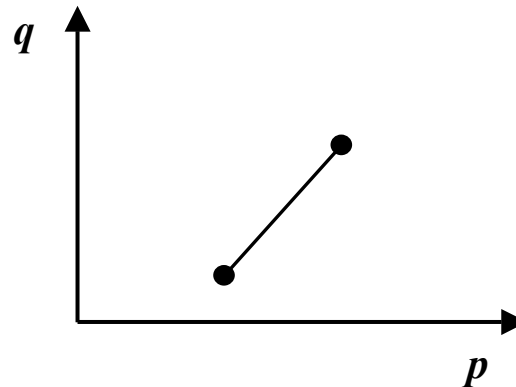
$$\sigma_1 = \sigma_v + \Delta\sigma_v$$

$$\sigma_3 = \sigma_h + \Delta\sigma_h$$



$$p = \frac{1}{3}(\sigma_1 + 2\sigma_3)$$

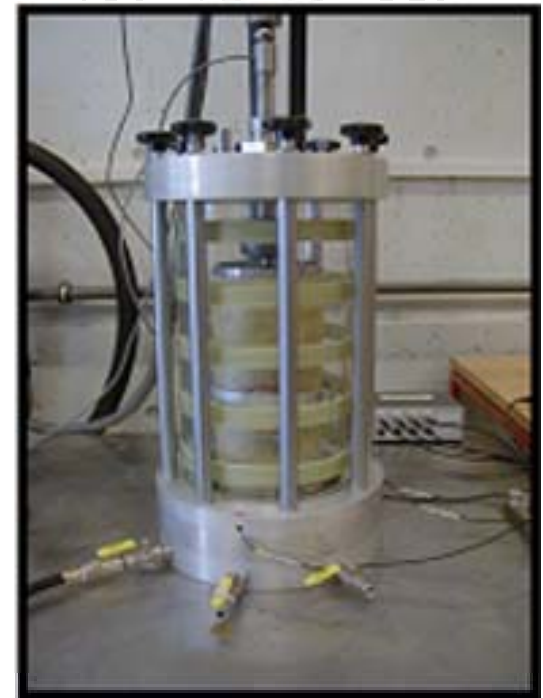
$$q = \sigma_1 - \sigma_3$$



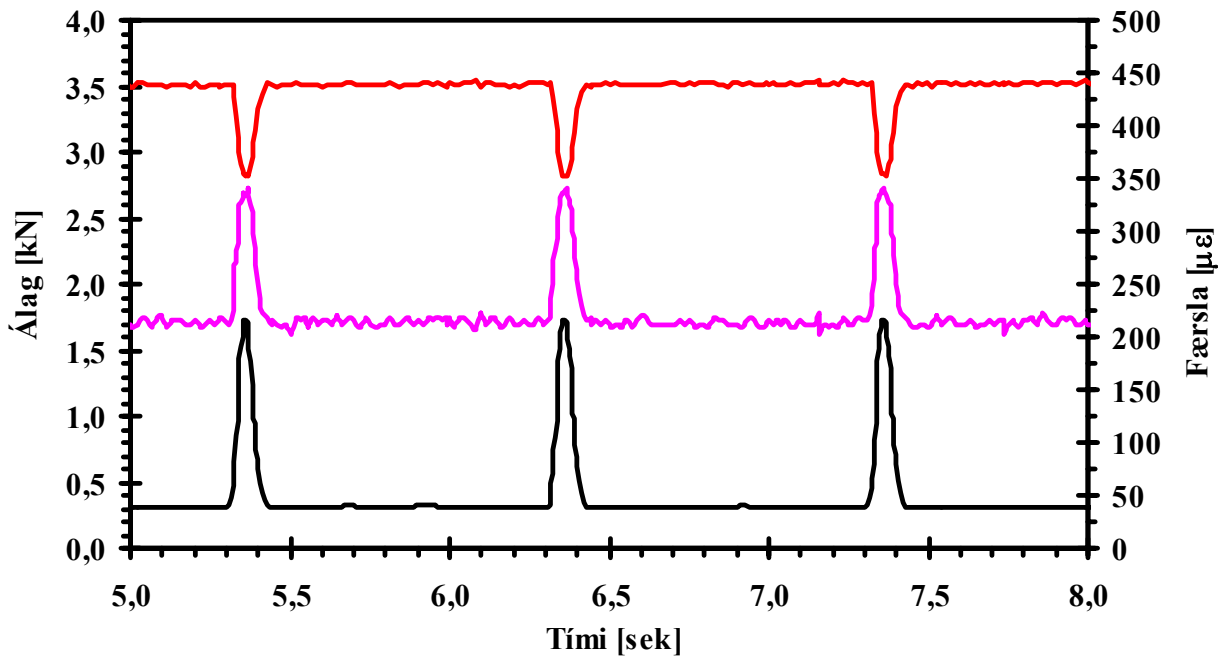
RLTT – Unbound granular materials



Specimen size: 150 x 300 mm, $d_{max} = 30$ mm



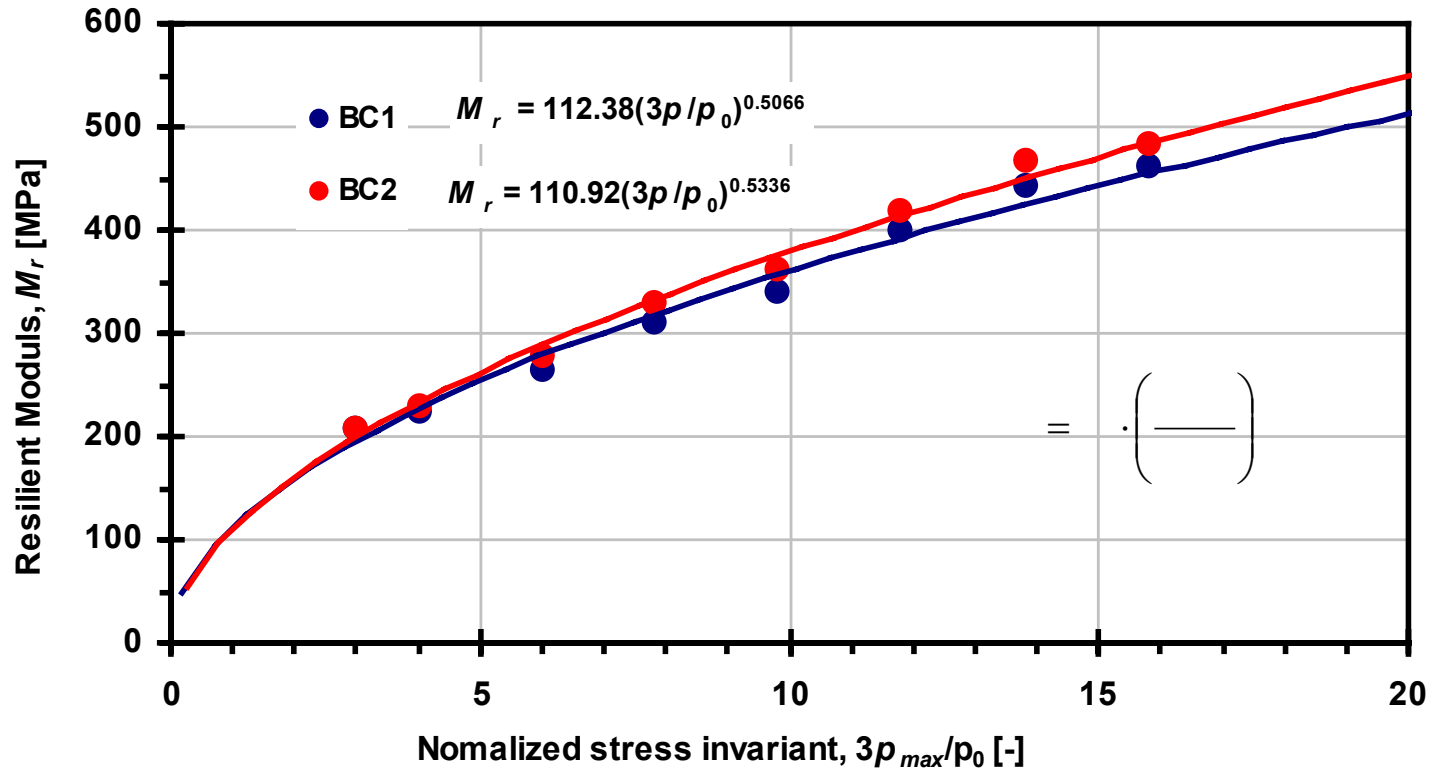
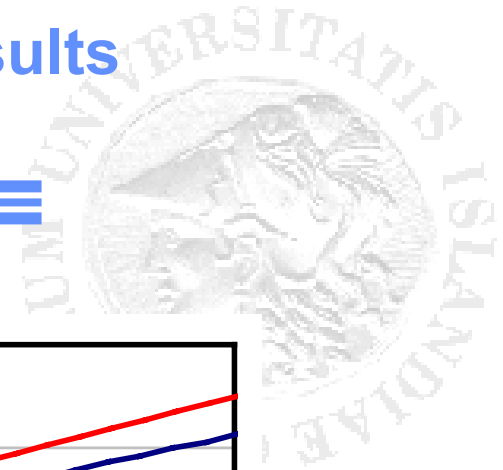
RLTT - measurements



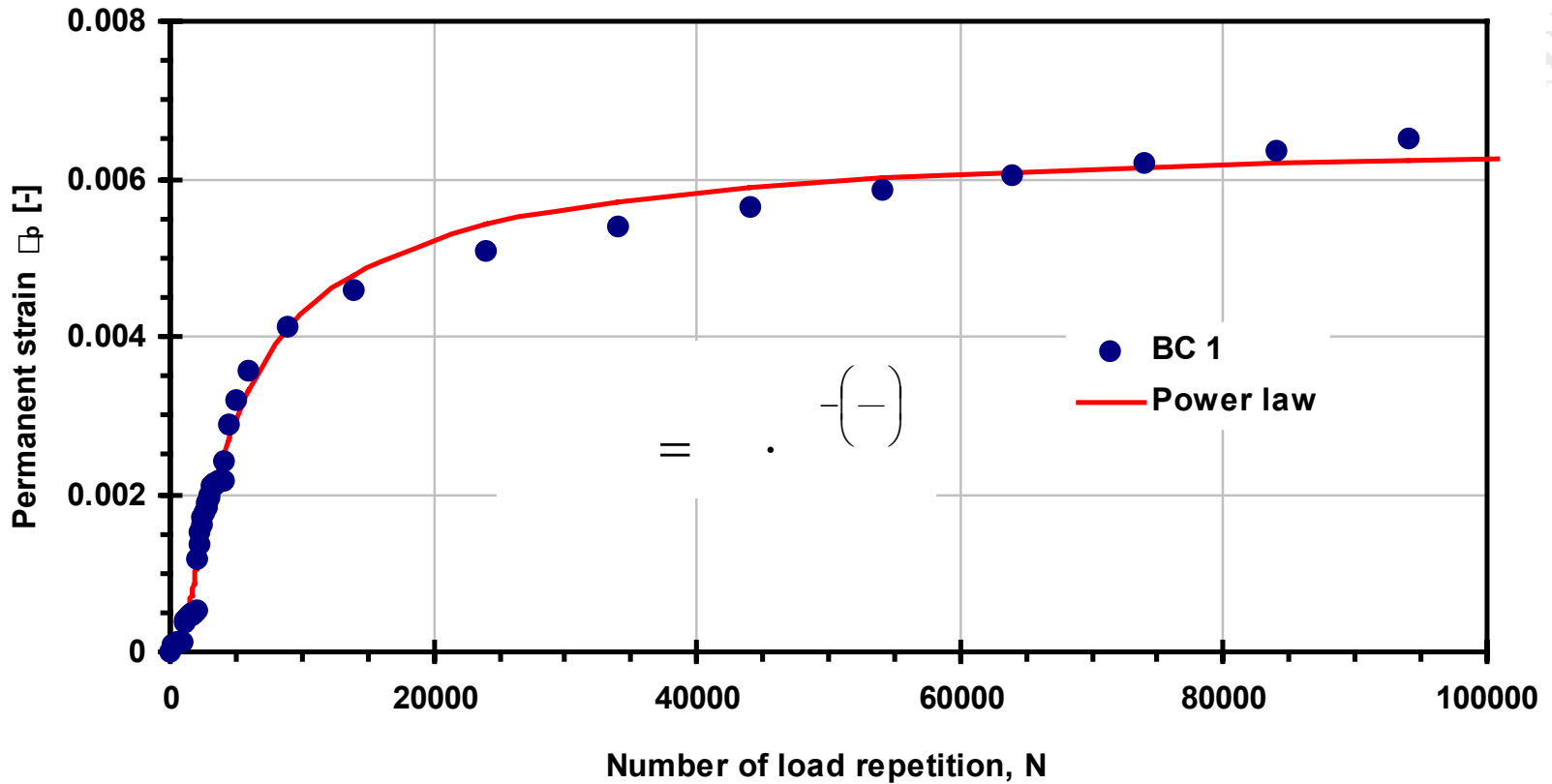
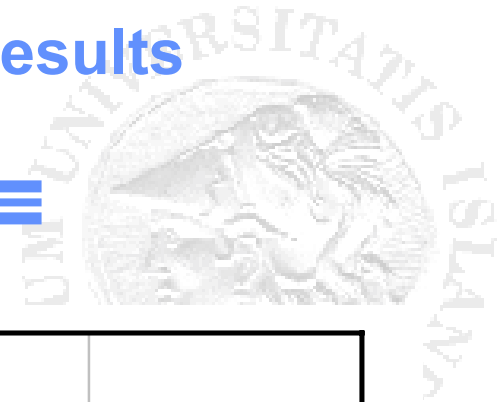
$$M_r = \frac{\sigma d}{\epsilon_1^r}$$

