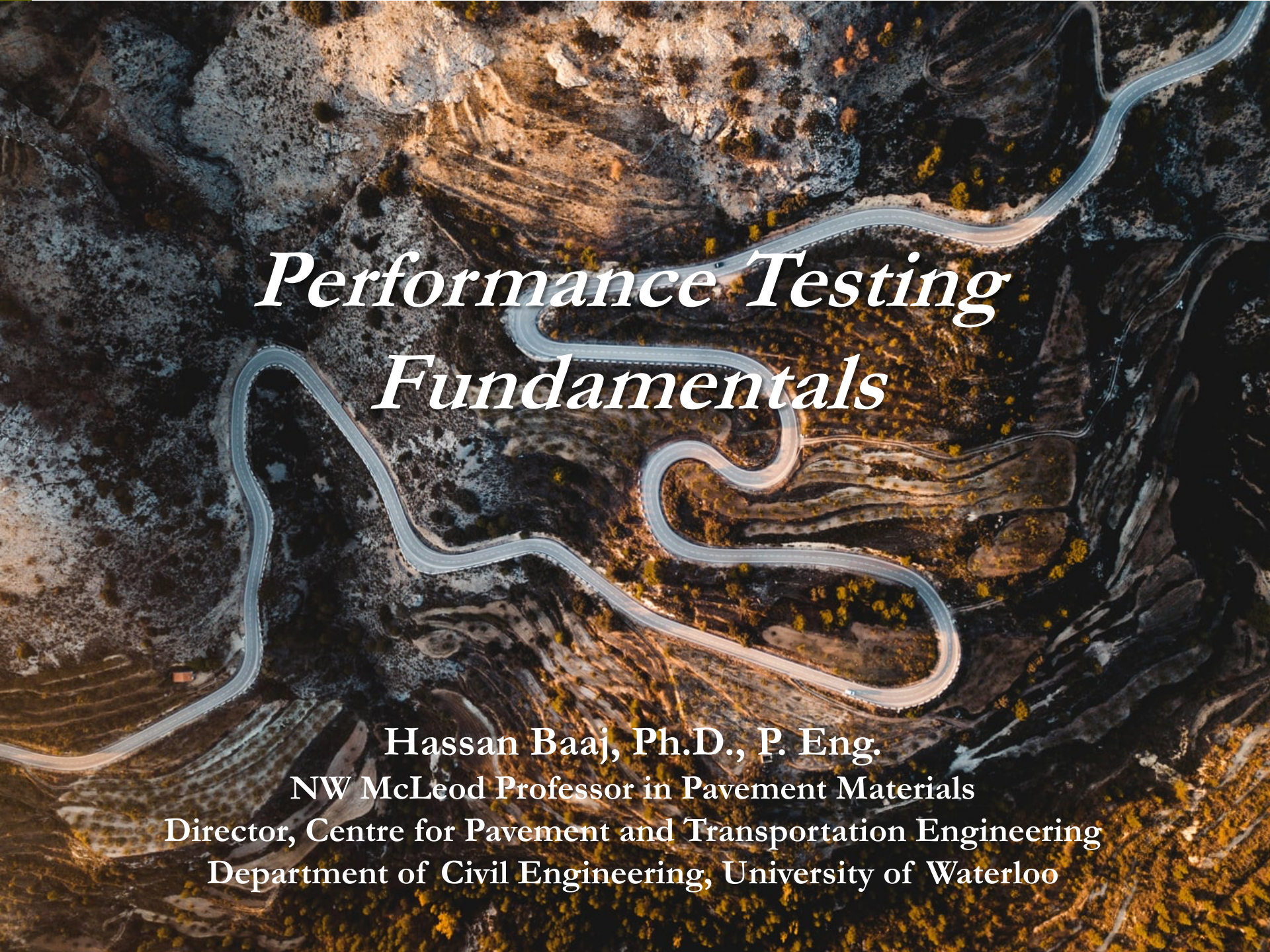

Performance Testing Fundamentals

Hassan Baaj, Ph.D., P. Eng.
NW McLeod Professor in Pavement Materials
Director, Centre for Pavement and Transportation Engineering
Department of Civil Engineering, University of Waterloo

Outline

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- Introduction – What is "Performance" and why we need "Performance Testing"
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CPATT & N.W. McLeod Chair

https://uwaterloo.ca/centre-pavement-transportation-technology/

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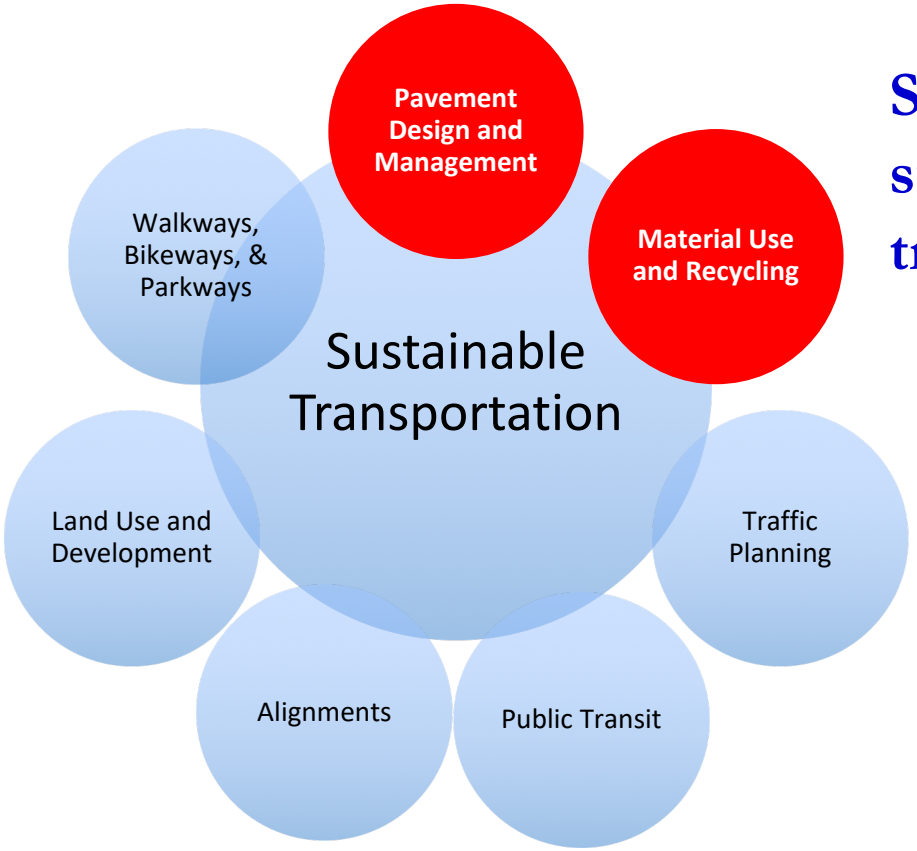
Shiloh Construction Ltd.

GRINCH Symposium at UW - 2019

RILEM Symposium at UW -2019

CPATT – Key Research Themes



Sustainable pavement is a subset of sustainable transportation

Main focus on Pavement Design and Management; and Material Use and Recycling

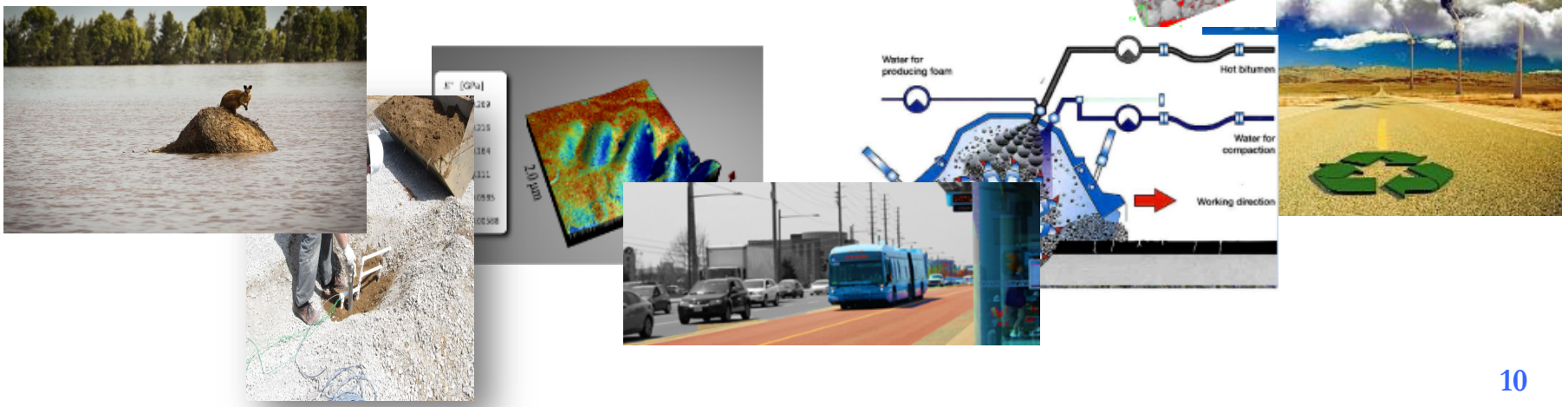
NORMAN W. McLEOD
CHAIR IN SUSTAINABLE PAVEMENT ENGINEERING

CPATT
CENTRE FOR PAVEMENT AND TRANSPORTATION TECHNOLOGY

CPATT – Key Research Themes

Sustainable Pavement Engineering and Materials

- Incorporating Sustainability into Pavement Design, Construction, Maintenance and Management
- Climate Change Impacts on Long Life Infrastructure
- Life Cycle Economic Analysis in Public and Private Sector Infrastructure
- Smart Pavement Materials And Structures for the Road of the Future (Nanomaterials, Self-Healing Materials, Phase-Change Materials, Anti-oxidants, Solar Pavements, Lightweight Aggregates, ..)
- Optimization of the Use of Recycled and Alternative Materials in Sustainable Infrastructure Systems
- Advanced Testing Methods and Characterization Techniques of Infrastructure Construction Materials



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Performance?

- What is Performance?

performance noun

Save Word

per·for·mance | \ pər-ˈfȯr-mən(t)s, pə- \

Definition of *performance*

1 **a** : the execution of an action

b : something accomplished : DEED, FEAT

2 : the fulfillment of a claim, promise, or request : IMPLEMENTATION

3 **a** : the action of representing a character in a play

b : a public presentation or exhibition
// a benefit *performance*

4 **a** : the ability to perform : EFFICIENCY

performance

noun

UK /pəˈfɔː.məns/ US /pəˈfɔːr.məns/

performance *noun* (ACTIVITY)

B2 [C or U]

how well a person, machine, etc. does a piece of work or an activity:

- *He was an experienced player who was always seeking to improve his performance.*
- ***High-****performance cars (= those that are fast, powerful, and easy to control) are the most expensive.*
- *This was a very **impressive** performance by the young player, who scored 14 points within the first ten minutes.*