$$v = -\frac{\epsilon_3^r}{\epsilon_1^r}$$

RLTT – Stiffness Testing - Typical Results



RLTT – Perm. Def. Testing - Typical Results



Seasonal Monitoring of Pavements Performance

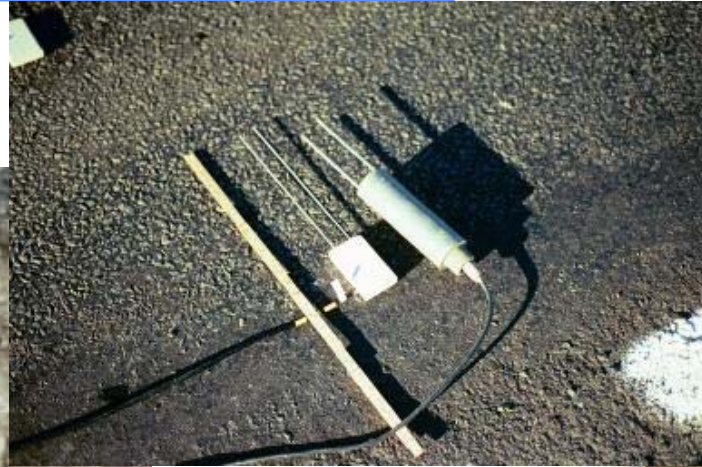
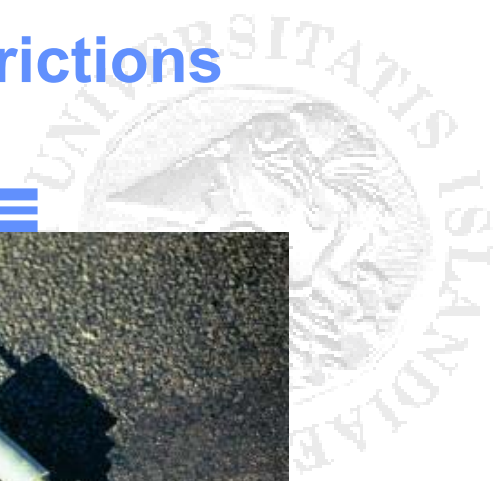
- **Purpose**

To gather information on the seasonal variability of environmental factors (temp., MC, frost etc.) and bearing capacity and their relationship for modelling purposes.

Spring Load Restrictions



Climatic Properties- Spring Load Restrictions

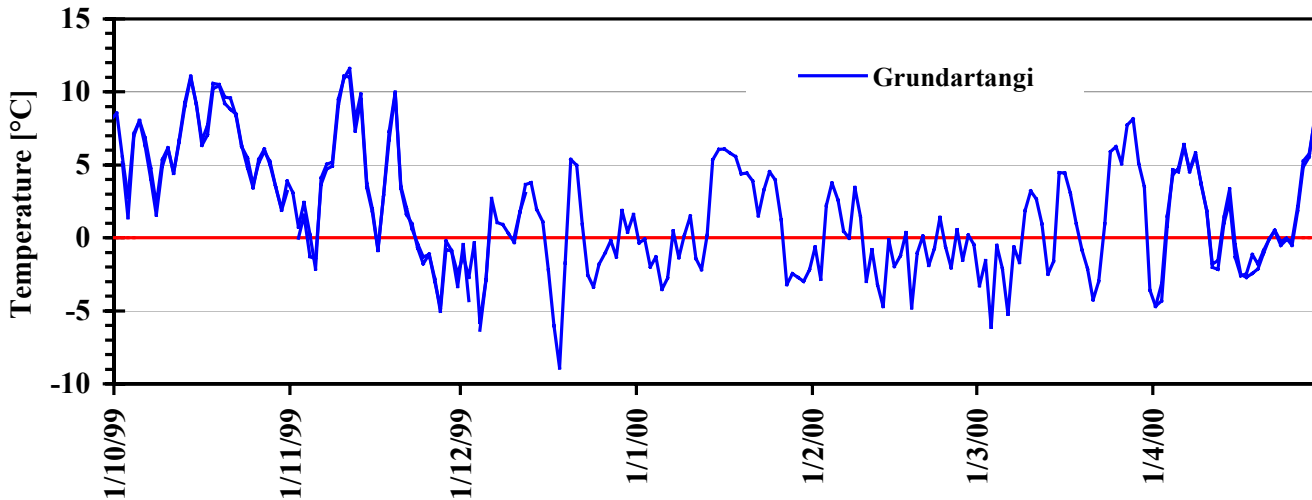
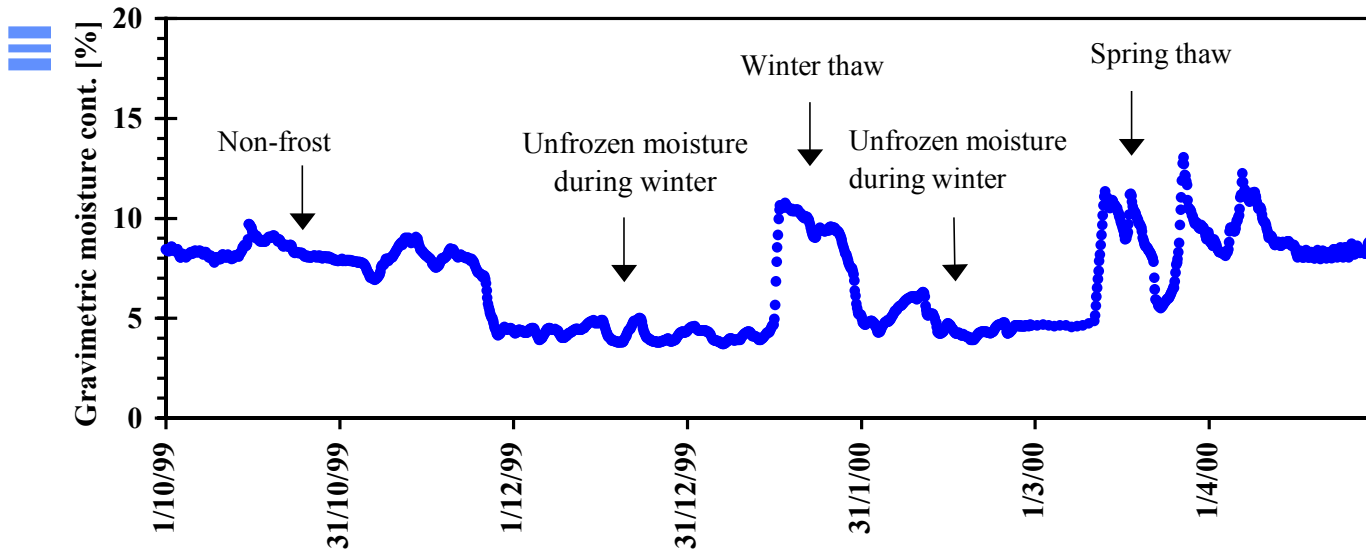
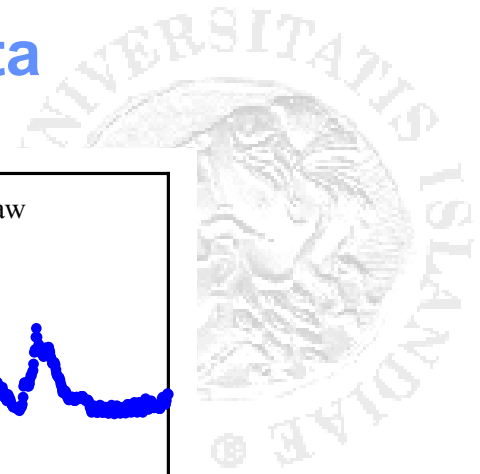


Measurements and Monitoring

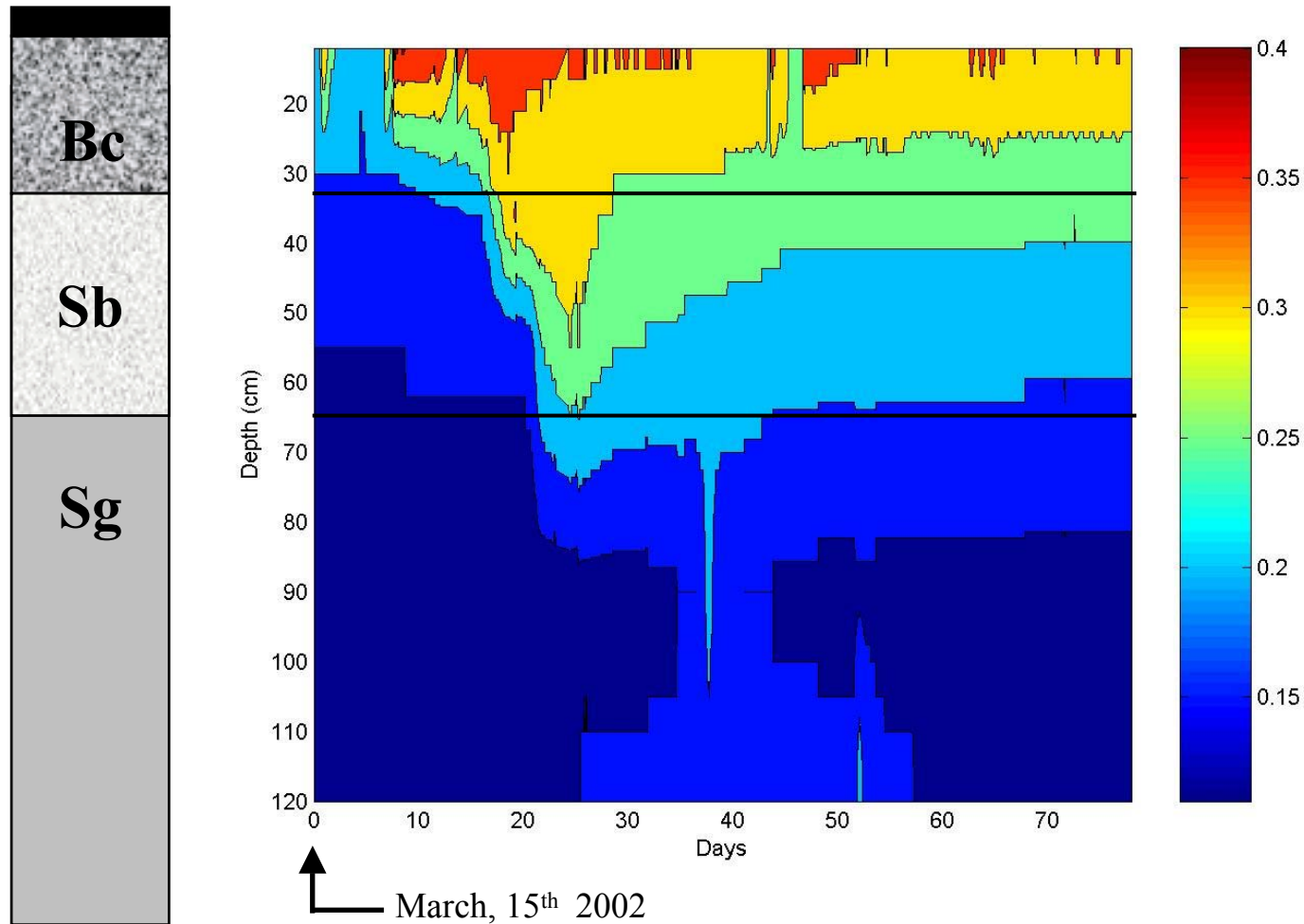
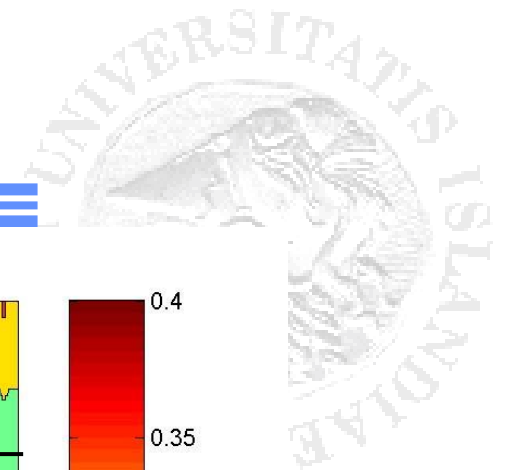


- **Collection of in-situ parameters :**
 - » **Groundwater level**
 - » **Frost penetration**
 - » **Moisture (TDR) and temperature monitoring**
 - » **Resistivity monitoring**
 - » **Meteorological data (daily precipitation & air temperature)**
 - » **FWD measurements**

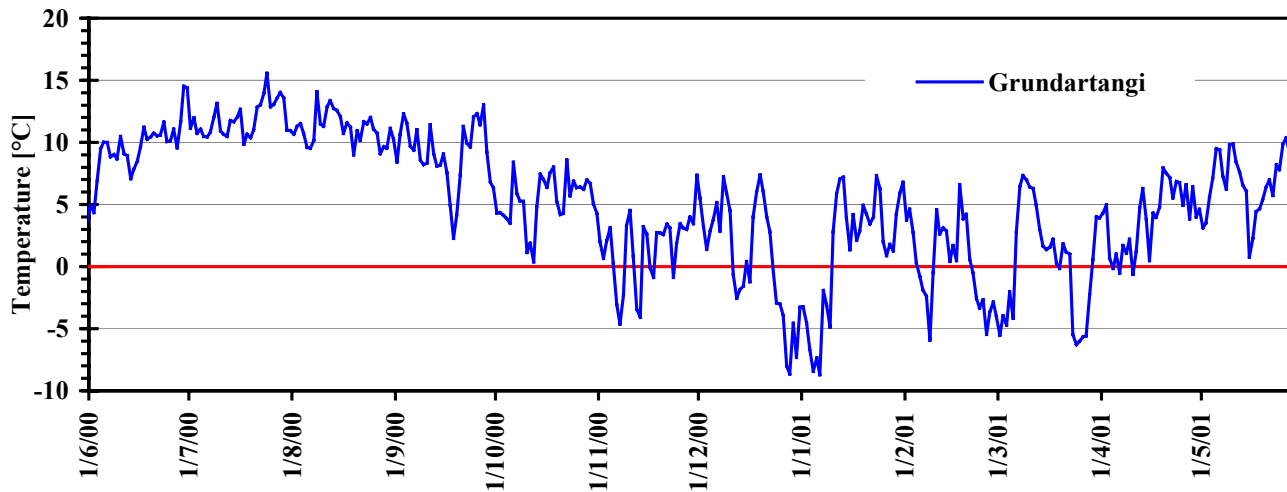
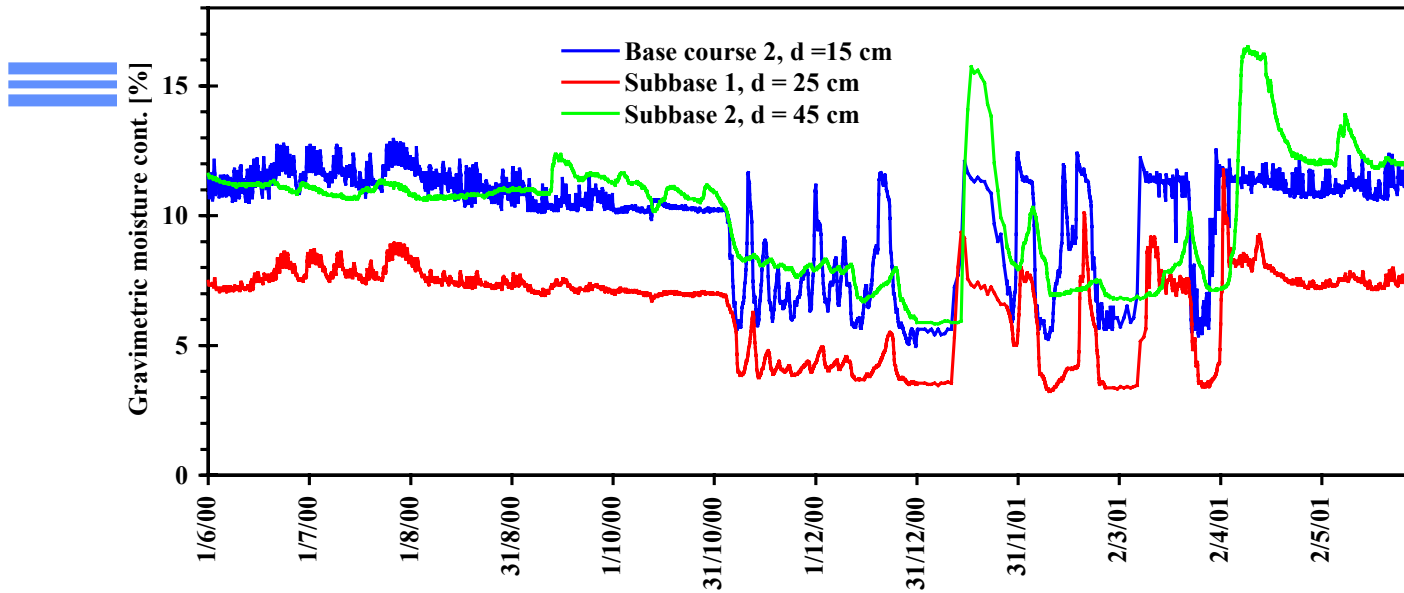
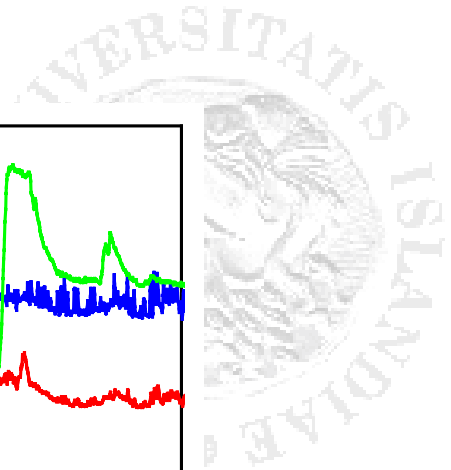
Moisture Content and Temperature Data



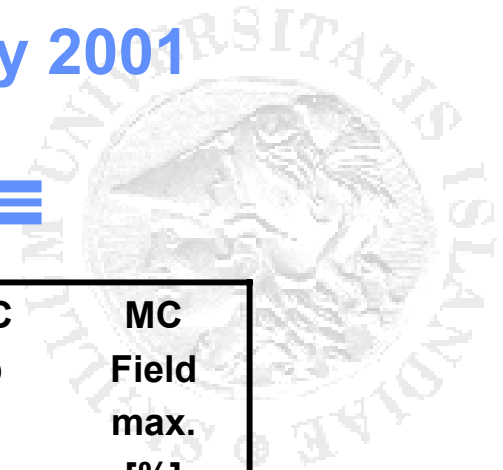
Moisture Content vs. Time & Depth



Moisture content, section 1.4.1

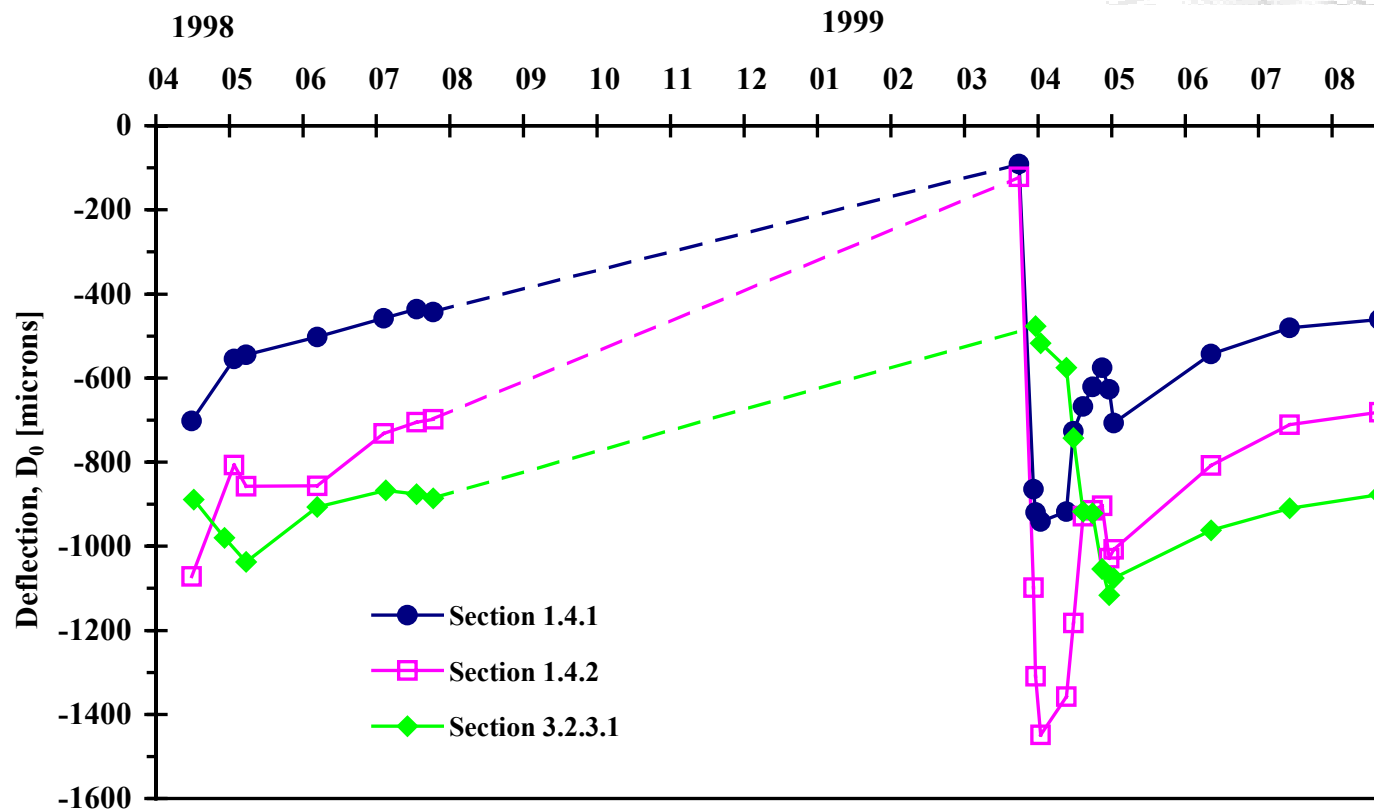


Gravimetric Moisture: June 2000 – May 2001



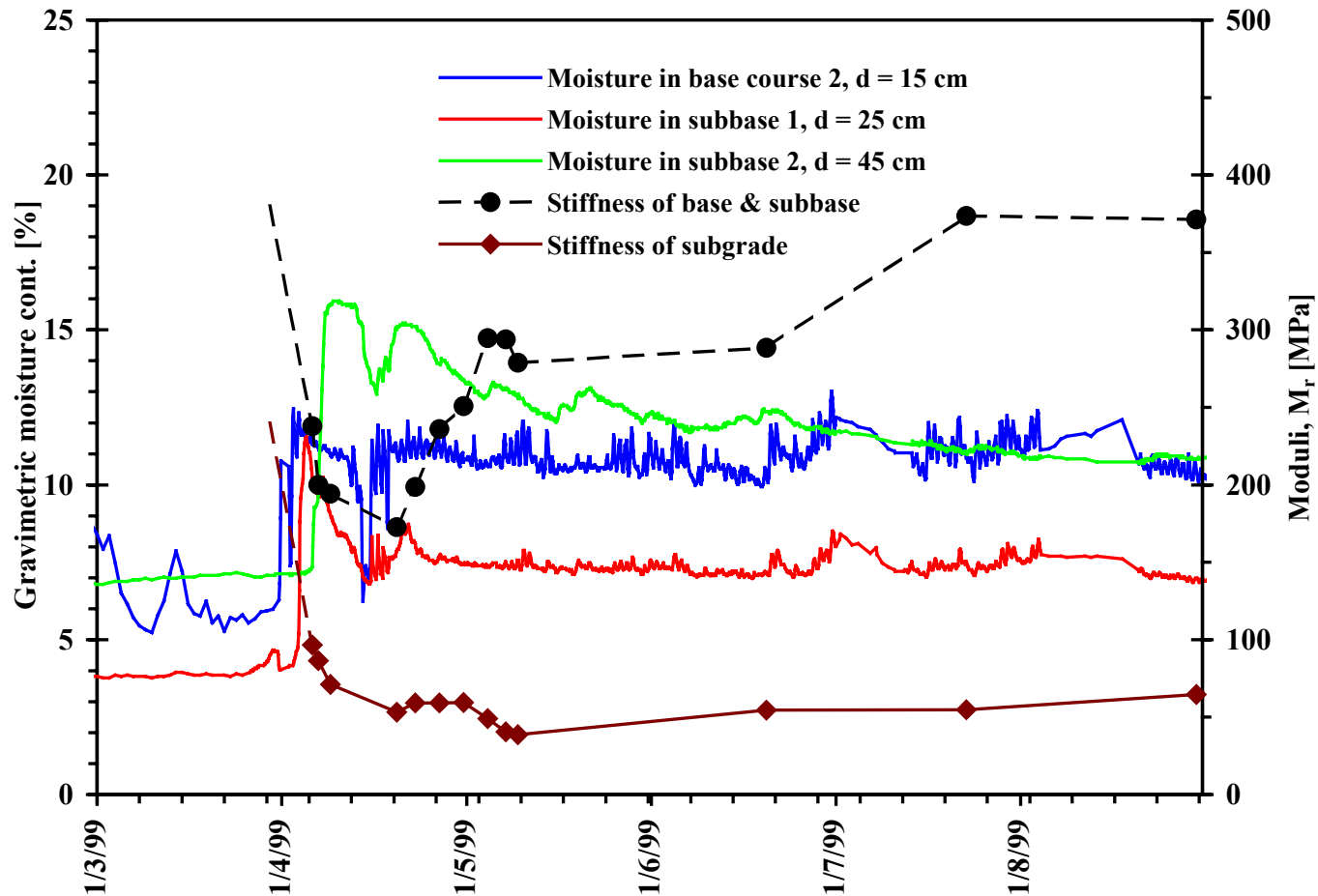
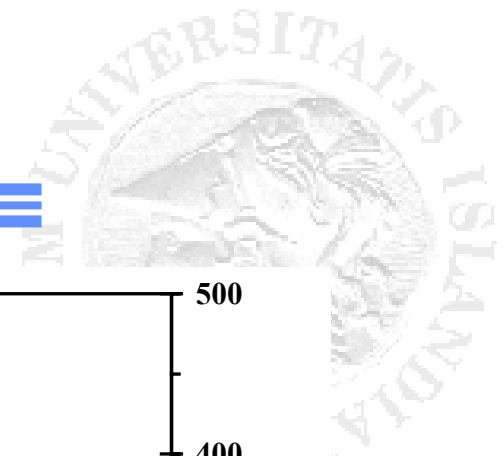
Section	Layer	Depth [cm]	USCS	D < 75 μm [%]	OMC Lab [%]	MC Field max. [%]
1.4.1	Base course 2	150	GW-GM	5,0	9,9	12,7
	Subbase 1	250	GW-GM	5,8	10,5	12,0
	Subbase 2	450	SW-SM	6,0	12,8	15,4
1.4.2	Base course 2	130	GW-GM	5,0	9,8	12,6
	Subbase 1	250	SM	14,7	10,8	13,1
	Subbase 2	560	SW-SM	10,3	10,7	12,3
3.2.3.1	Subbase 1	150	SP	3,5	12,0	15,4
	Subbase 1	290	SP	3,5	12,0	17,1
	Subbase 2	500	SP-SM	10,5	12,0	13,3