Credit Photo Eric Weber on Unsplash

1- Merriam-Webster Dictionary
2- Cambridge Dictionary

Pavement Performance

Photo by Michael Shannon on Unsplash

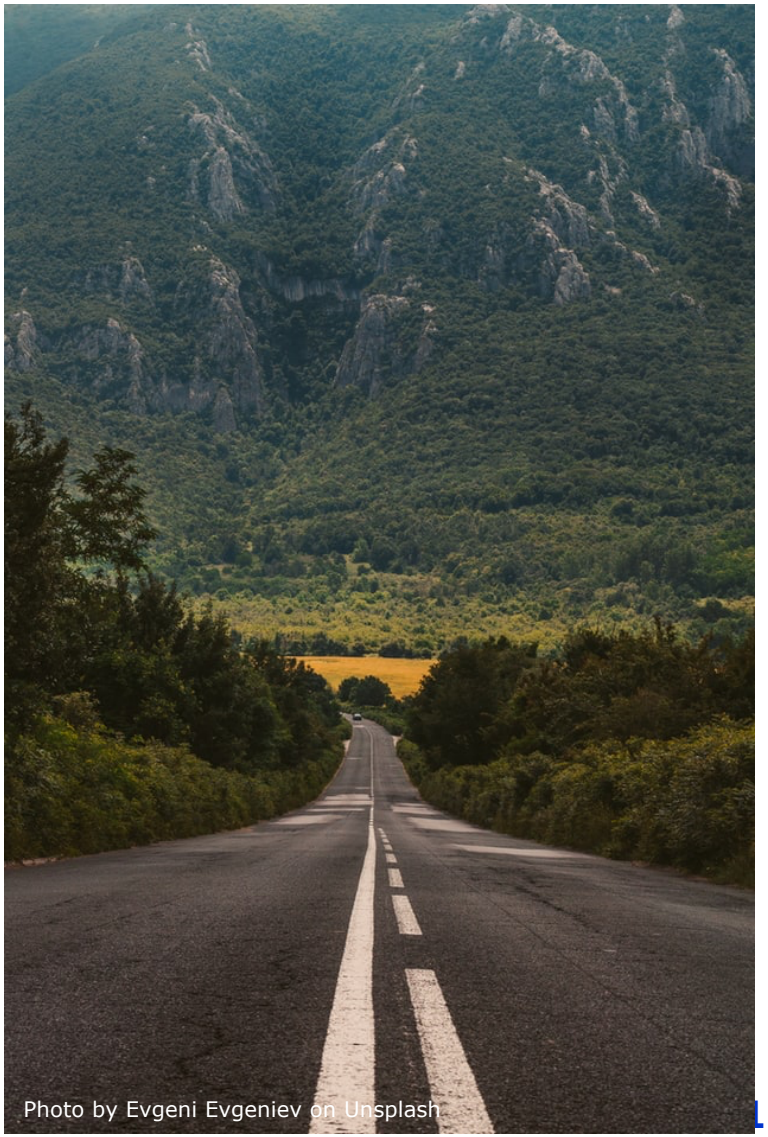

Photo by Evgeni Evgeniev on Unsplash

Pavement Performance


Photo by Evgeni Evgeniev on Unsplash


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Pavement Performance

Photo by Jeremy Bishop on Unsplash

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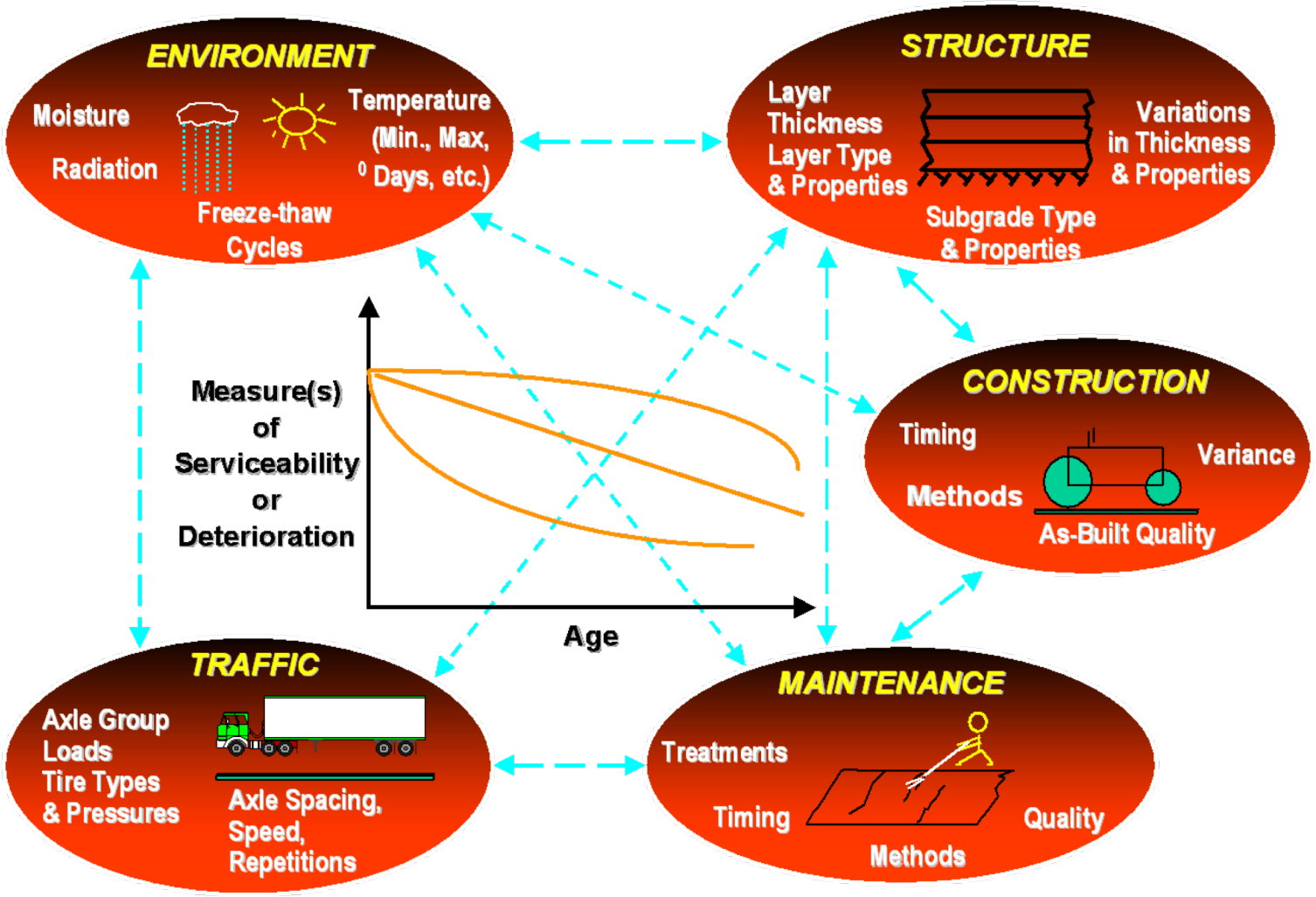
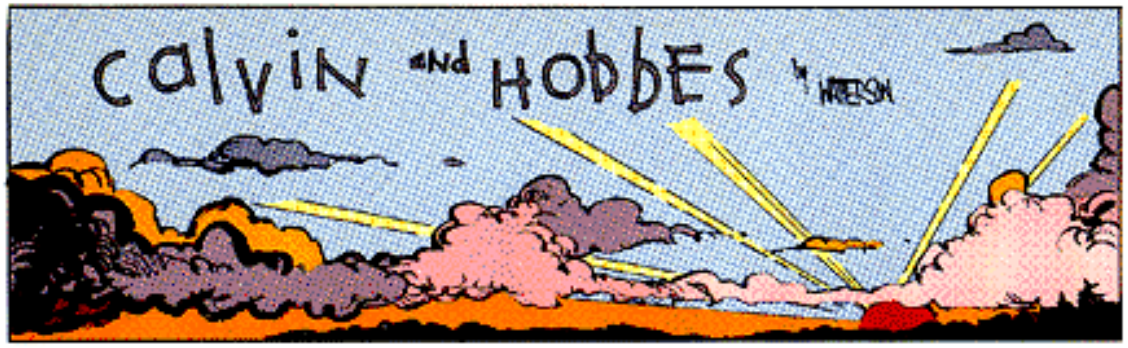
Pavement Performance

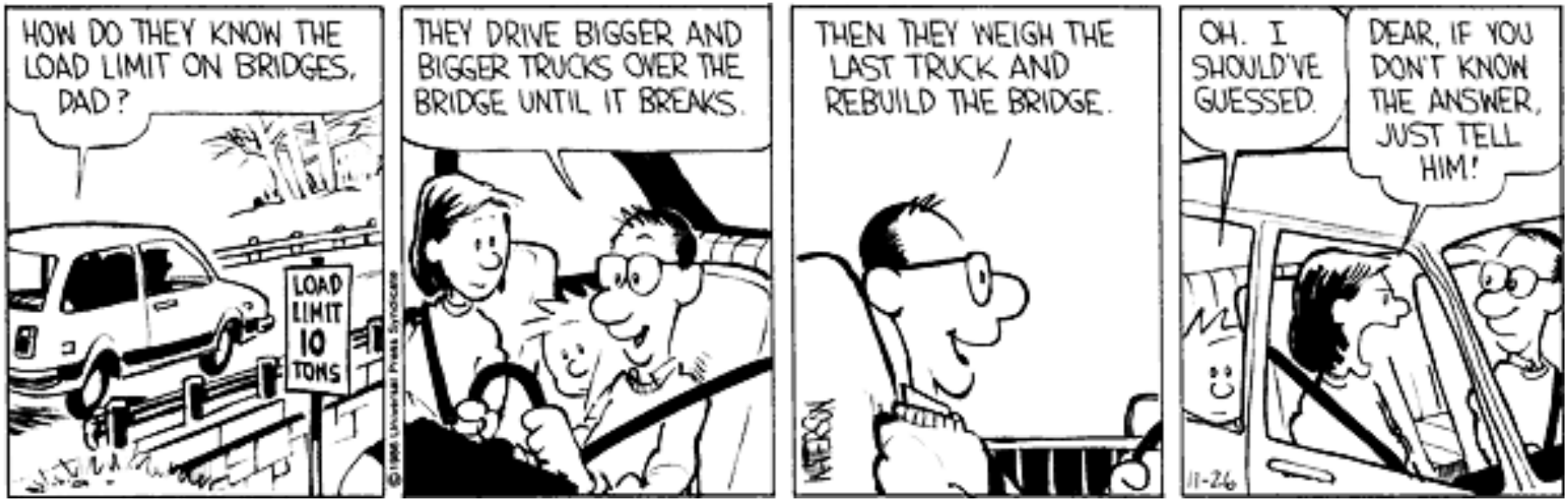


Tighe, S., K. Huen., and R. Haas. 2007. Environmental and Traffic Deterioration with Mechanistic-Empirical Pavement Design Model. Journal of the Transportation Research Board, No. 1989, Vol.2. Washington, D.C. pp. 336-343.

Performance Testing

Why do we need performance testing?





Why do we need performance testing?

- Testing for Mix Design
- Testing for Pavement Design
- Testing for Forensic Analysis
- Testing for Research
- Testing for Product Development

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Performance Testing Fundamentals

- Understand the material: Determining the right testing conditions
  - Sample geometry and size
  - Loading mode and parameters
  - Test Conditions (temperature, frequency, speed of loading, time, etc.)
- Why we're testing? How accurate this should be?
  - Testing for mix design
  - Testing for pavement design
  - Testing for forensic analysis
  - Testing for research
  - Testing for product development
  - …
- What performance: Know what you're looking for?
- What is good performance?
  - Determine performance criteria
  - Compare against standard materials
  - Using the right test for the right property
- Do the test results make sense?
  - Repeatability, reproducibility, statistical significance
- Make sure your testing equipment and tools are calibrated and in good condition
- Make sure you're following the test standards and test protocols

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Hot Mix Asphalt

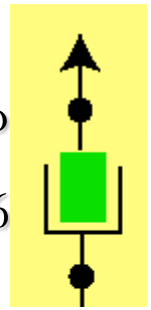
Hot Mix Asphalt

Bitumen

Neat or modified

4 to mass

40 to 6 the cost

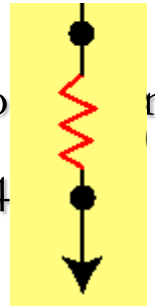


Aggregates

Natural, manufactured & recycled

93 to n mass

25 to 4 the cost



Energy

Drying and heating

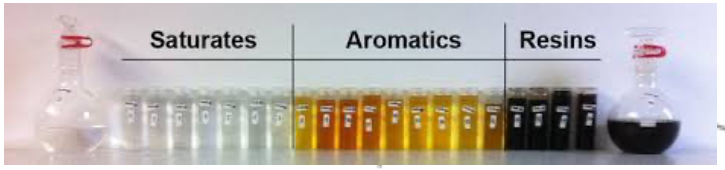
10 to 15% of the cost

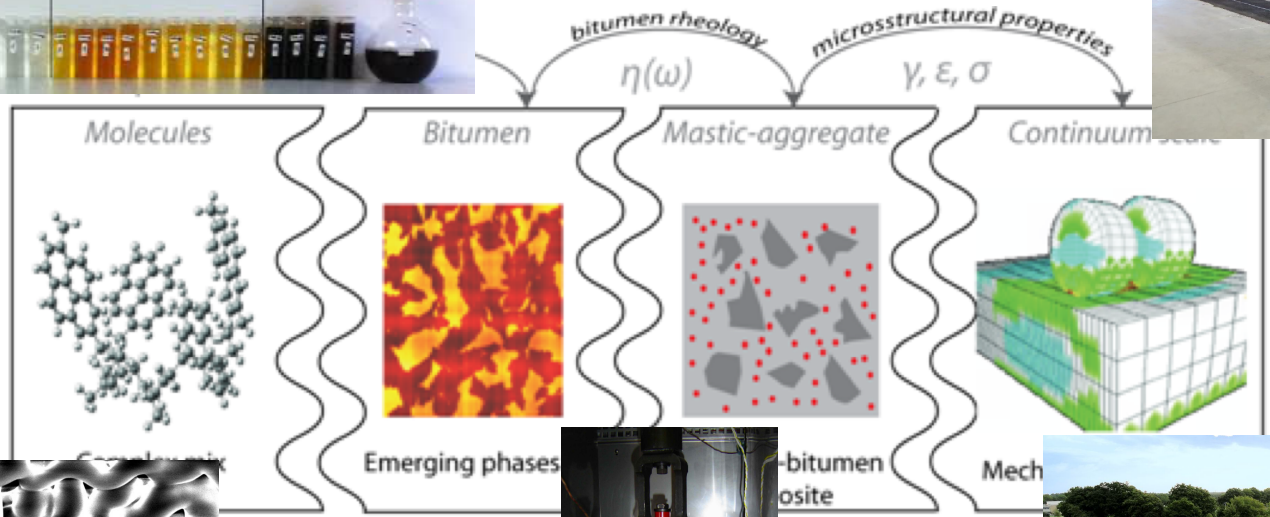
Behaviour of bituminous materials

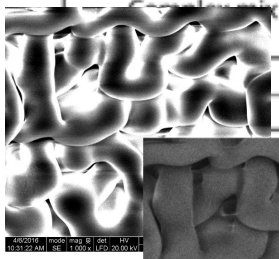
Two levels should be considered:

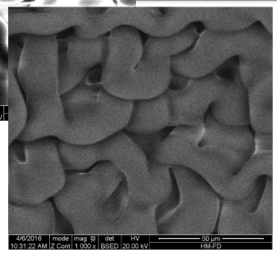
Level 1: Materials Behaviour

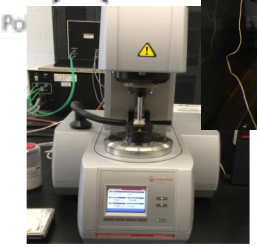
Level 2: Pavement Structure

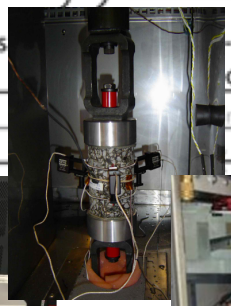


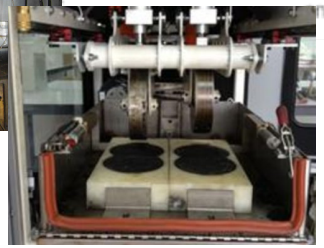




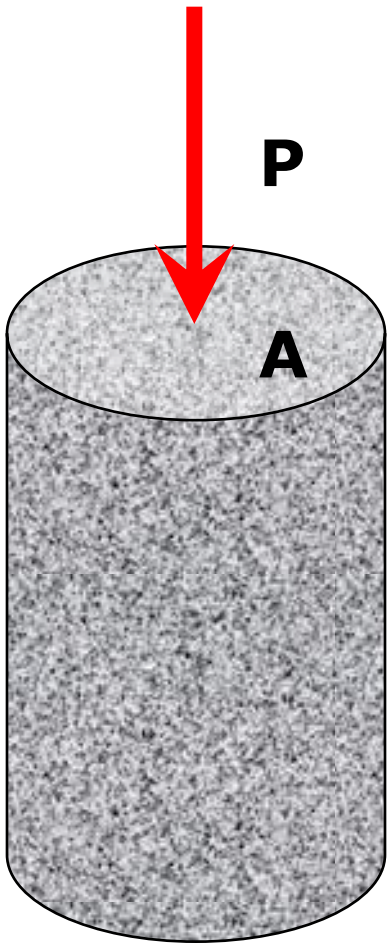




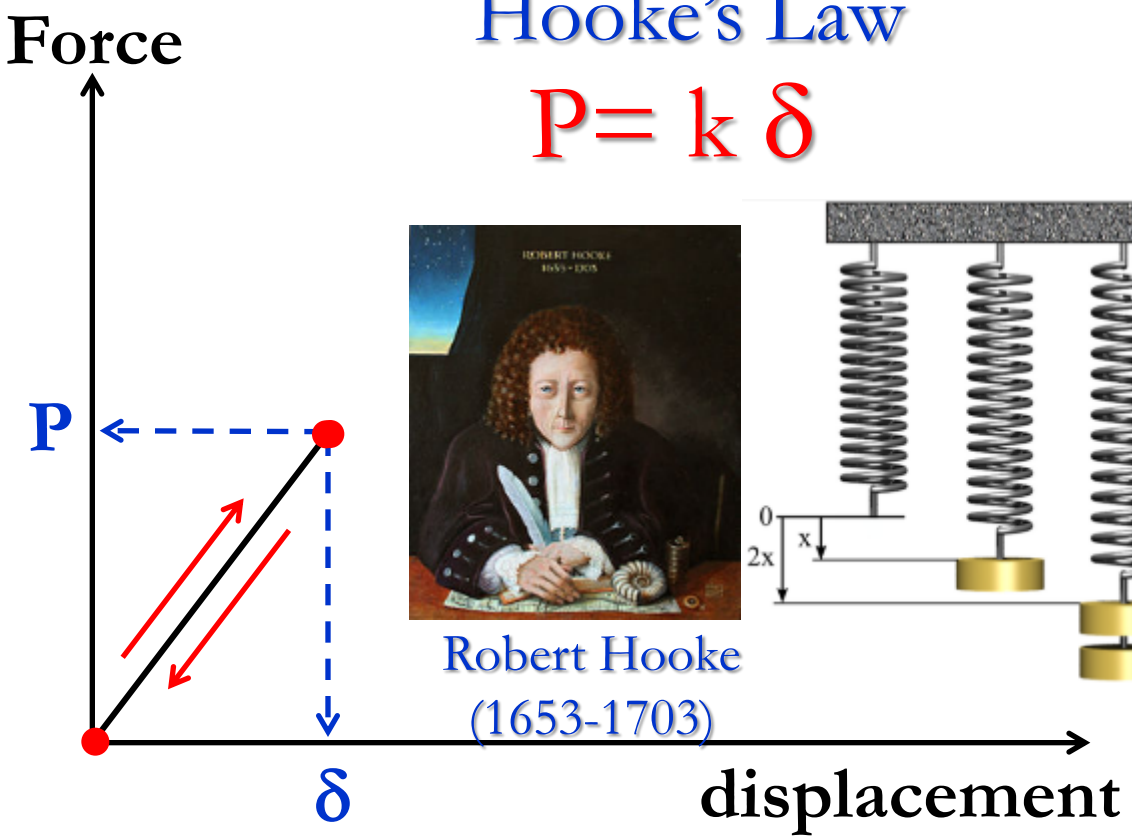




Linear Elastic Behaviour



Linear Elastic Behaviour

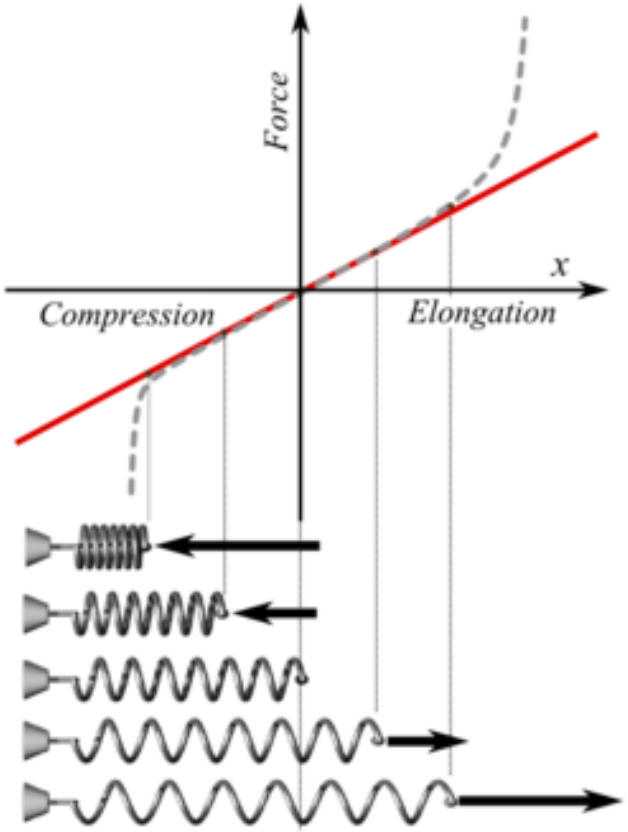


Hooke's Law

$$P = k\,\delta$$

Robert Hooke
(1653-1703)

Viscous Behaviour

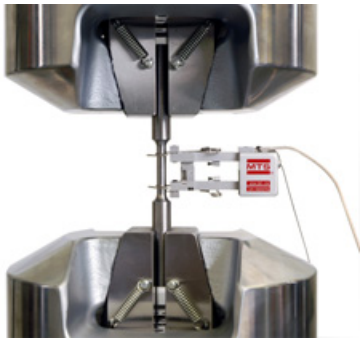


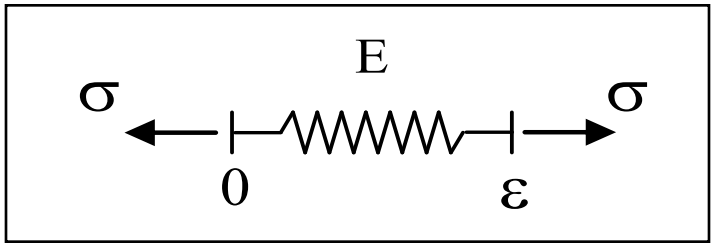
The spring is used to represent linear elasticity

Young's Modulus

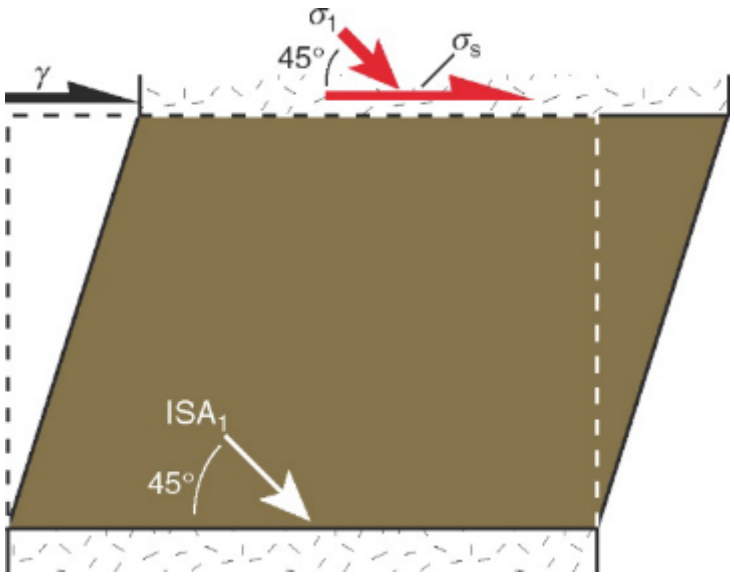
$$\sigma = E\,\varepsilon$$

Thomas Young
(1773-1829)

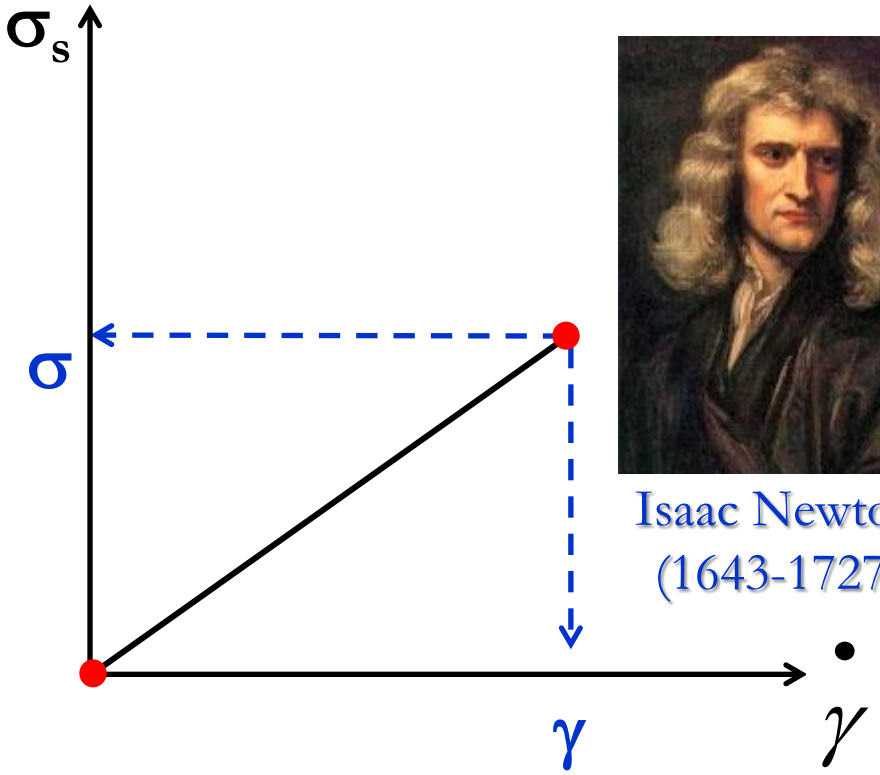




Viscous Behaviour

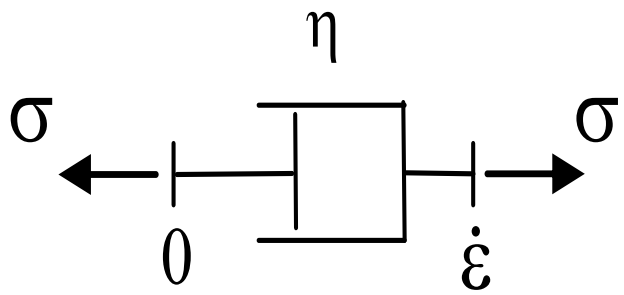


$$\sigma_s = \eta \dot{\gamma}$$



Isaac Newton
(1643-1727)