Measured Deflection Values in 2nd Drop

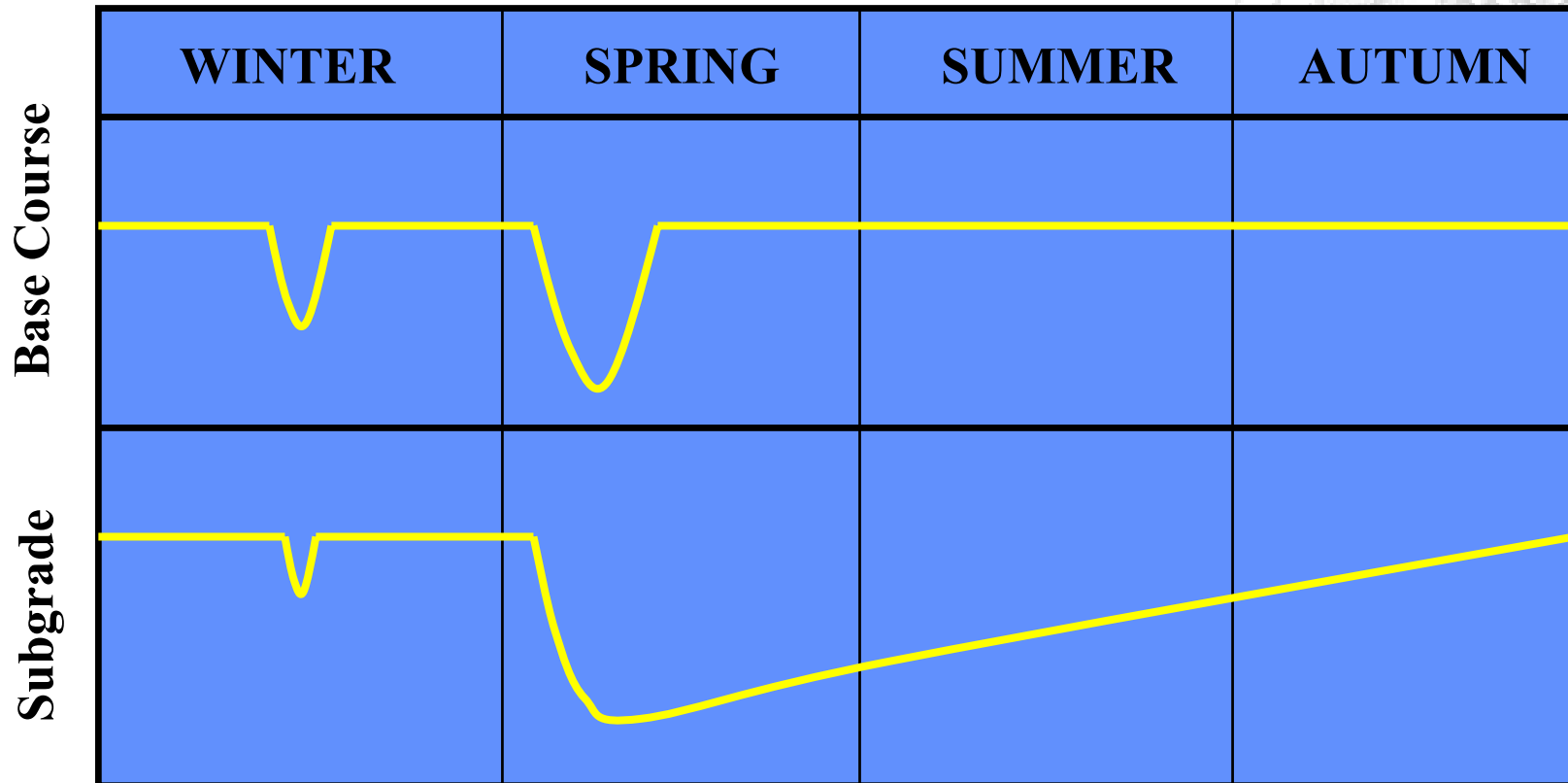


FWD results & grav. moisture in 1999

Section 1.4.1



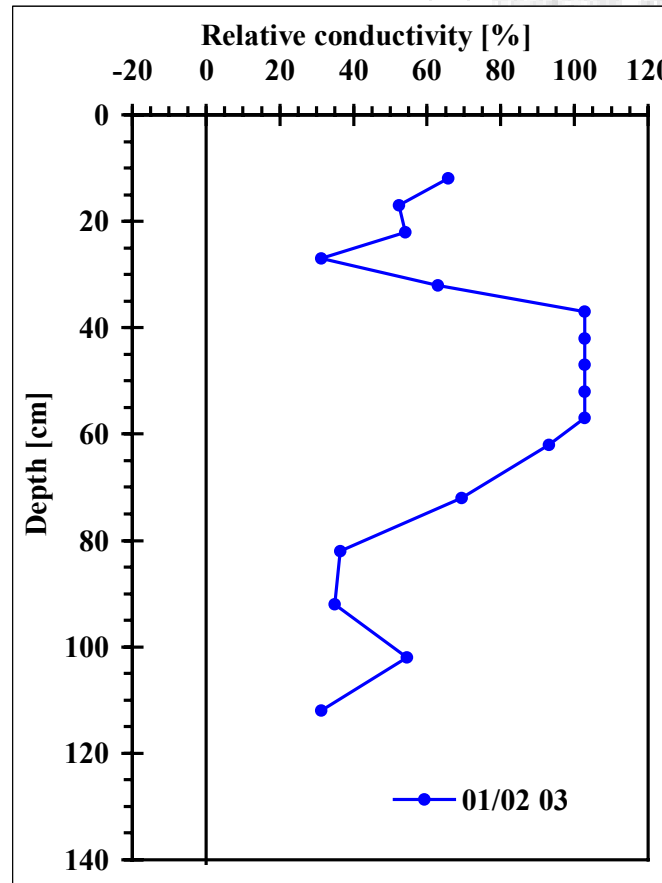
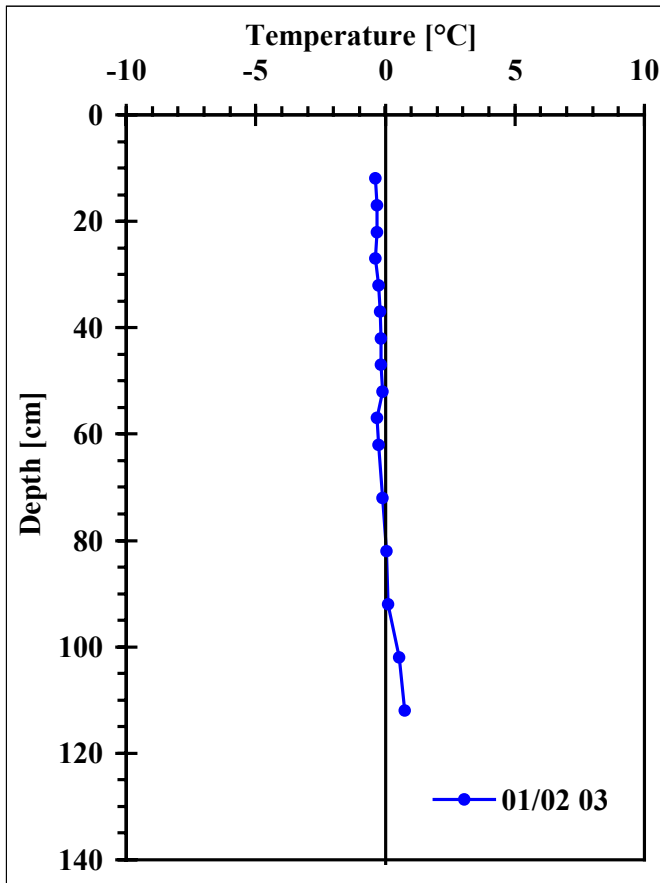
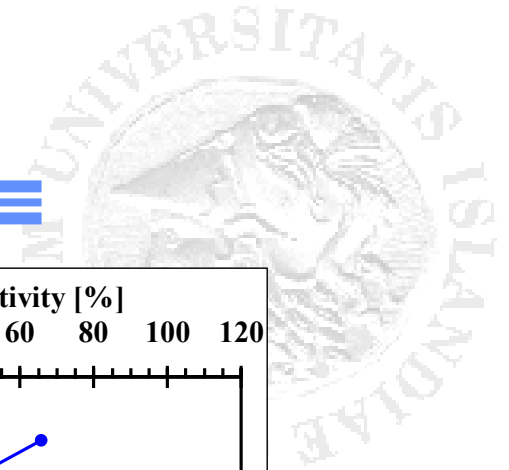
Seasonal Variation of Stiffness in Unbound Layers



Innovative Technique – Temperature & Resistivity Probe



Temperature & Resistivity Probe



Accelerated Pavement Testing



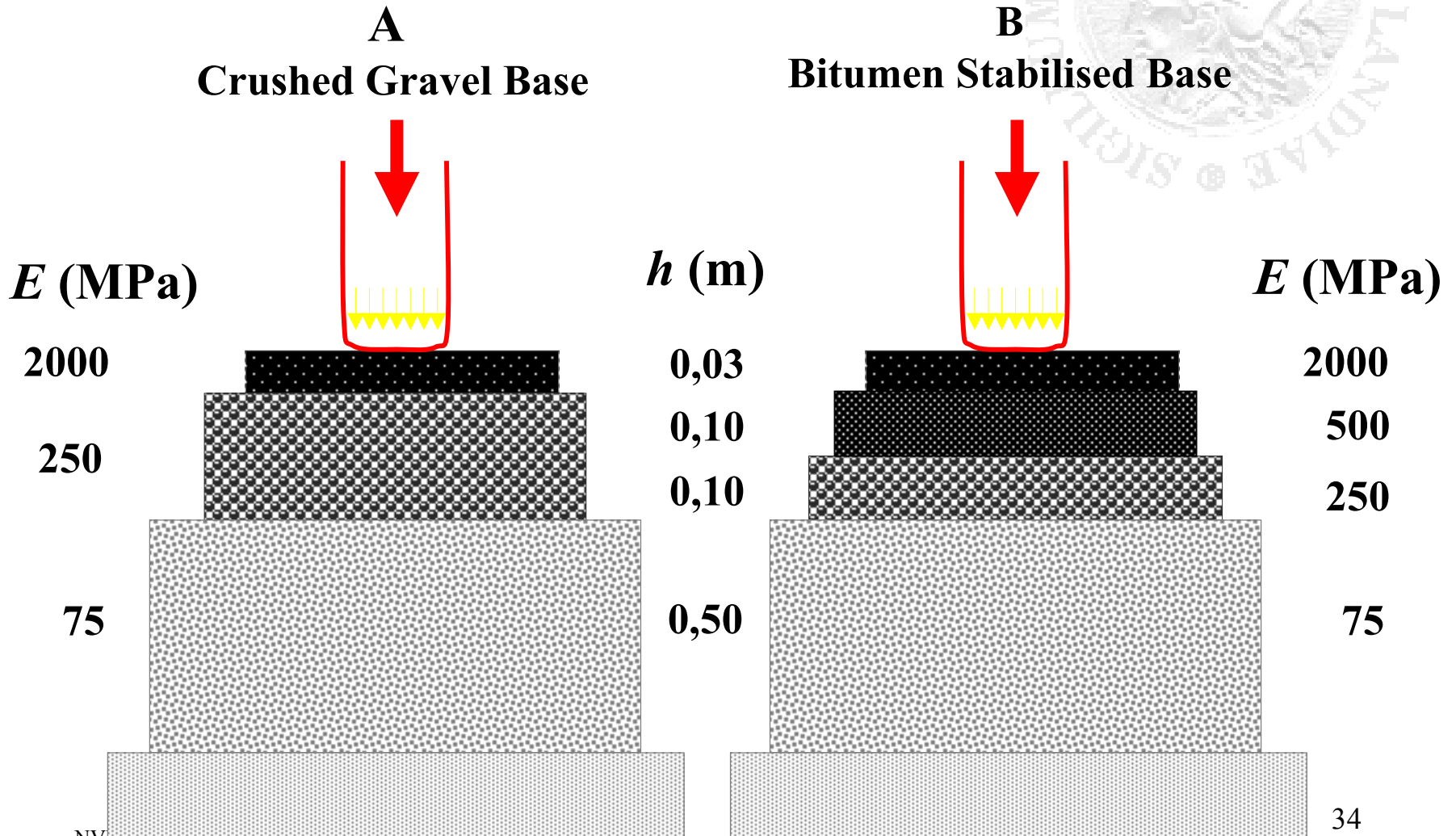
- **Purpose**

To increase the understanding of pavements performance under heavy loading conditions.