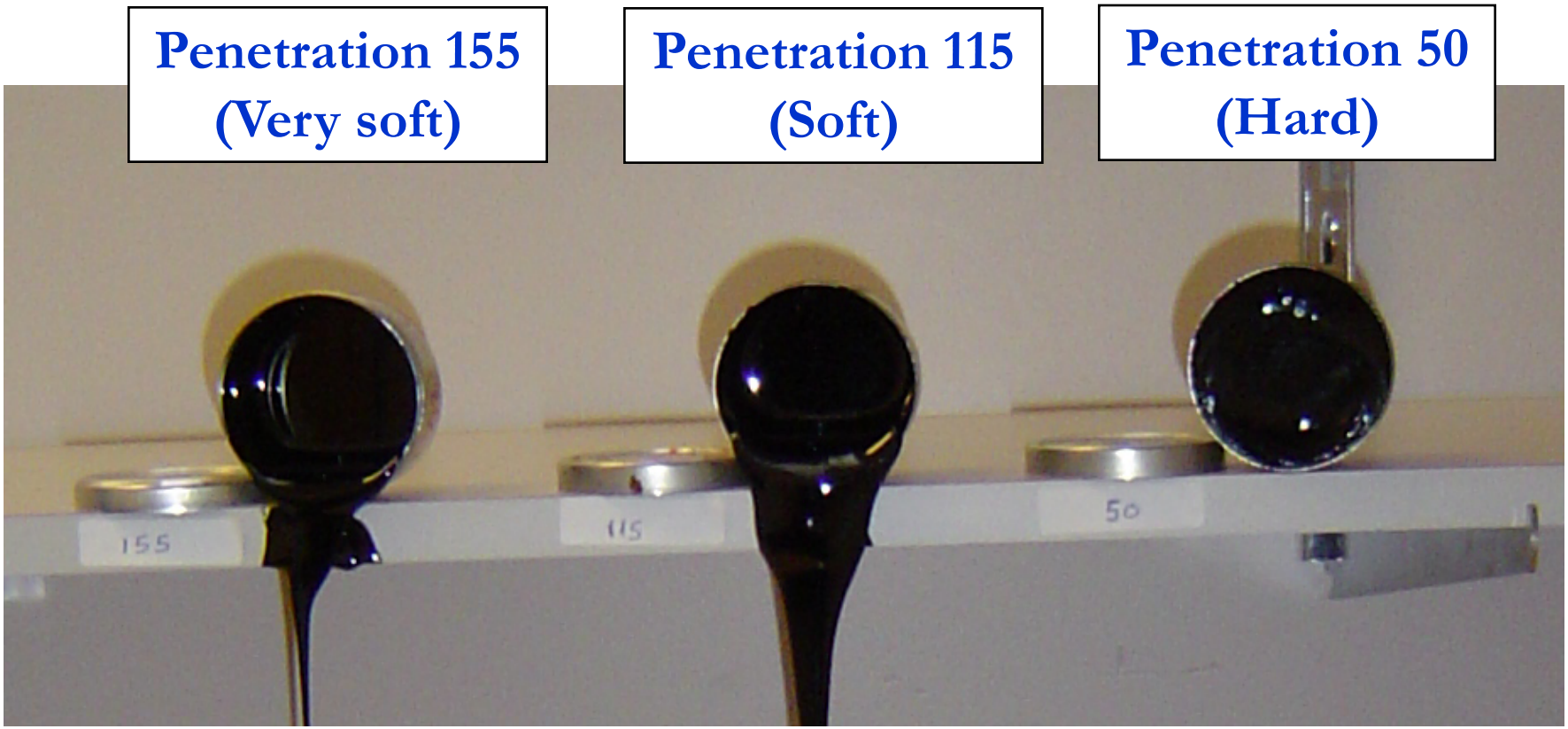
The Linear Viscosity is represented by a dashpot