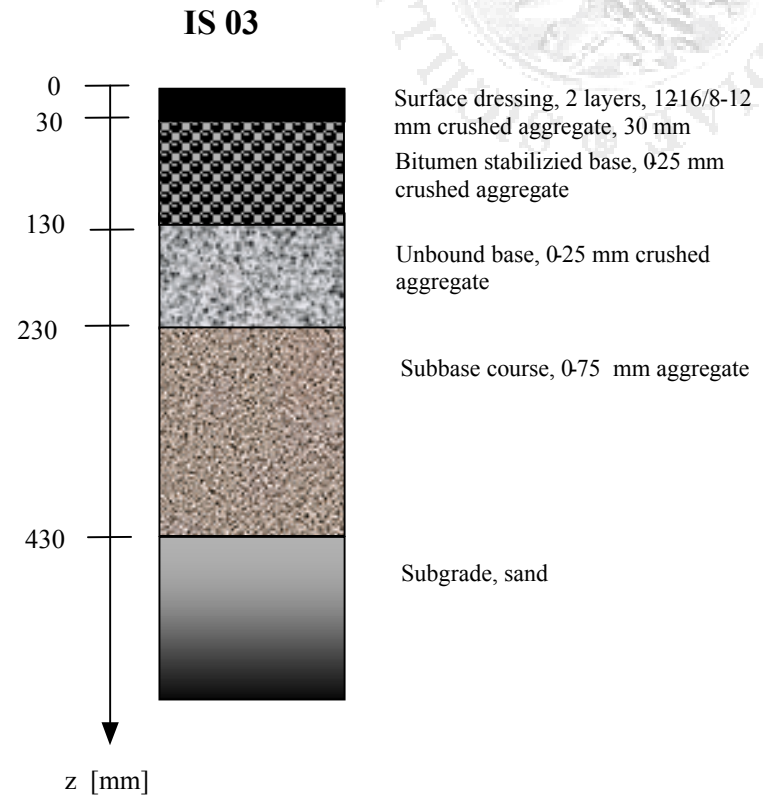
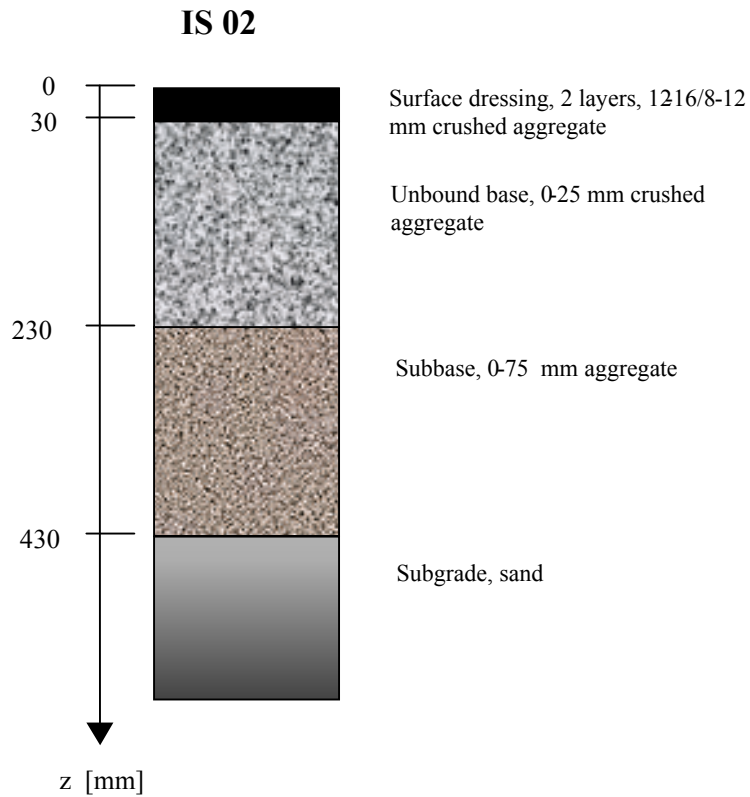


Heavy Vehicle Simulator

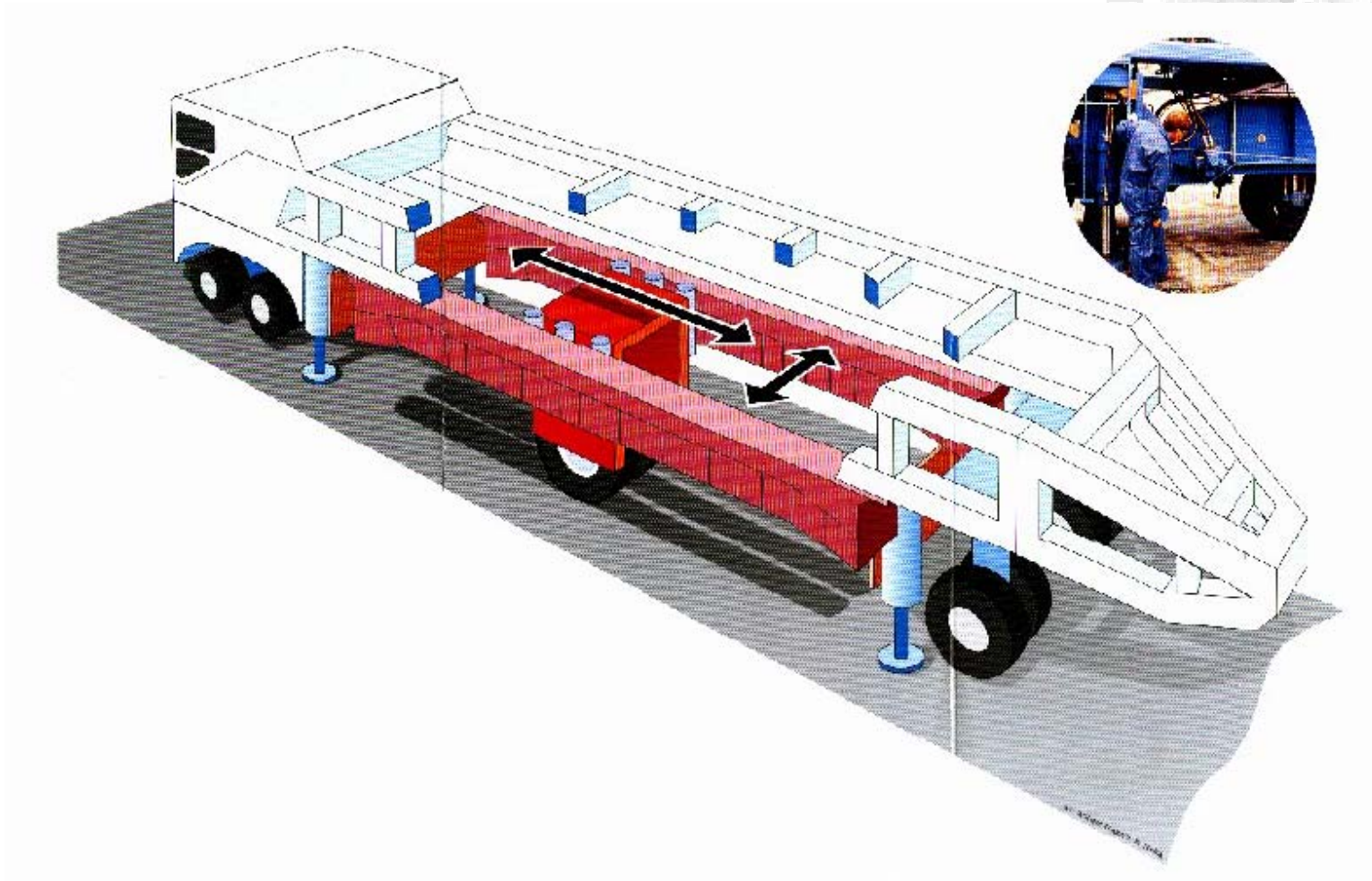
Typical Pavement Structures



The Pavement Structures (IS02 & IS03)



The HVS-Equipment

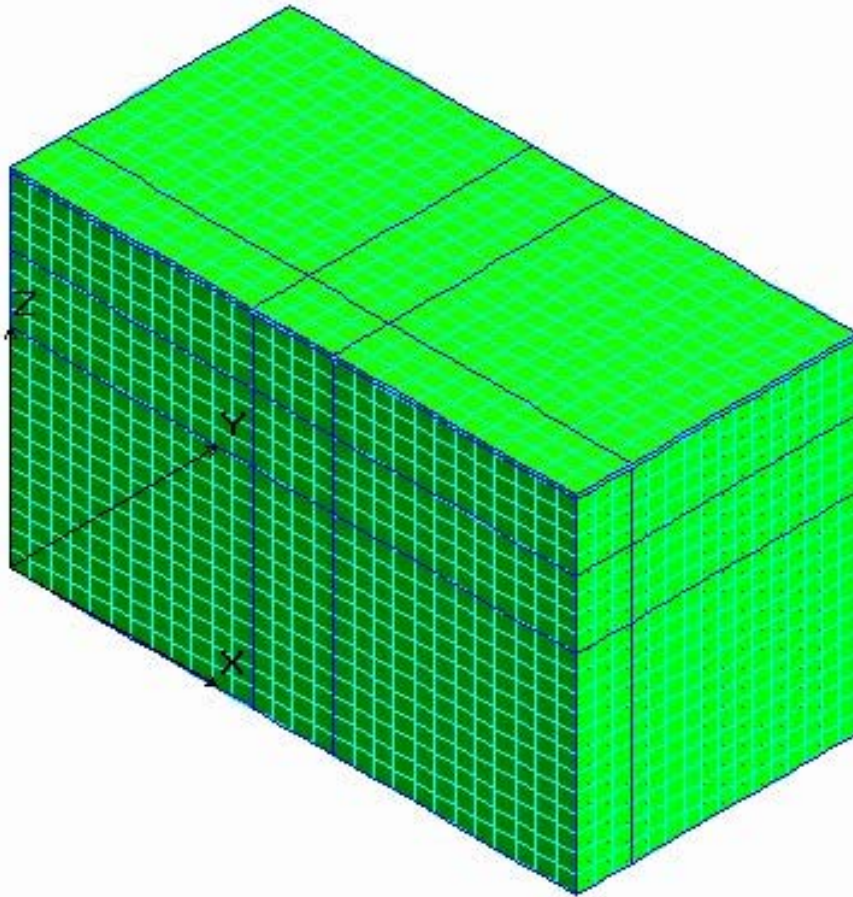


Response Testing - Numerical Simulations

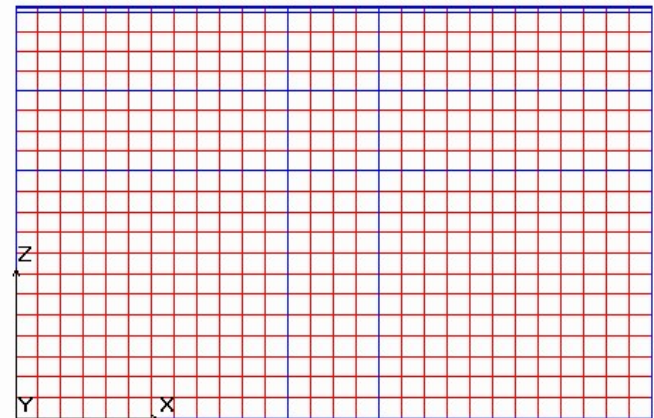


- 2-D Axi & 3-D analysis.
- MLET & FEM analyses
- Linear and non-linear base behaviour