Newtonian fluid = Linear stress-strain rate relation

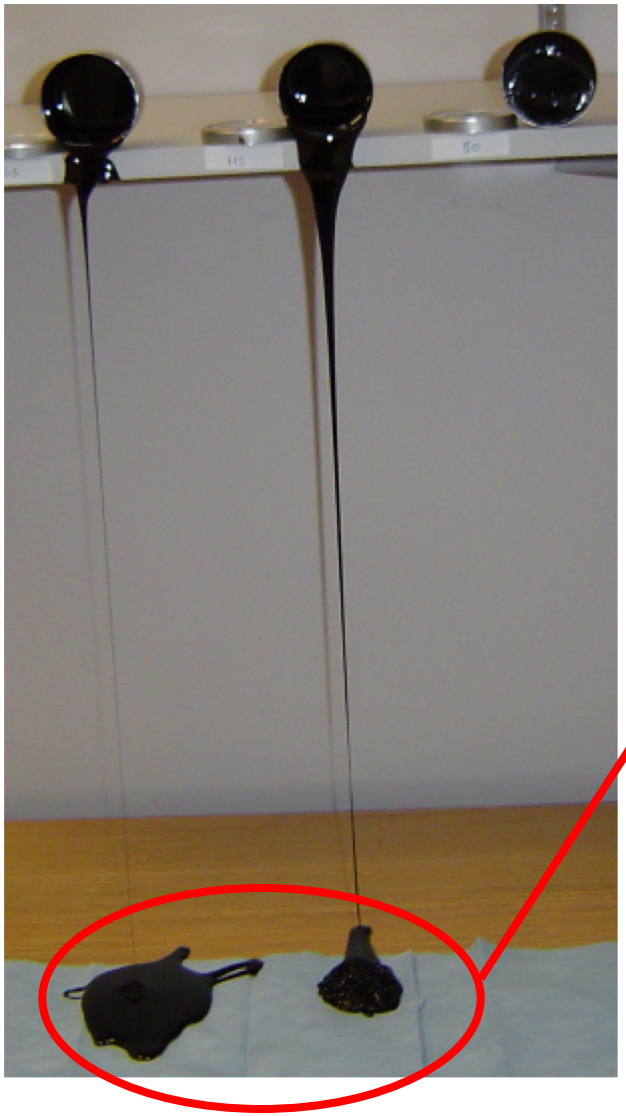
Visco-Elastic Behaviour

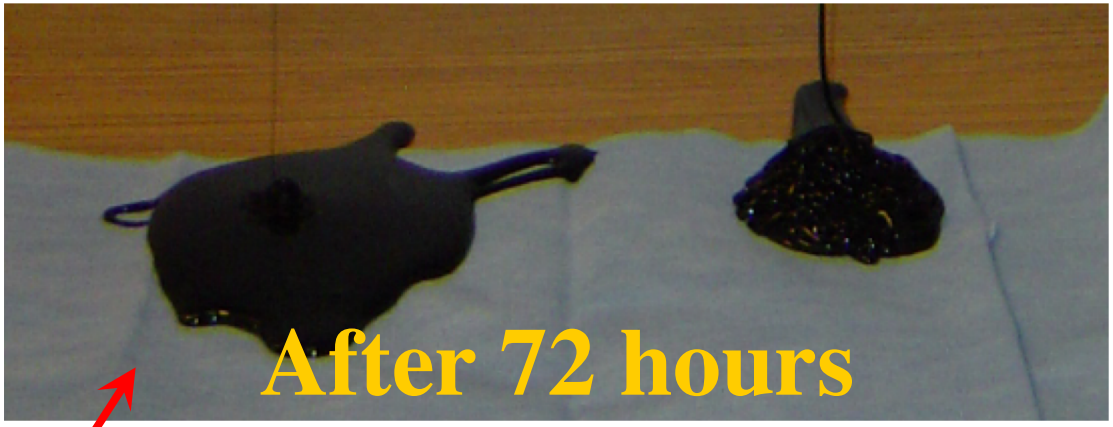
Visco-Elastic Behaviour



After 72 hours

Visco-Elastic Behaviour

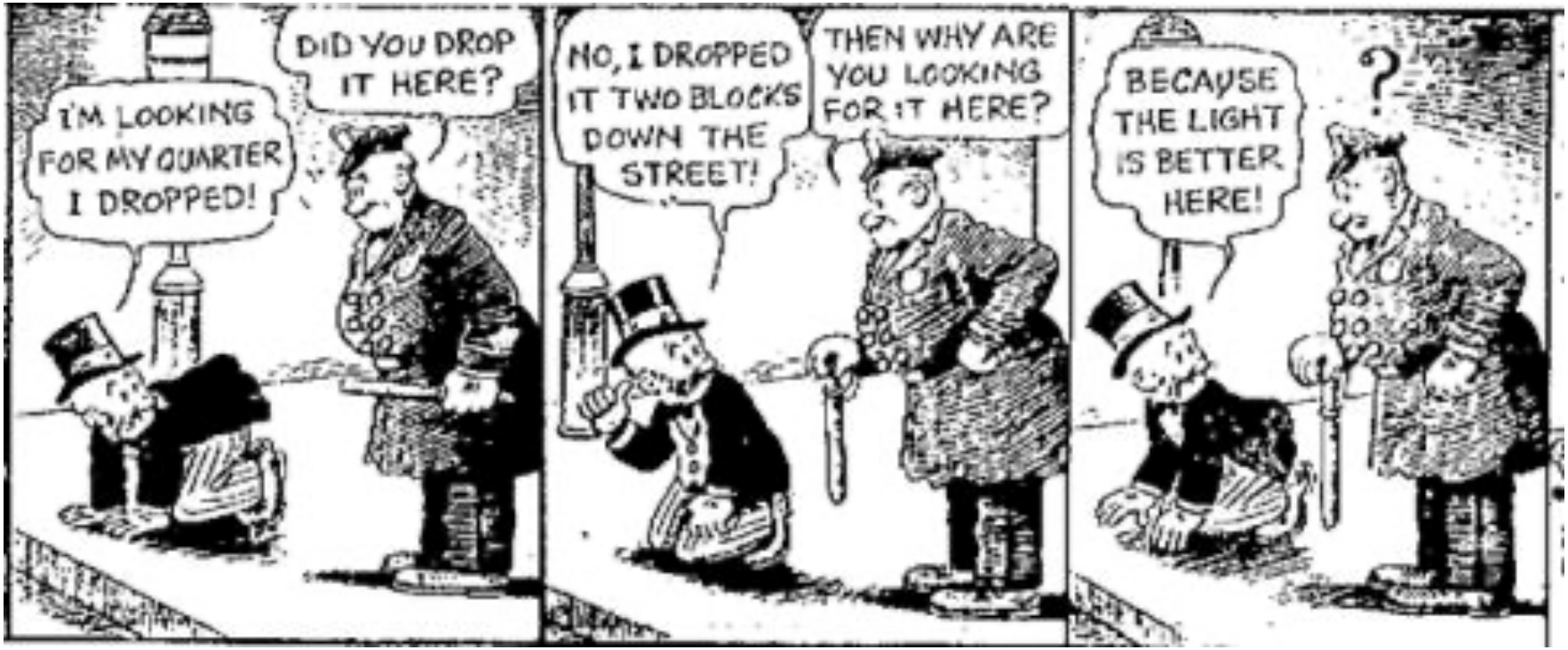




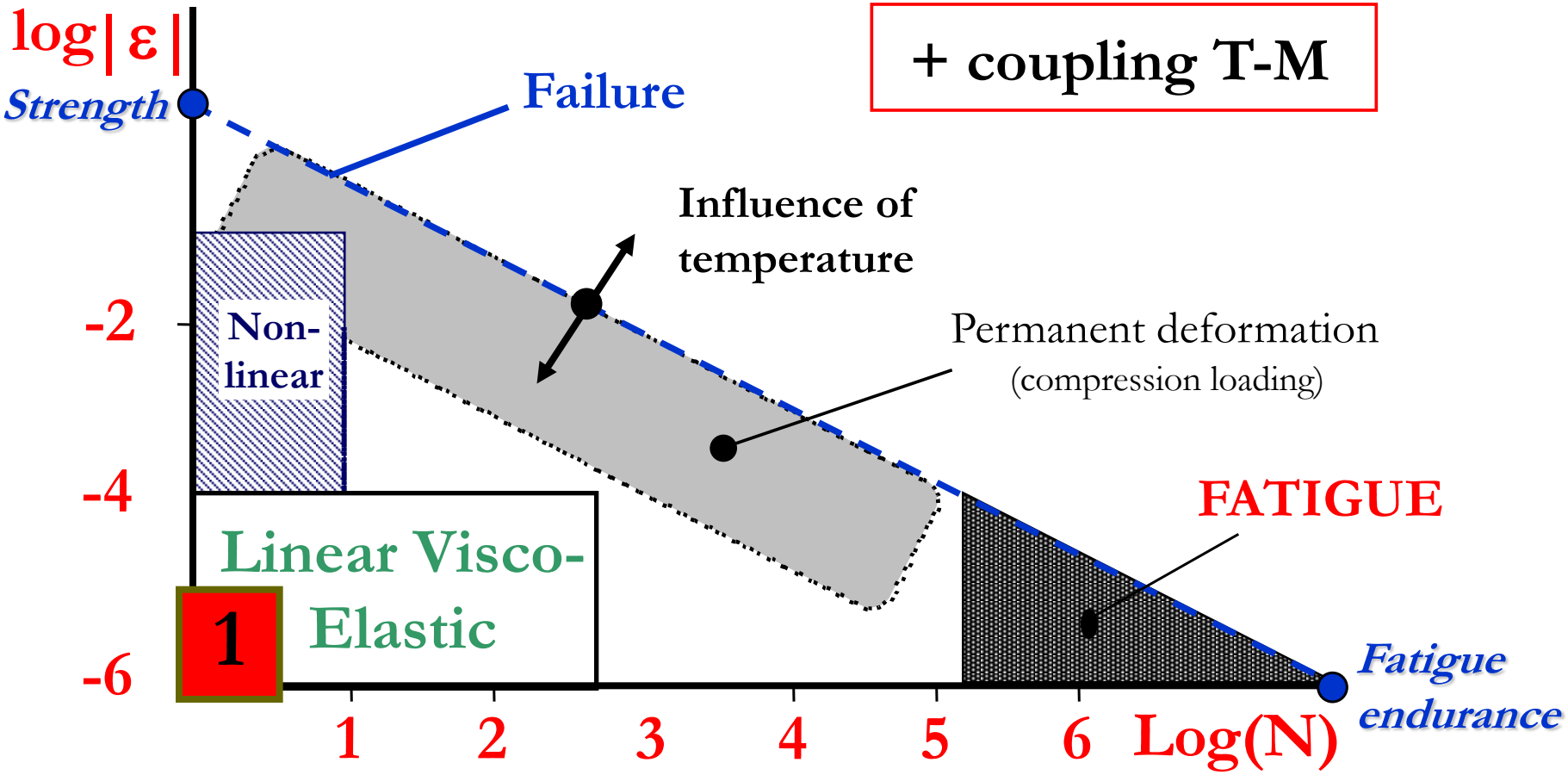
- Asphalt cement is sensitive to both Time and Temperature
- Studying the behavior of the asphalt requires taking both factors into account

Behaviour of bituminous materials

Testing Conditions



Behaviour of bituminous materials



➢ *Importance of a « good » modelling for road design*

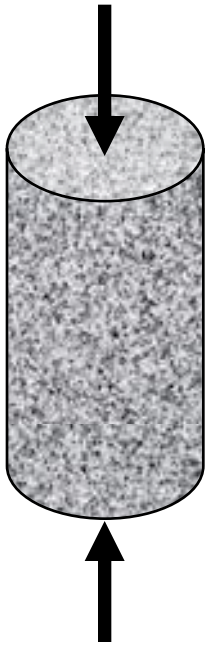
Di Benedetto (1990)