IS02 – The mesh

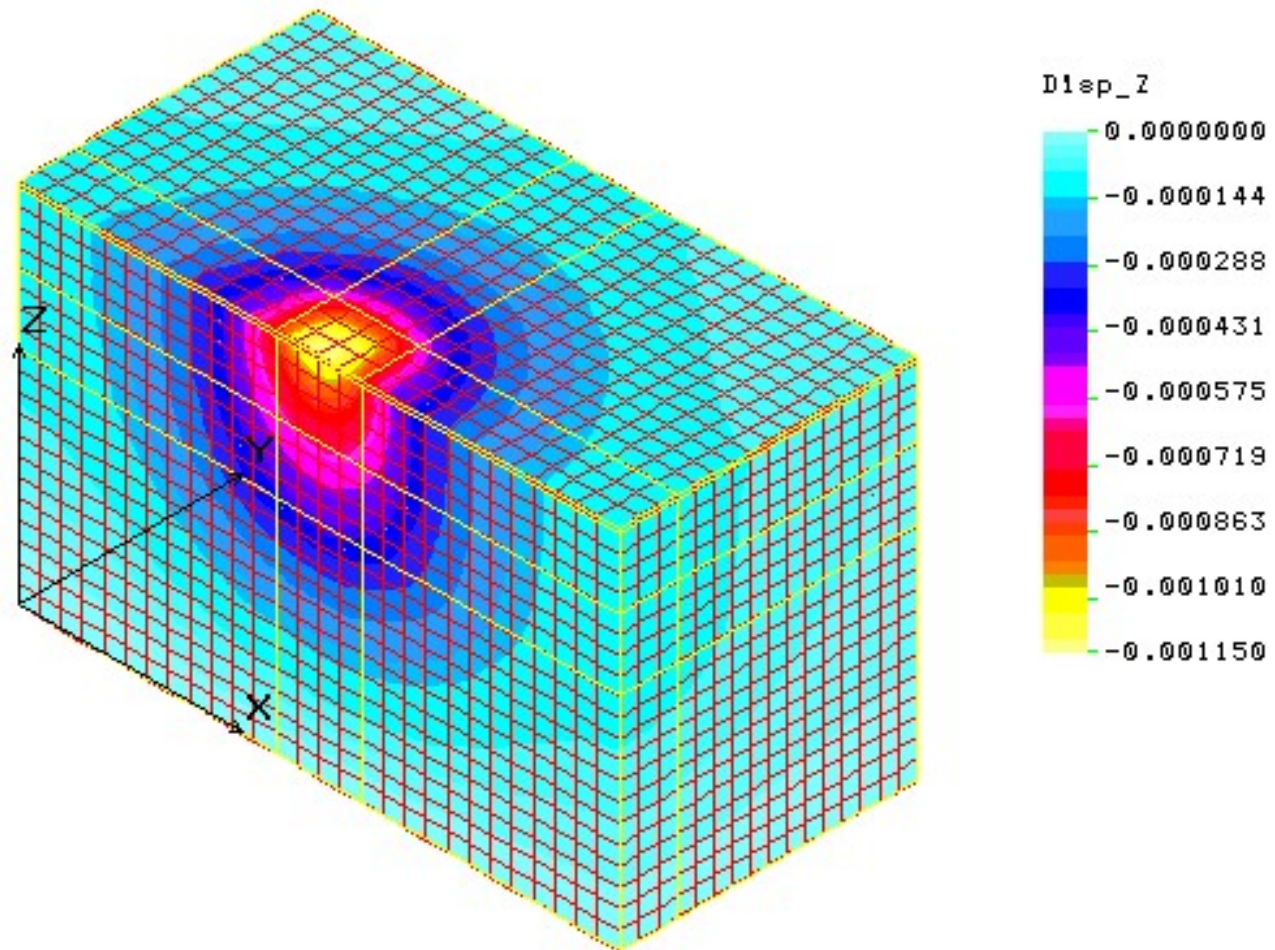


Length: 1200 mm
Width: 600 mm
Height: 1000 mm



IS02 – Single wheel, $p = 800$ kPa

FEM: Vertical displacement

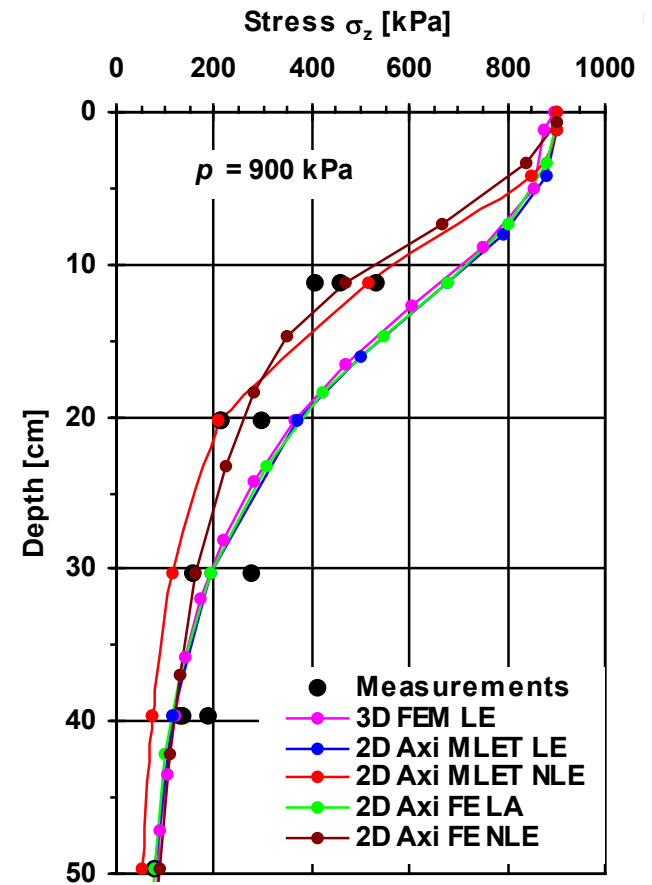
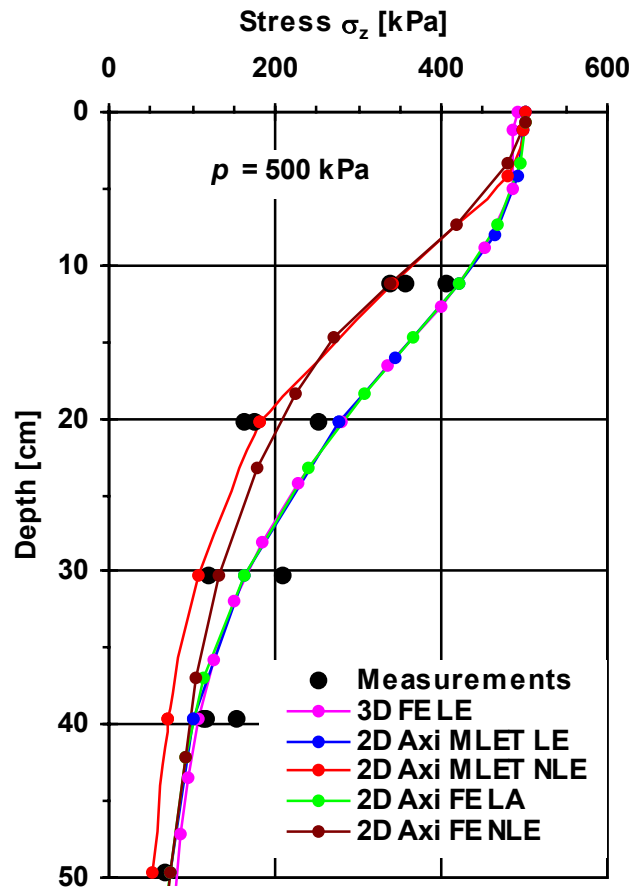
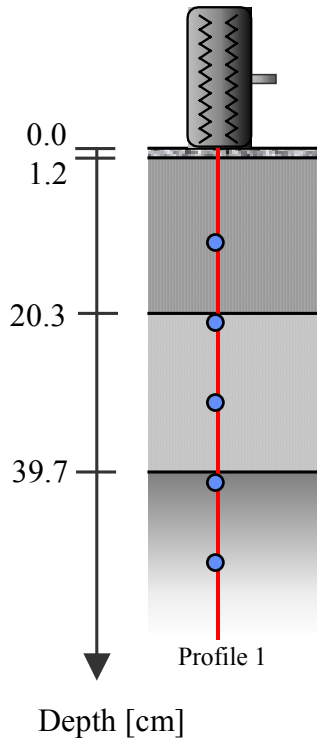


IS02 Vertical Stresses vs. Depth



$W = 120 \text{ kN}$

Single wheel

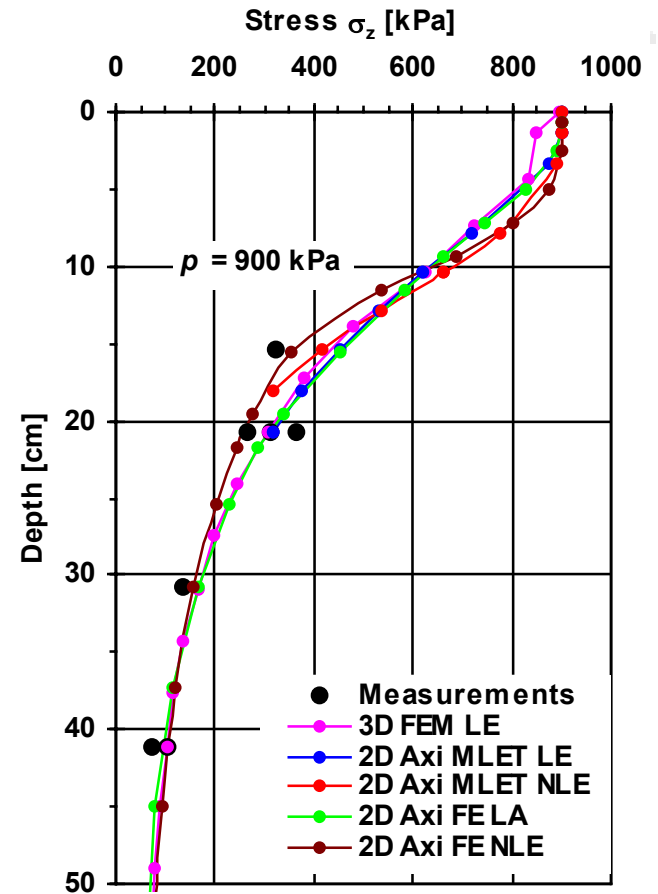
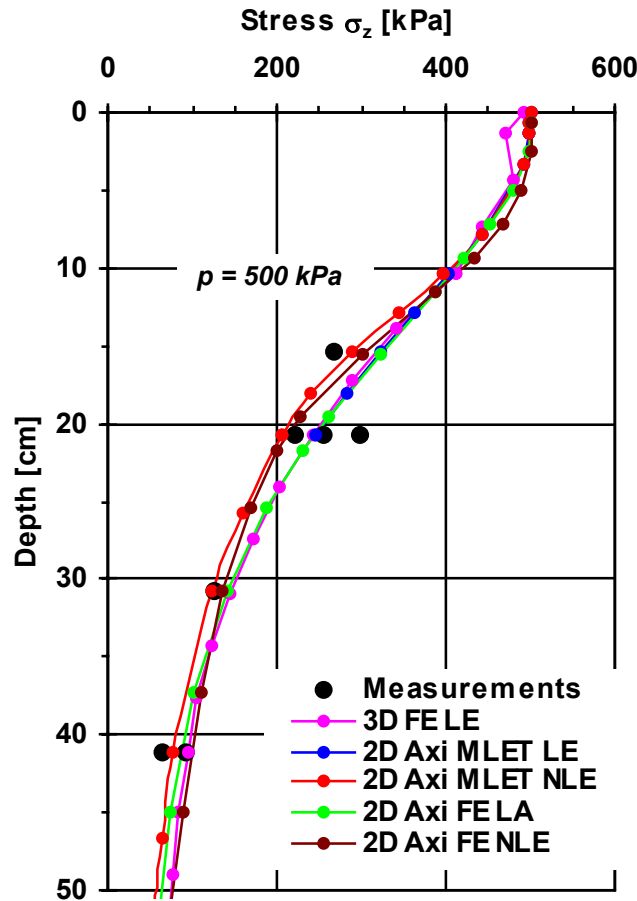
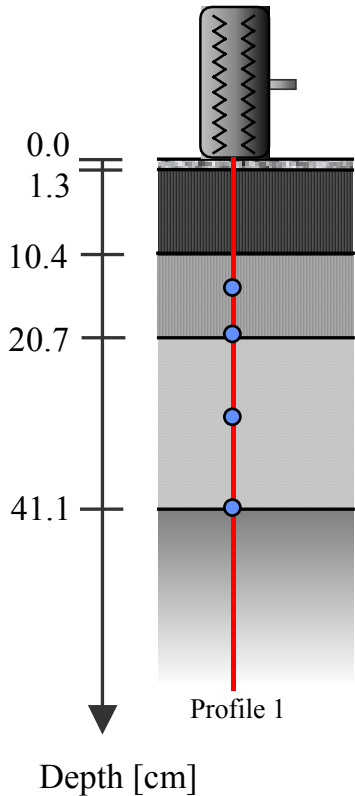