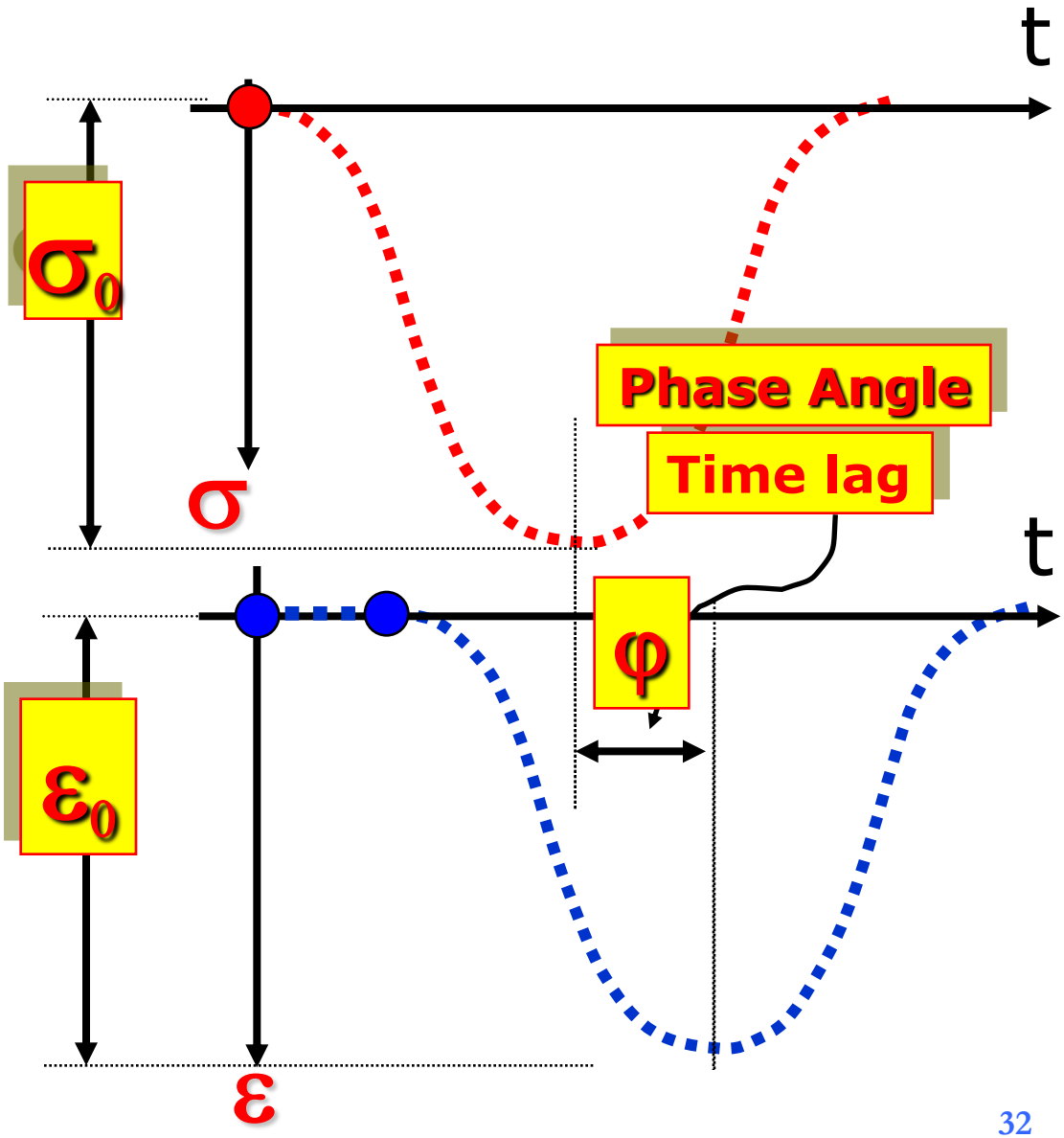
Concept of Complex Modulus

Complex Modulus

Dynamic Modulus (Stiffness) | E* |

$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

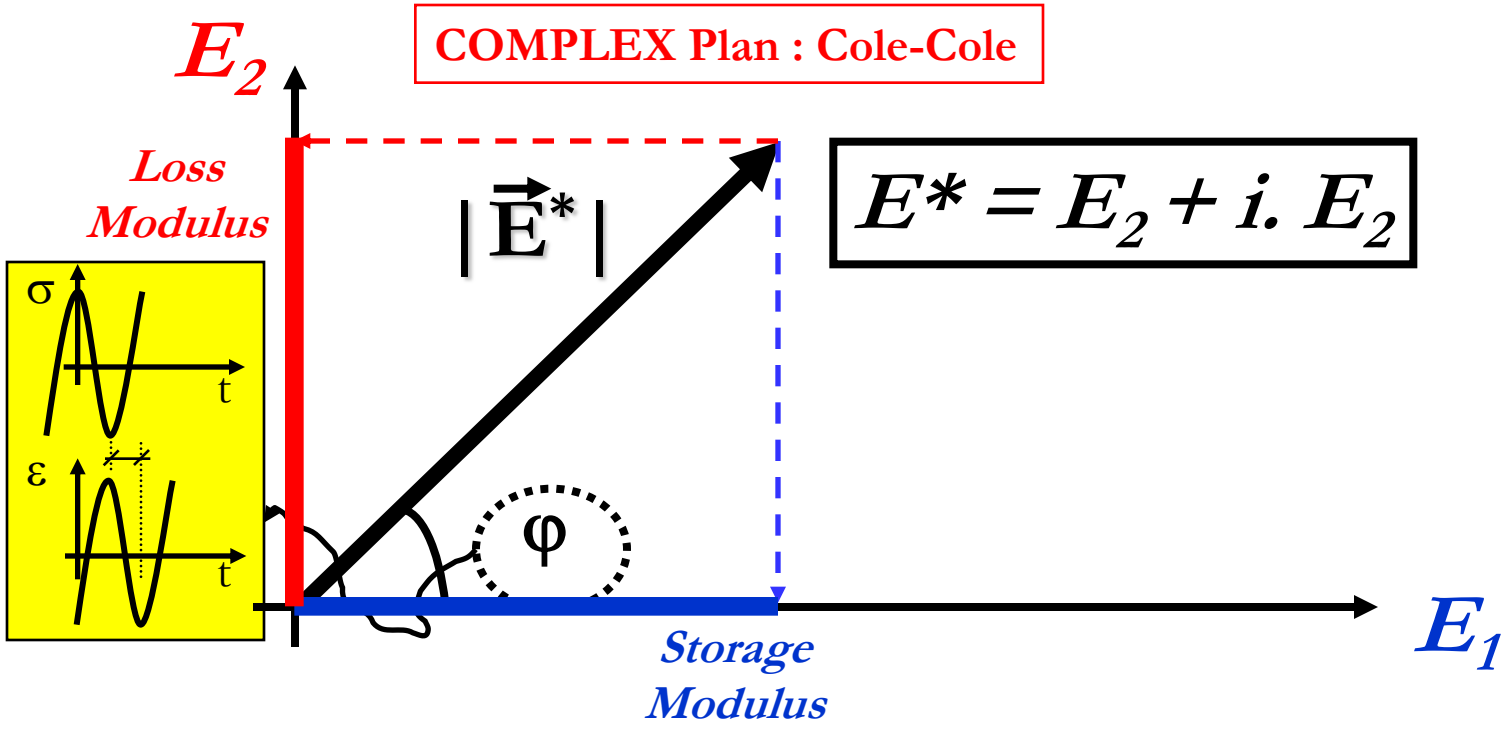




Concept of Complex Modulus

Linear Viscoelastic Behaviour

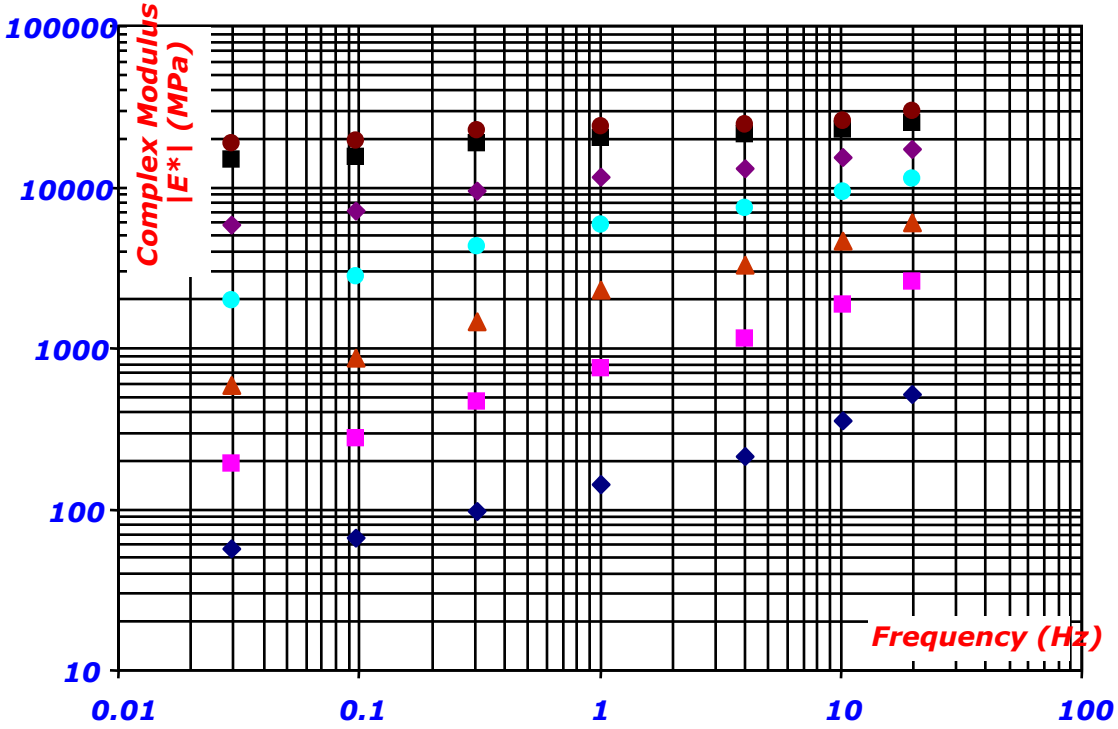
The Complex Modulus is a VECTOR



Concept of Complex Modulus

Linear Viscoelastic Behaviour

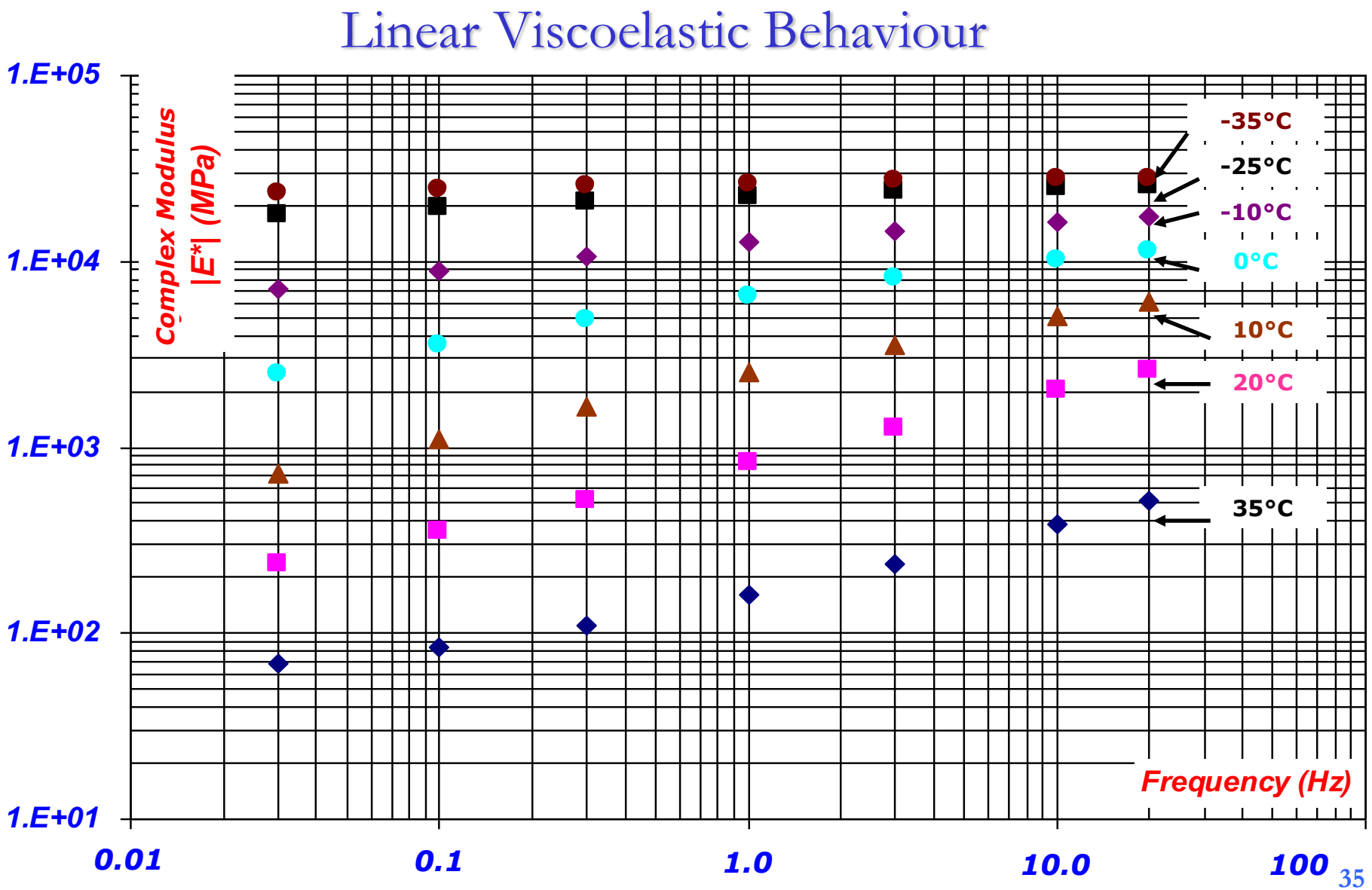
Complex Modulus



Temperatures (°C): -35, -25, -10, 0, 10, 20, 35

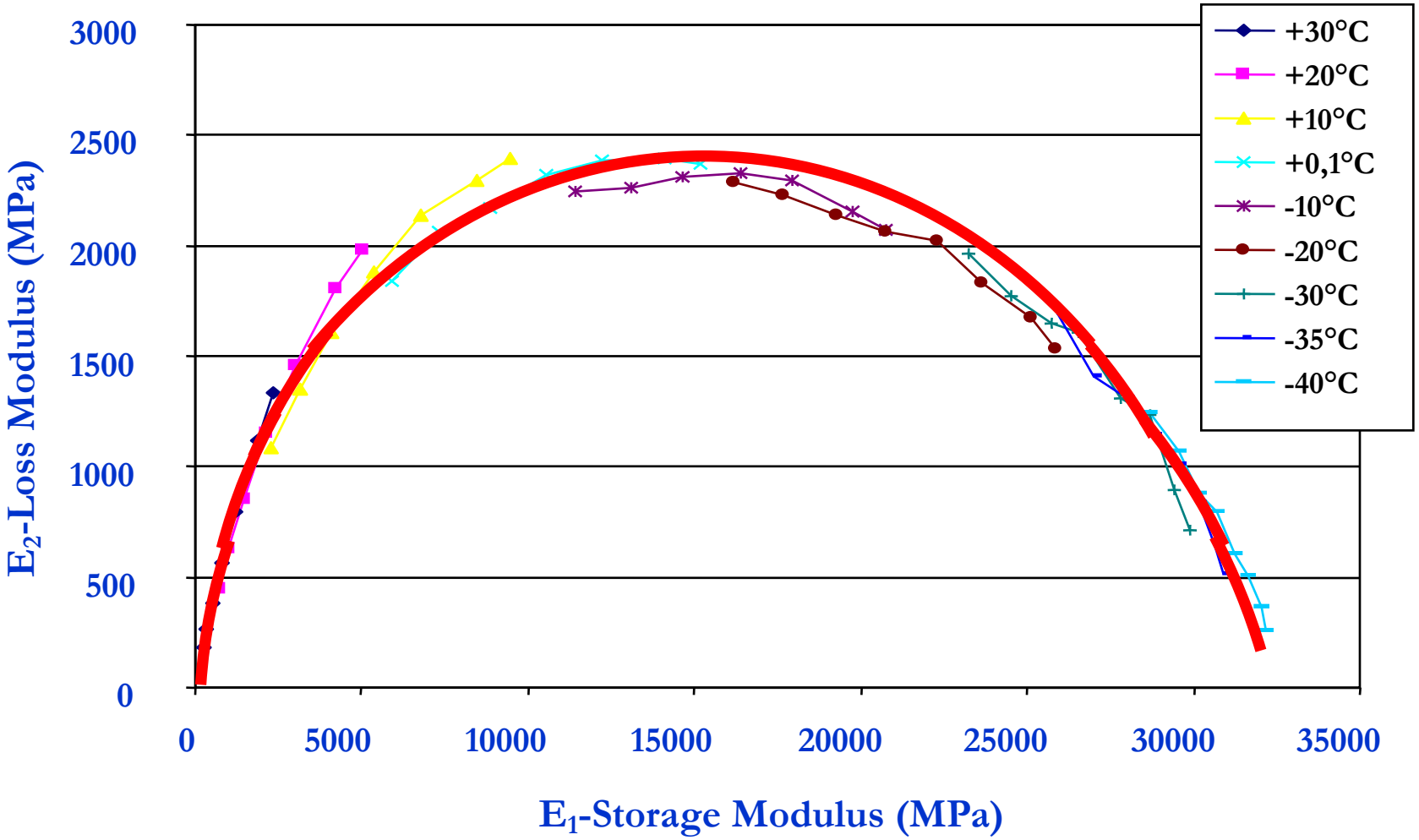
Frequencies (Hz): 20, 10, 3, 1, 0.3, 0.1, 0.03, 0.01

Master Curve



Master Curve

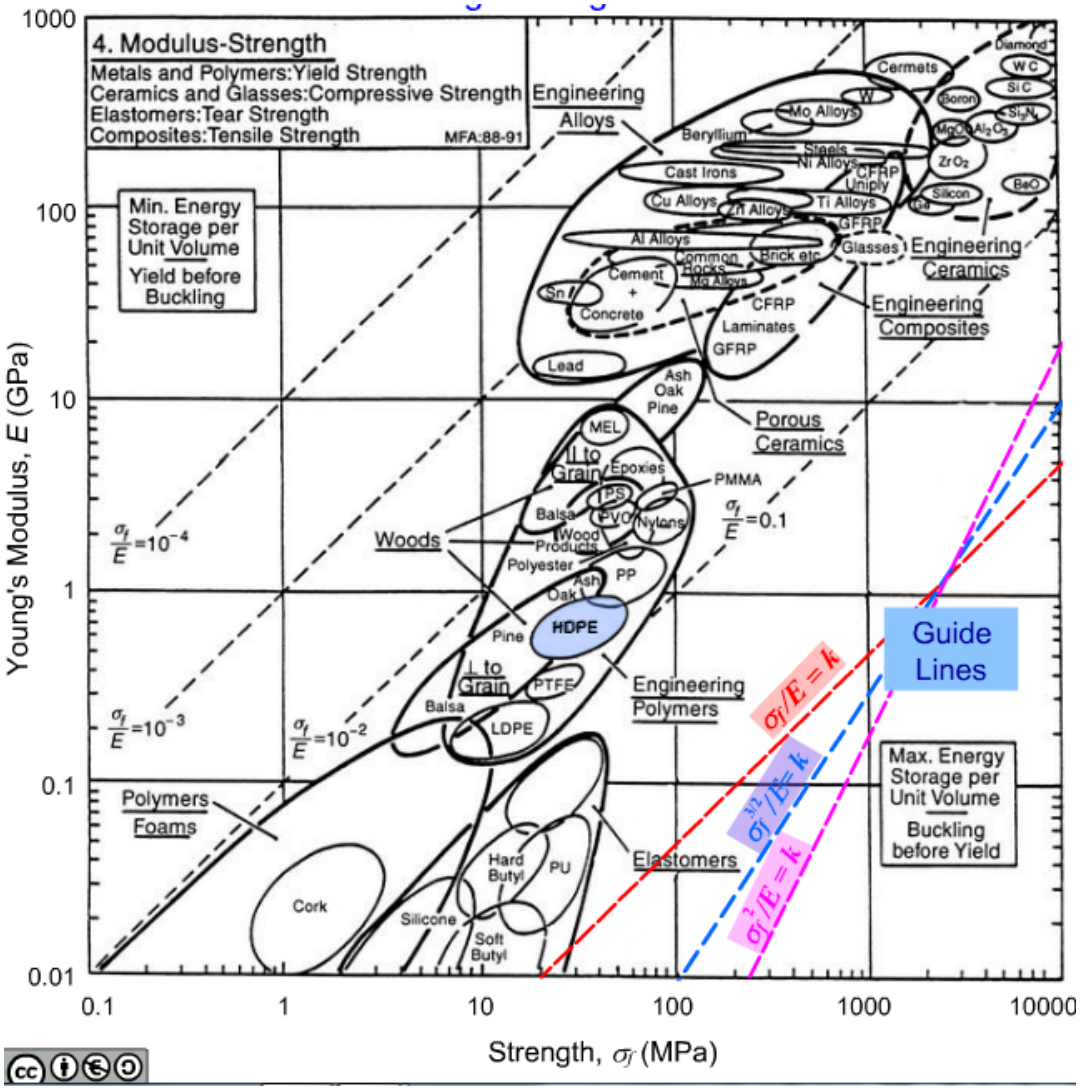
Linear Viscoelastic Behaviour



Behaviour of bituminous materials

Behavior Characterization vs Performance

Modulus vs. Strength

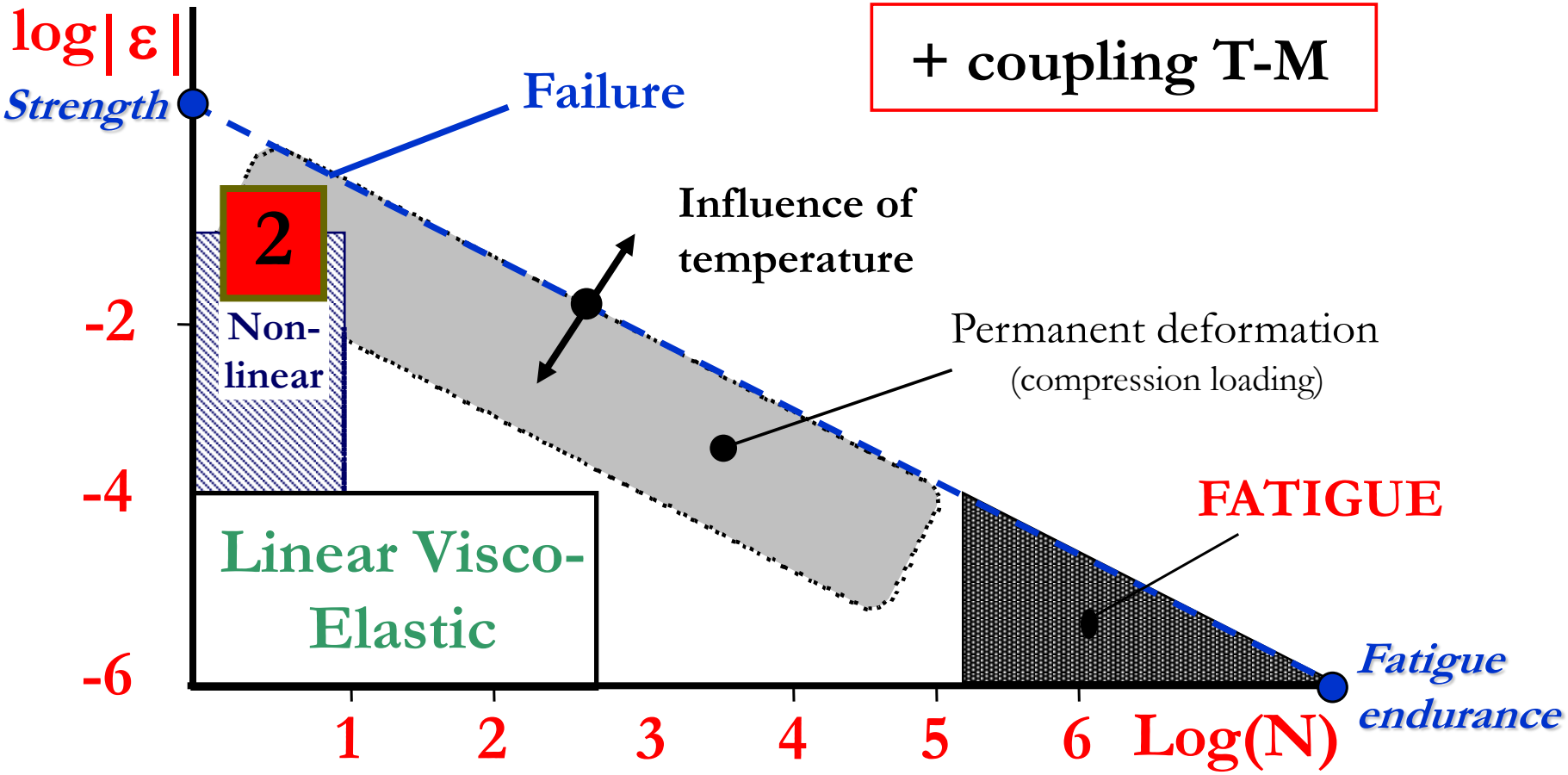


http://www.doitpoms.ac.uk/tlplib/optimisation-biomaterials/modulus_strength.php

Dynamic Modulus – Performance test?

- Determine the stiffness of the mix under different loading conditions ➔ Pavement Design
  - Need a high stiffness at design temperature
  - Allow considering the speed (reflected by the frequency)
- Predict the Rutting Resistance
  - Min|E*| at High Temperature
    - Is this really sufficient?
    - How accurate is the prediction?
- Fatigue Cracking
  - Max|E*| at Intermediate Temperature
    - Almost abandoned idea
    - Not supported by studies
- Low Temperature Cracking
  - Max|E*| at Low Temperature
    - Very rarely mentioned in the literature!
    - Not supported by studies
    - Not possible with AMPT as the minimum temperature is 4°C

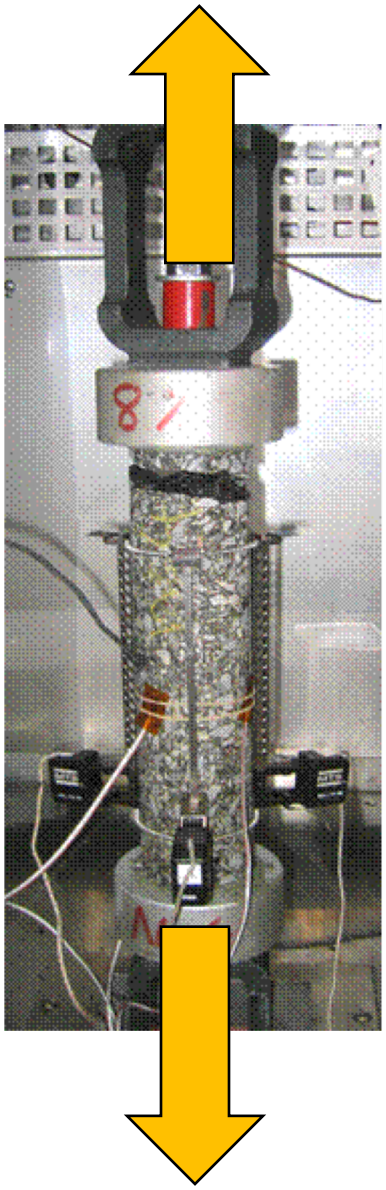
Behaviour of bituminous materials

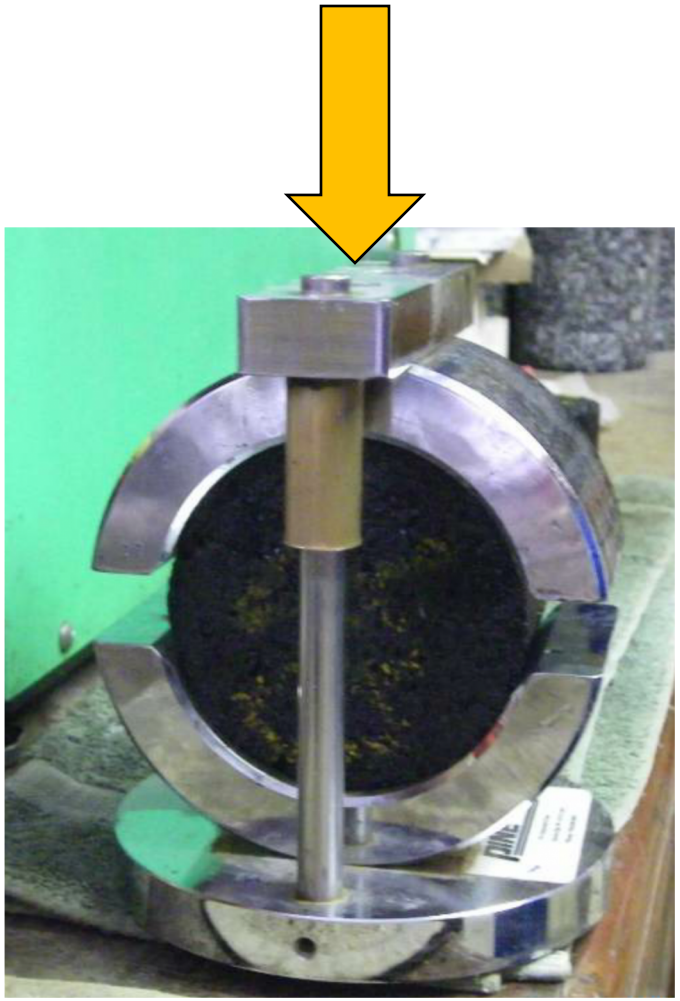


➢ *Importance of a « good » modelling for road design*

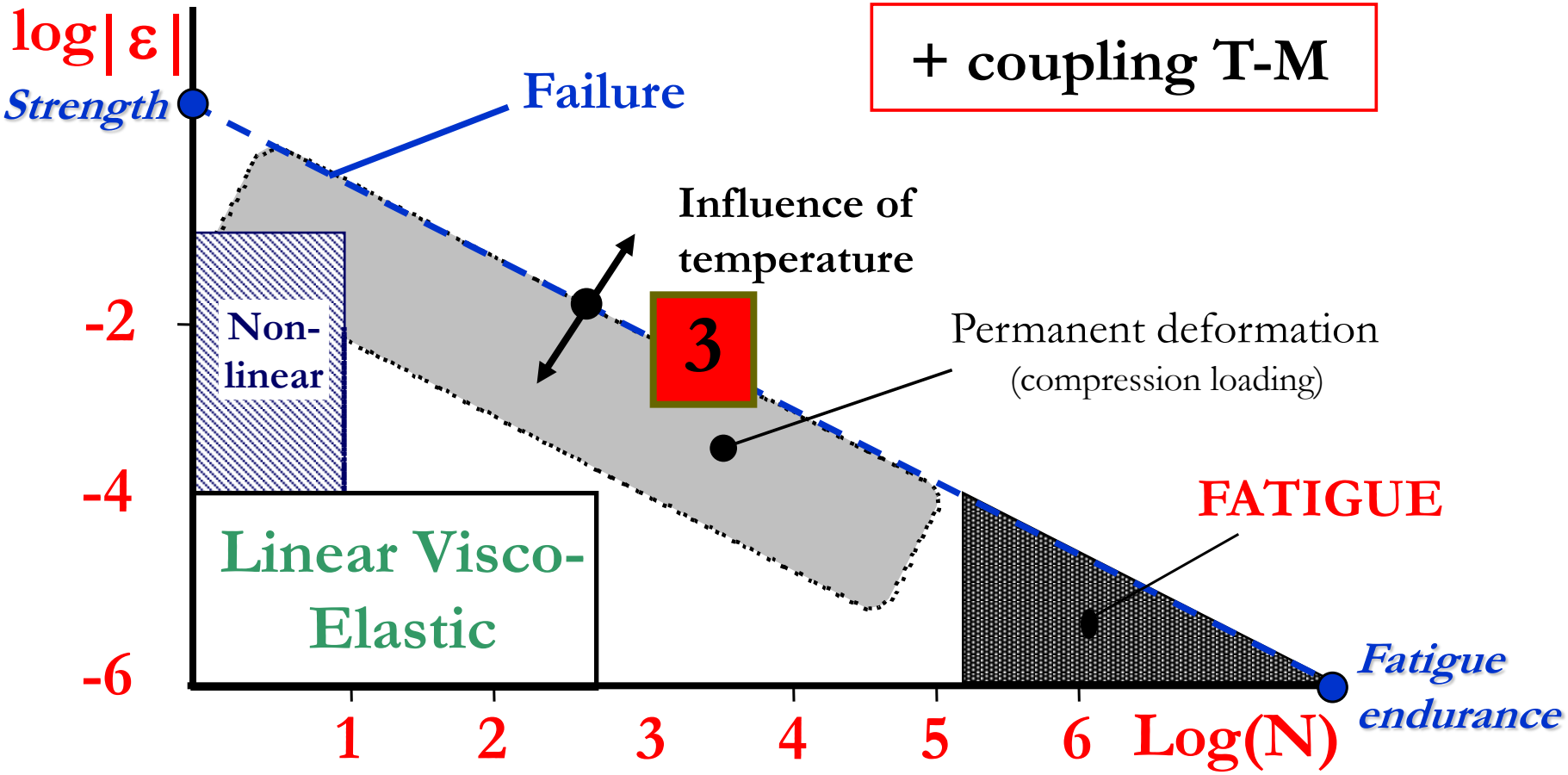
Di Benedetto (1990)

Behaviour of bituminous materials





Behaviour of bituminous materials



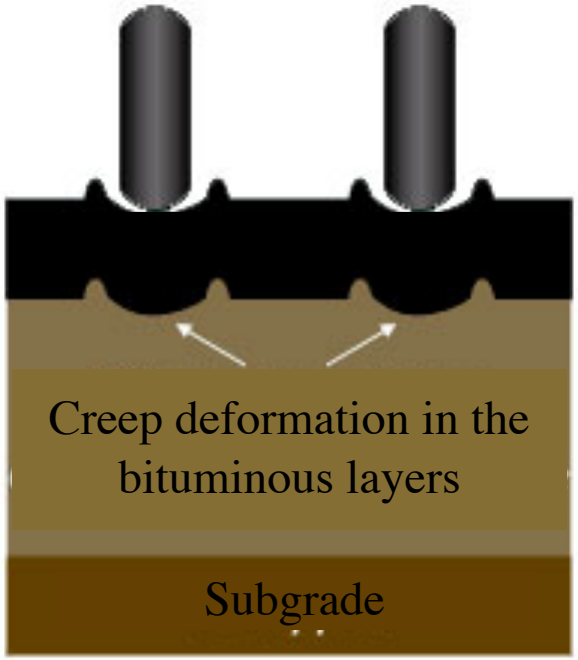
➢ *Importance of a « good » modelling for road design*

Di Benedetto (1990)

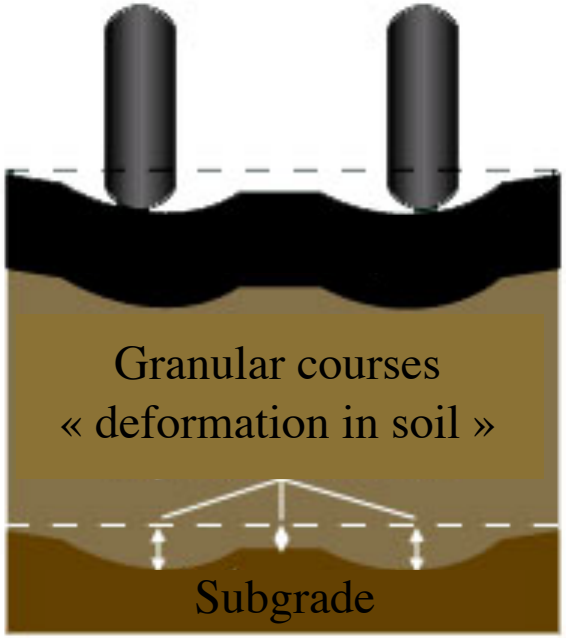
Rutting (Permanent deformation)

Rutting is the permanent deflection in the longitudinal direction of the pavement.