IS03 Vertical stresses vs. depth

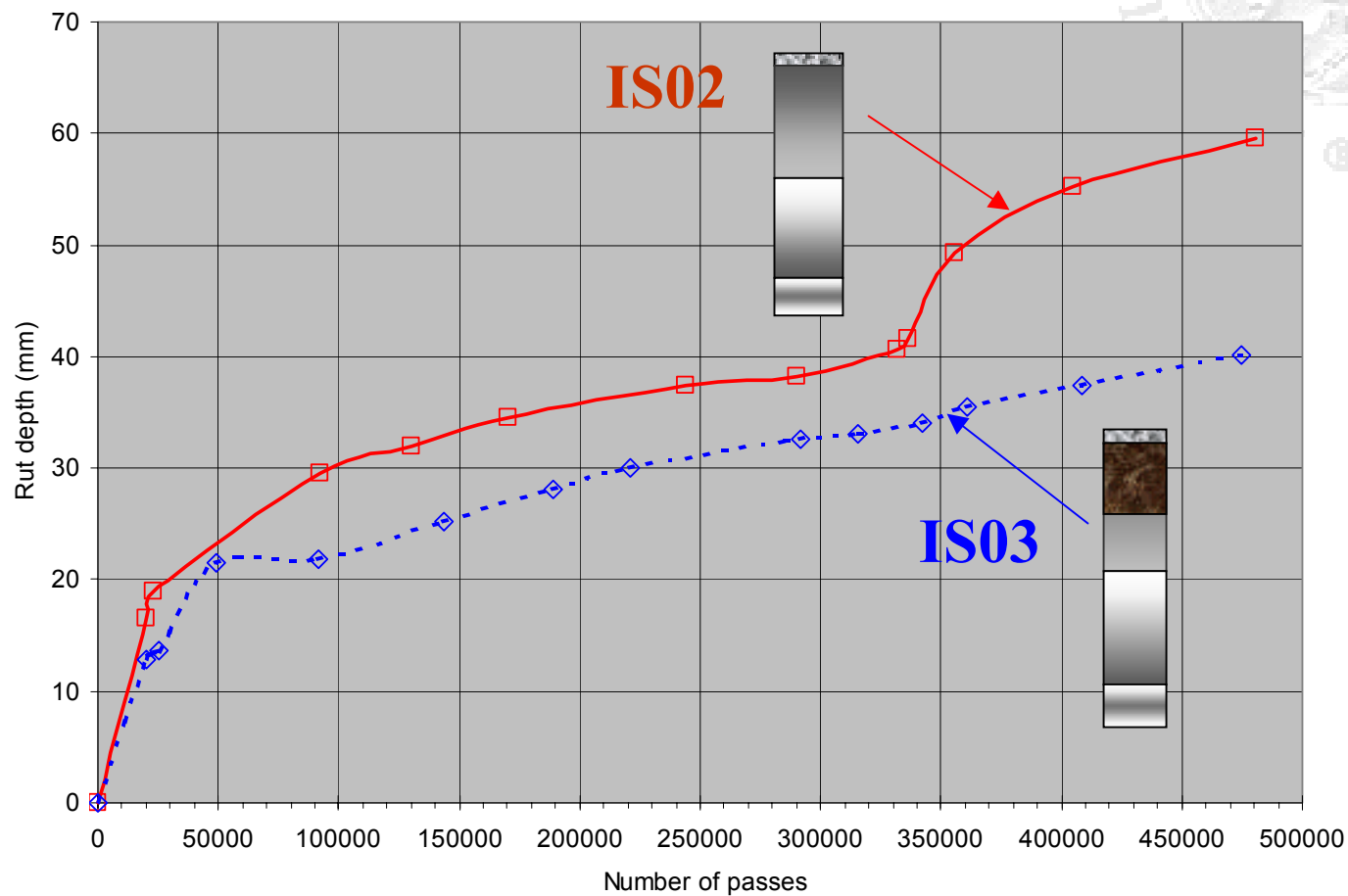
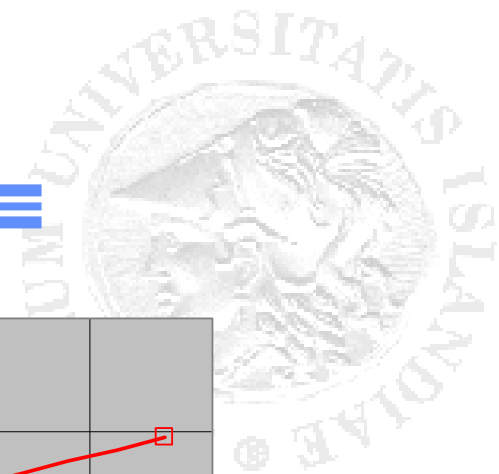


$W = 120 \text{ kN}$

Single wheel



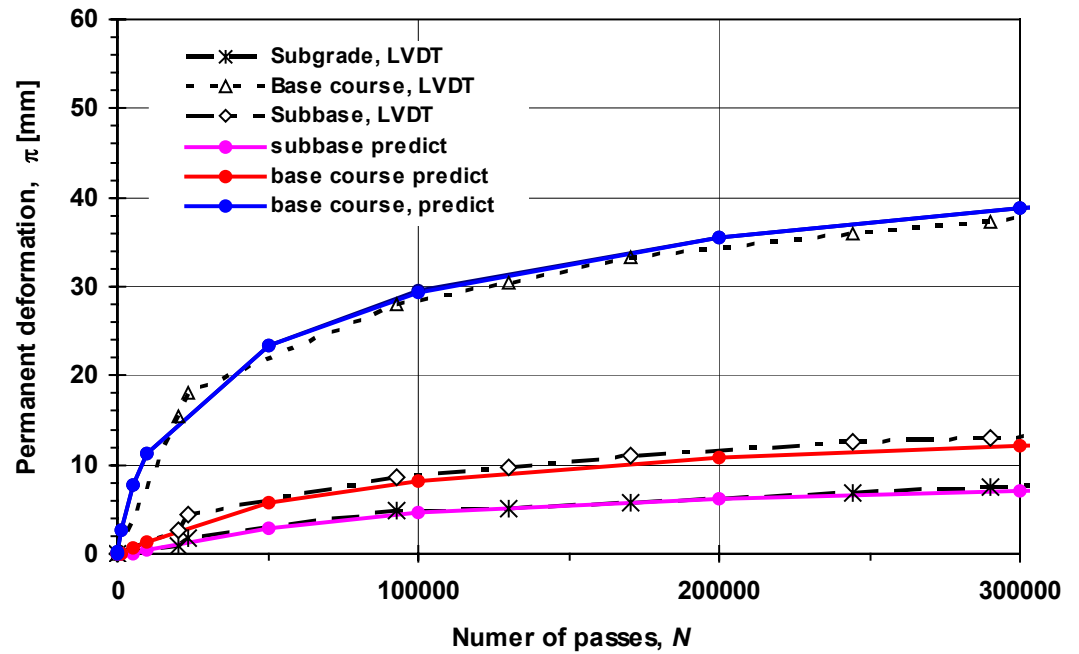
Rutting



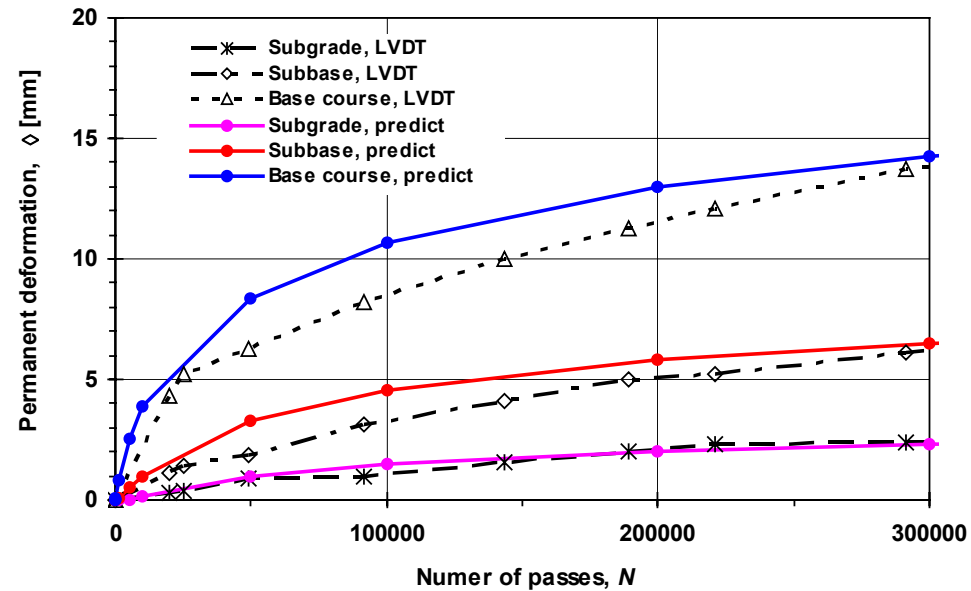
Distress prediction – rutting in IS02



$$= \sum_{=} \left[\text{---} \cdot \text{---} \cdot \int \text{---} \cdot \left(\int \text{---} \right) \right]$$



Distress prediction – rutting in IS03



Conclusions

- **Mechanistic-empirical based design methods will probably be in use in many countries in the near future. To be able to use such methods we need to obtain information for modelling purposes on factors affecting pavement performances, such as**
 - » **Axle loading**
 - » **Material properties**
 - » **Weather and environmental conditions**
- **Further we need information to calibrate and validate such methods if acceptable agreement between real performance and our estimation is to be achieved.**

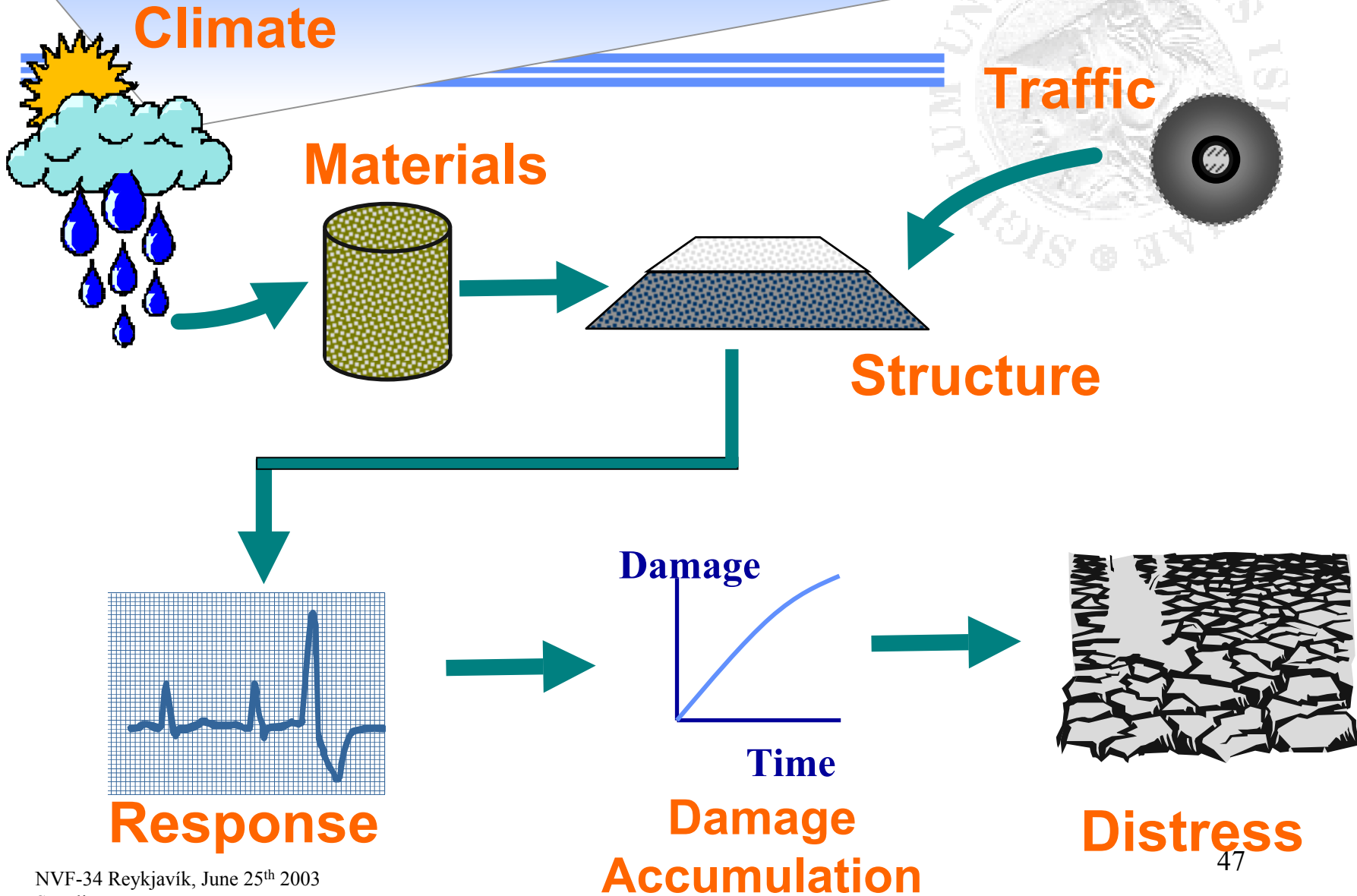
AASHTO 2002 Design Guide



Mechanical – empirical design procedure of pavement structure

www.2002designguide.com

Mechanistic-Empirical Design

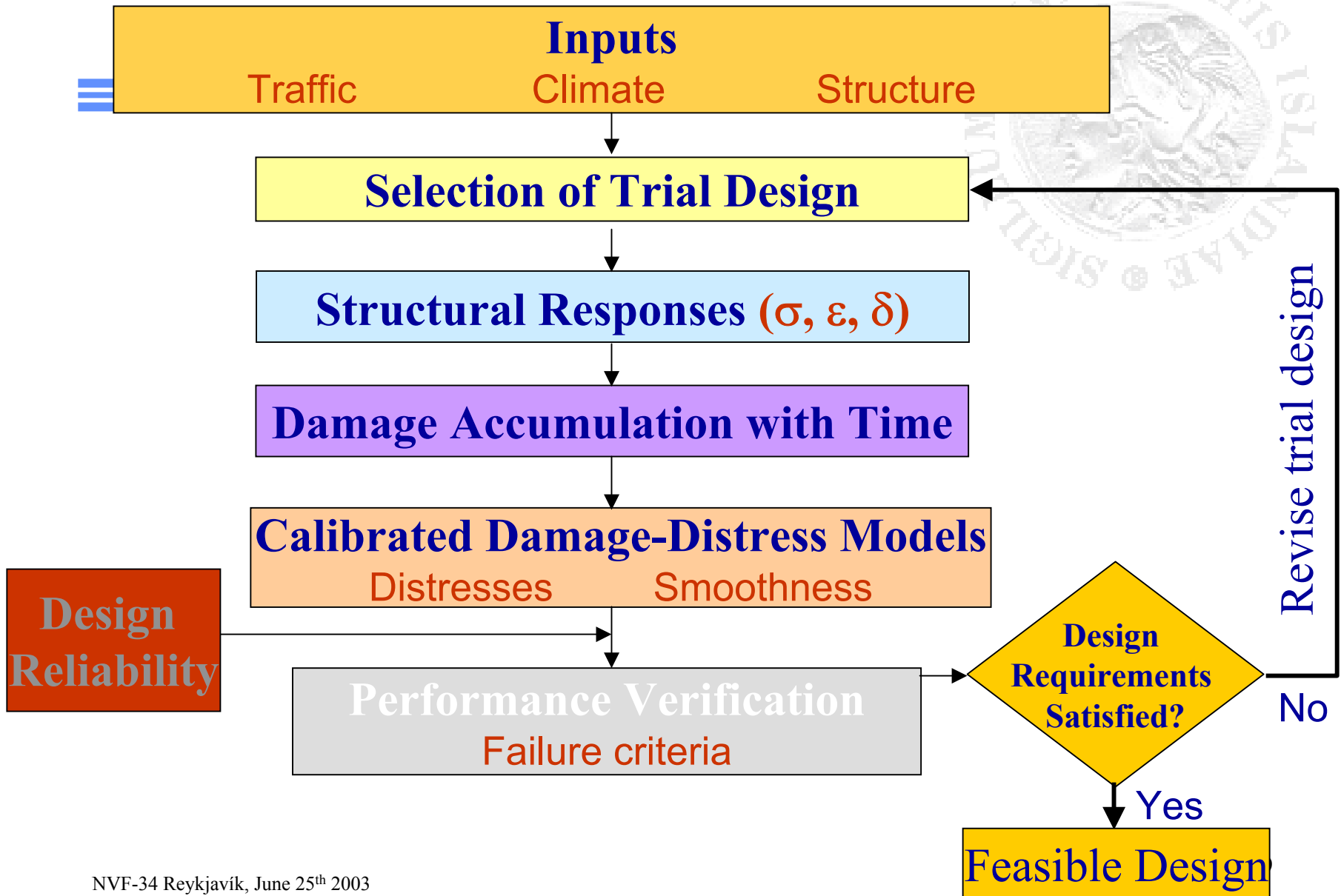


Mechanistic-Empirical Design

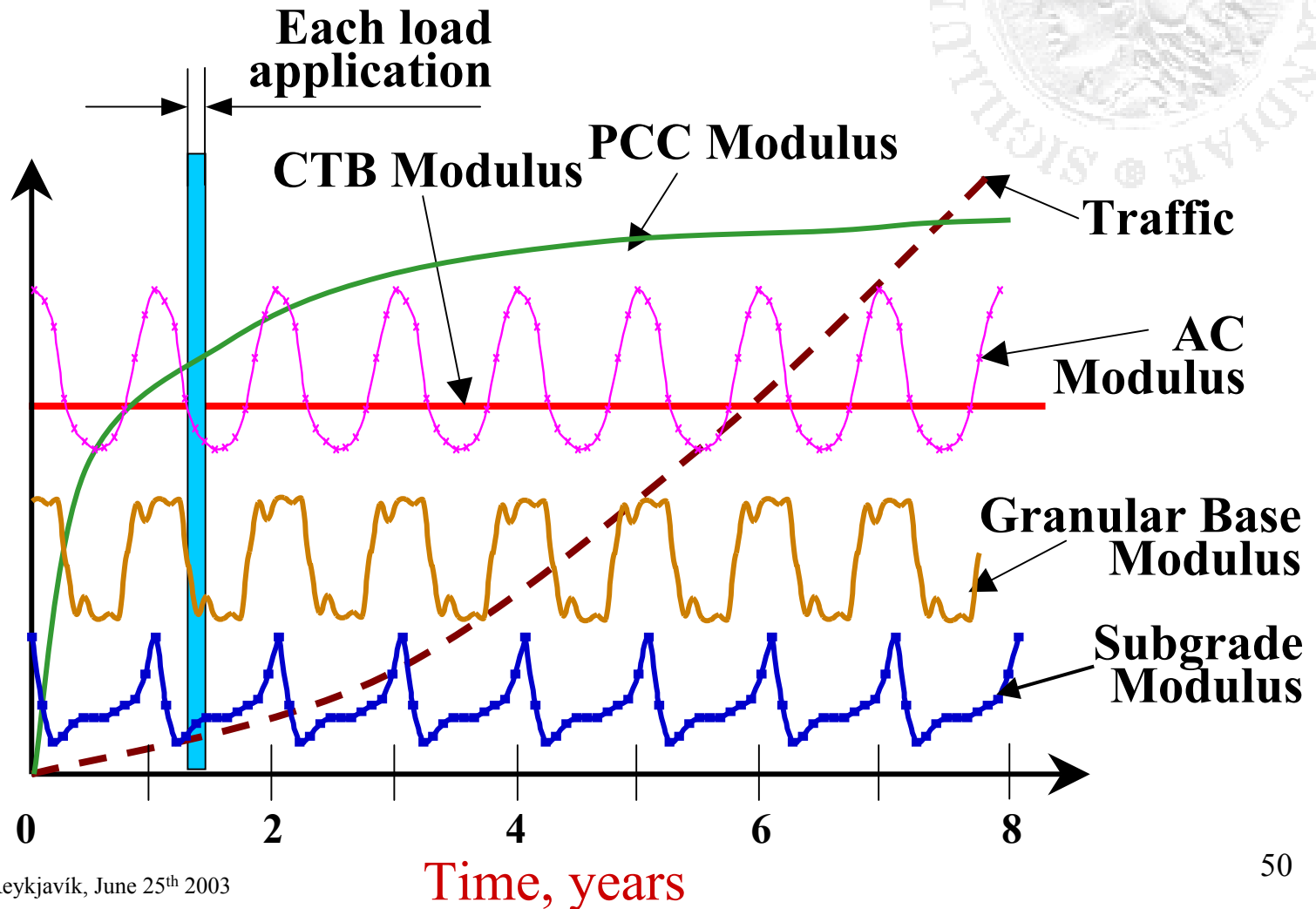


- *Mechanistically* calculate pavement response (i.e., stresses, strains, and deflections) due to:
 - » Traffic loading
 - » Environmental conditions
- Accumulate *damage* over time
- *Empirically* relate damage over time to pavement distresses, e.g.:
 - » Cracking
 - » Rutting
 - » Faulting
- *Calibrate* predictions to observed field performance

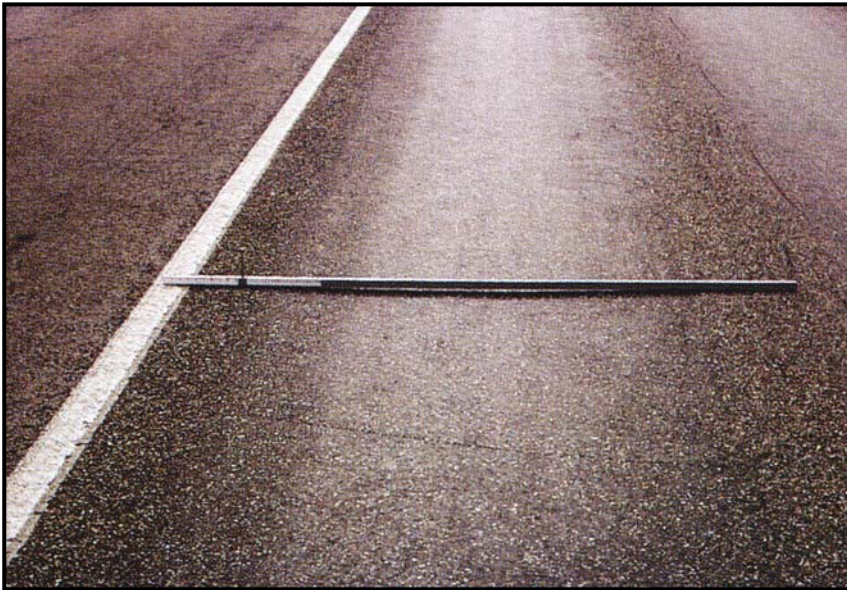
2002 Guide Design Process



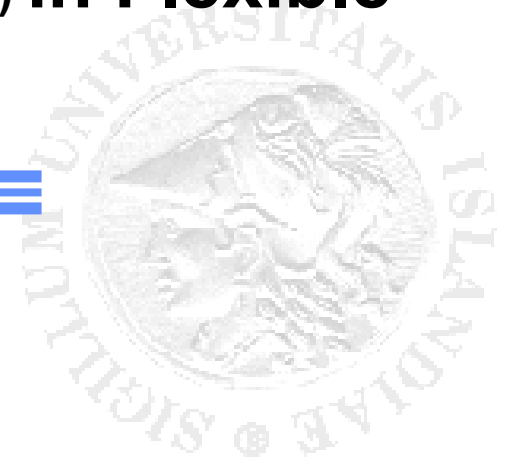
Design Parameters Over Pavement Life



Rutting in Flexible Pavements



Fatigue Cracking (“Alligator Cracking”) in Flexible Pavements



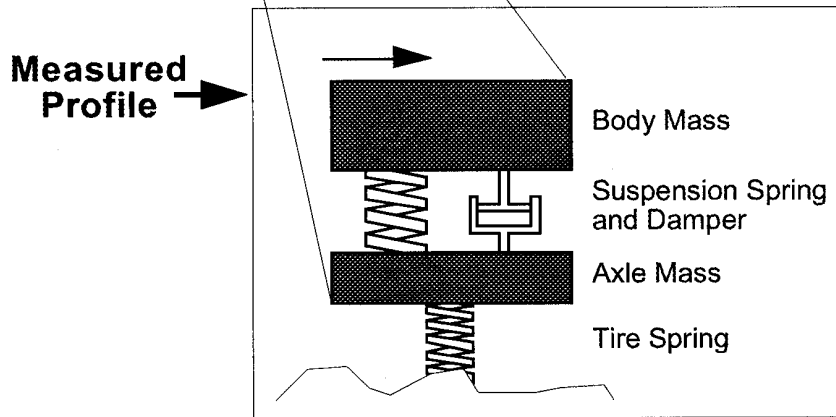
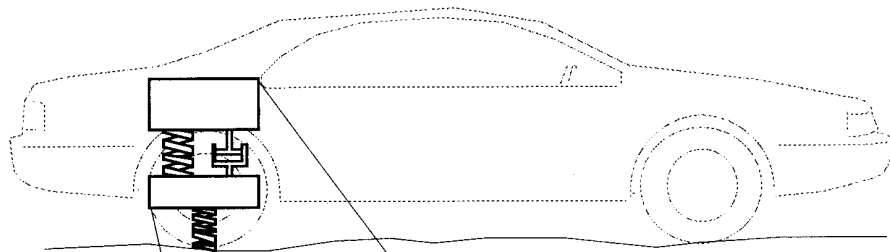
(SHRP, 1993)

Thermal Cracking in Flexible Pavements



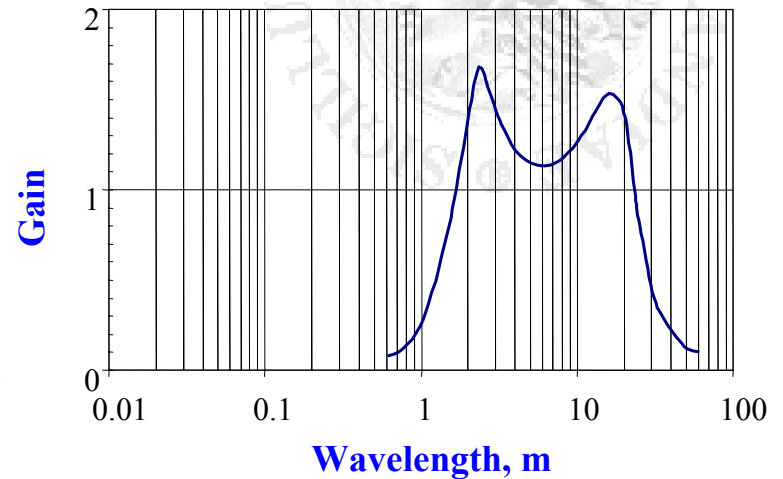
Ride Quality – International Roughness Index (IRI)

Speed = 80 km/h



Computer Algorithm

$$\text{IRI} = \frac{\sum (\text{Vertical Distance})}{\text{Horizontal Distance}}$$



AASHTO 2002 Design Guide – Design Inputs

The screenshot shows the 'Design Guide 2002 - 28_mr700' application window. The interface is divided into several panes:

- Project Information:** Shows the project path [C:\DG2002\Projects\28_mr700.dgp] and three main categories: General Information, Site/Project Identification, and Analysis Parameters.
- Inputs:** A tree view containing:
 - Traffic
 - Traffic Volume Adjustment Factors
 - Monthly Adjustment
 - Vehicle
 - Hour
 - Tr
 - Axle
 - Gen
 - Climate
 - Structure
 - Design
 - Drainage
 - Layers
 - Layer 1 - CR
 - Layer 2 - Cement Stabilized
 - Layer 3 - CL
 - Layer 4 - CL

- Results:** A tree view containing:
- Input Summary
 - Project
 - Traffic
 - Climatic
 - Design
 - Layer
- Output Summary
- CRCP Summary
 - Punchouts (plot)
 - IRI (plot)
 - Crack Width (plot)
 - LTE (plot)
- Analysis Status:** A table showing the completion percentage for various analyses:

Analysis	% Complet
Traffic	0%
Climatic	0%
Modulus	0%
Punchout CRCP	0%
Summary	0%
- General Project Information:** A table with columns for Parameter, Type, Design Life, and Location.
- Properties:** A table with columns for Setting and Value:

Setting	Value
Units	US Customary
Analysis Type	Deterministic
Default Input	Level 3
- Run Analysis:** A button with a circular arrow icon.

Four callouts are overlaid on the screenshot:

- A green oval labeled 'General Information' points to the Project Information pane.
- A green oval labeled 'Inputs Traffic Climate Structure' points to the Inputs tree view.
- A white oval labeled 'View Results and Outputs' points to the Results tree view.
- A white oval labeled 'Status and Summary' points to the Analysis Status and General Project Information panes.

At the bottom left, it says 'For Help, press F1'. At the bottom right, there is a 'NUM' indicator.