Rutting (Permanent deformation)



Rutting by excessive creep in the HMA



Rutting by deformation of granular layers

Rutting (Permanent deformation)

LCPC Rutting Test

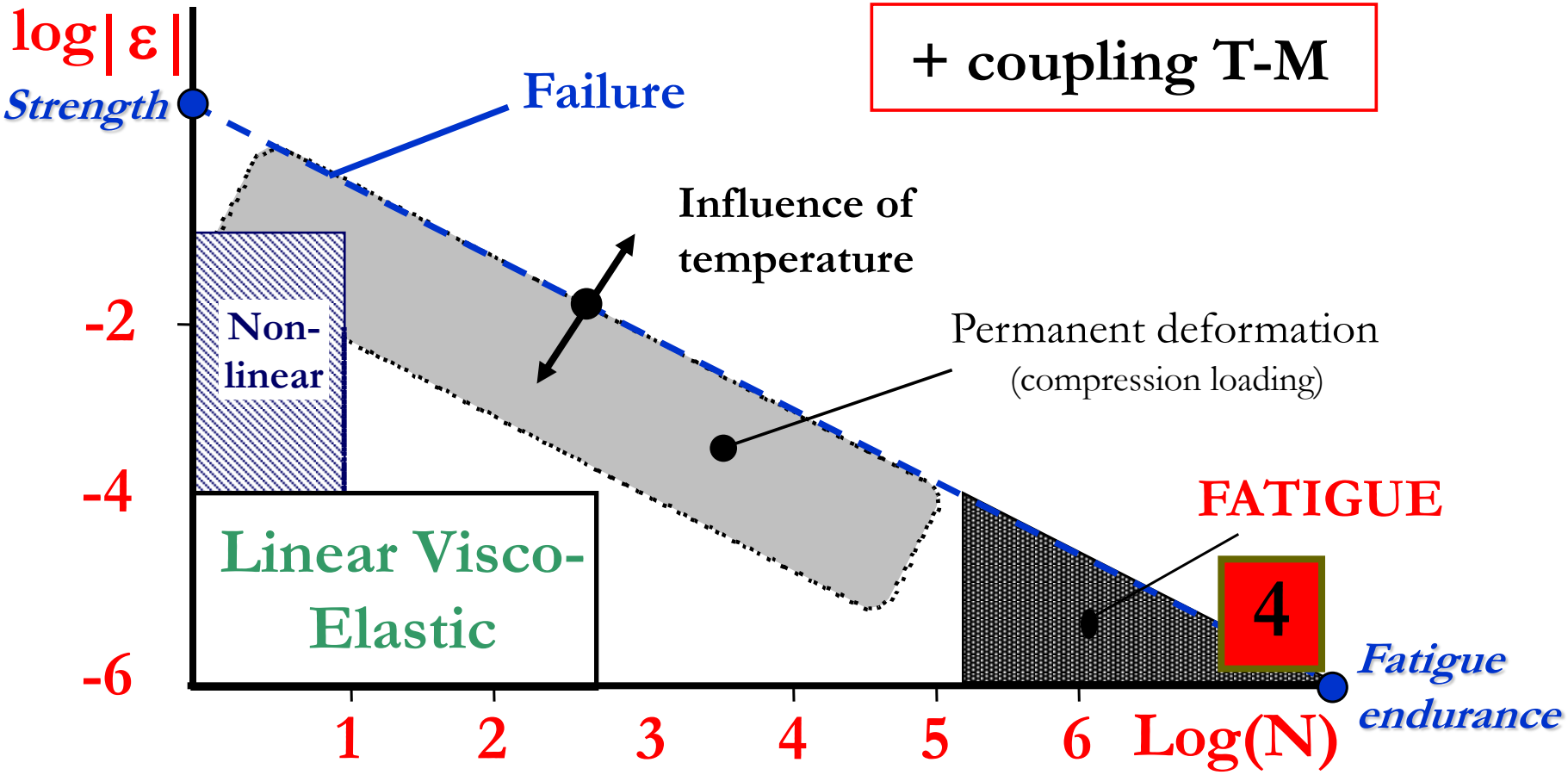
Rutting (Permanent deformation)

LCPC Rutting Test

Rutting (Permanent deformation)

LCPC Rutting Test

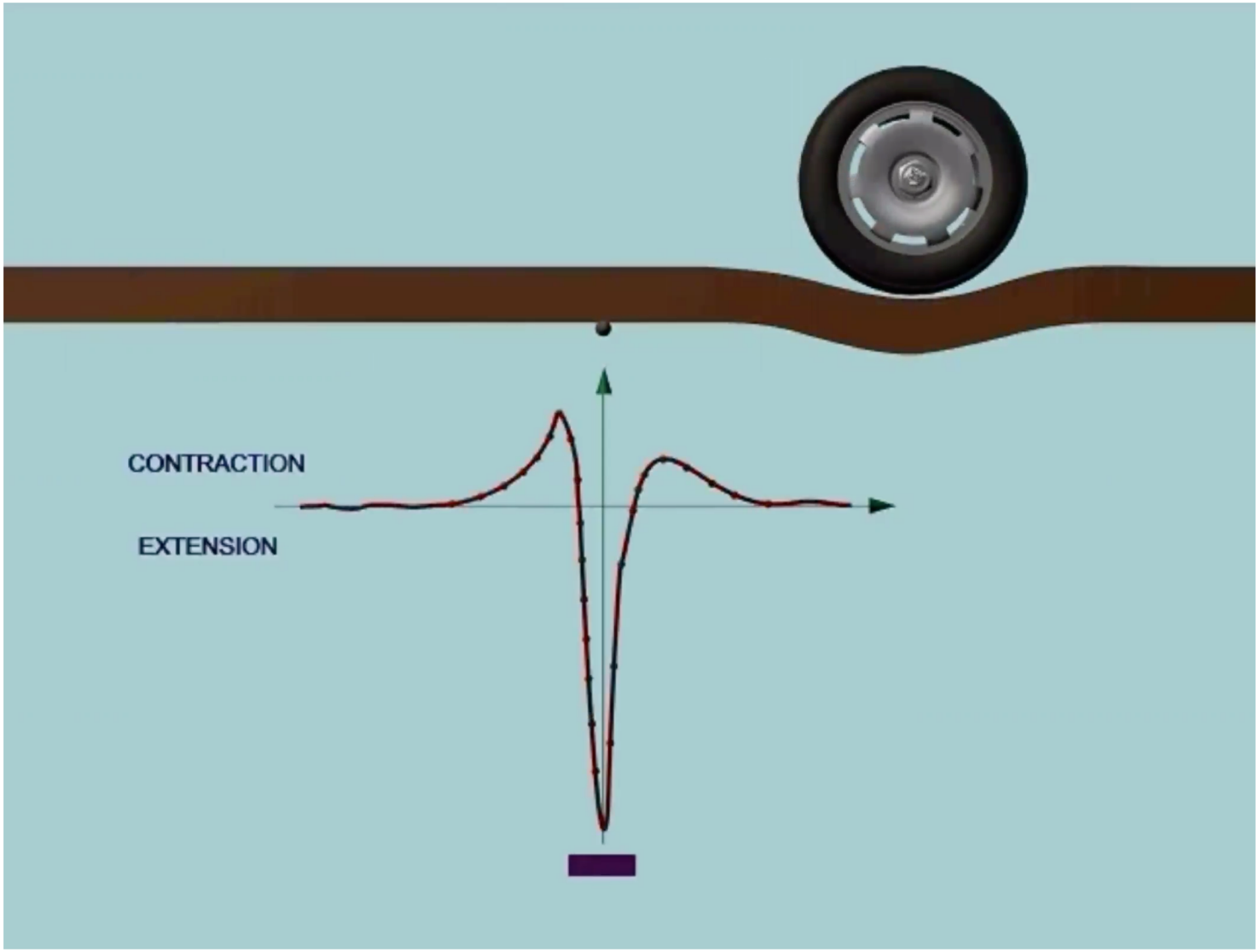
Behaviour of bituminous materials



➢ *Importance of a « good » modelling for road design*

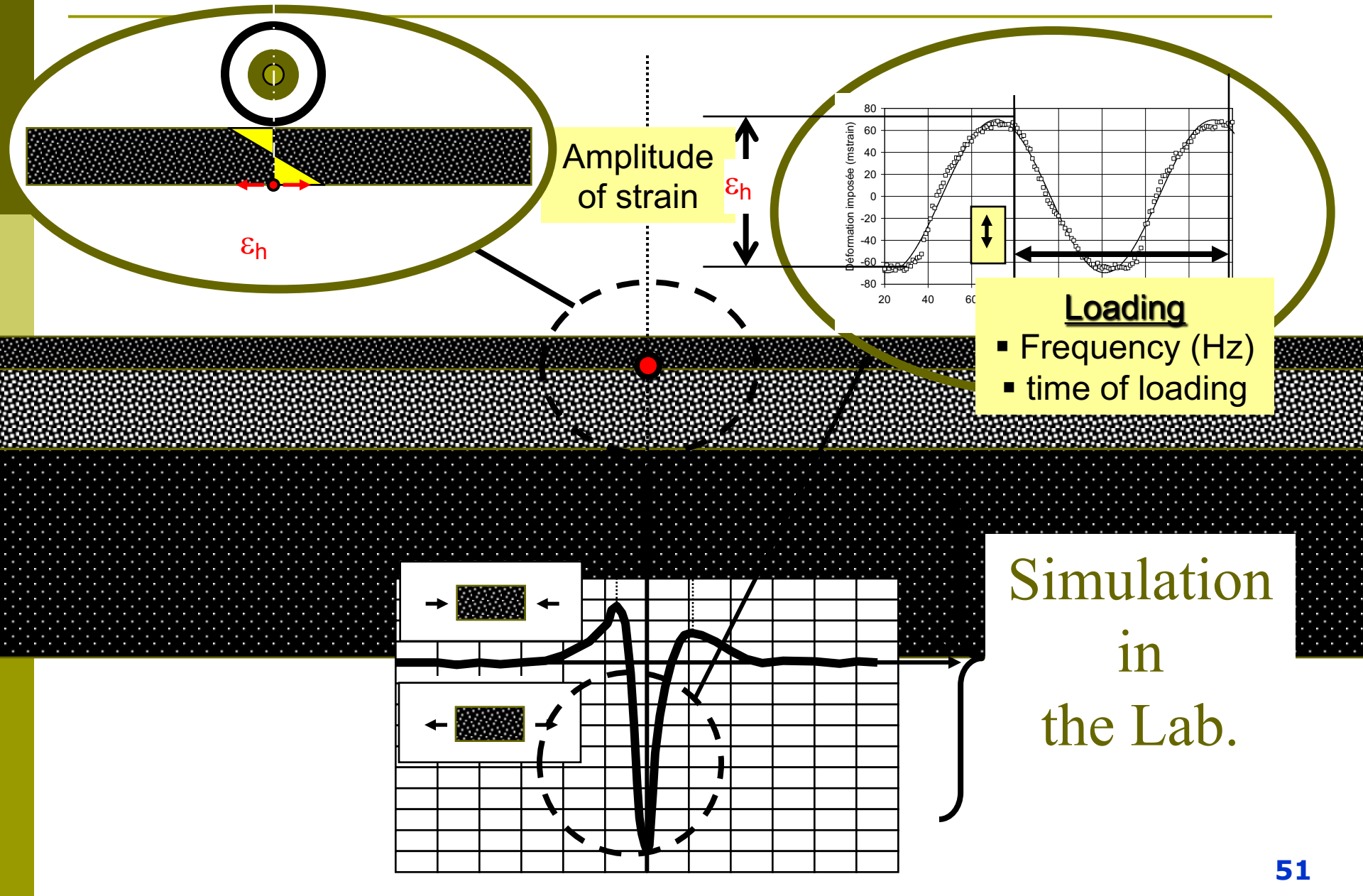
Di Benedetto (1990)

Fatigue mechanism

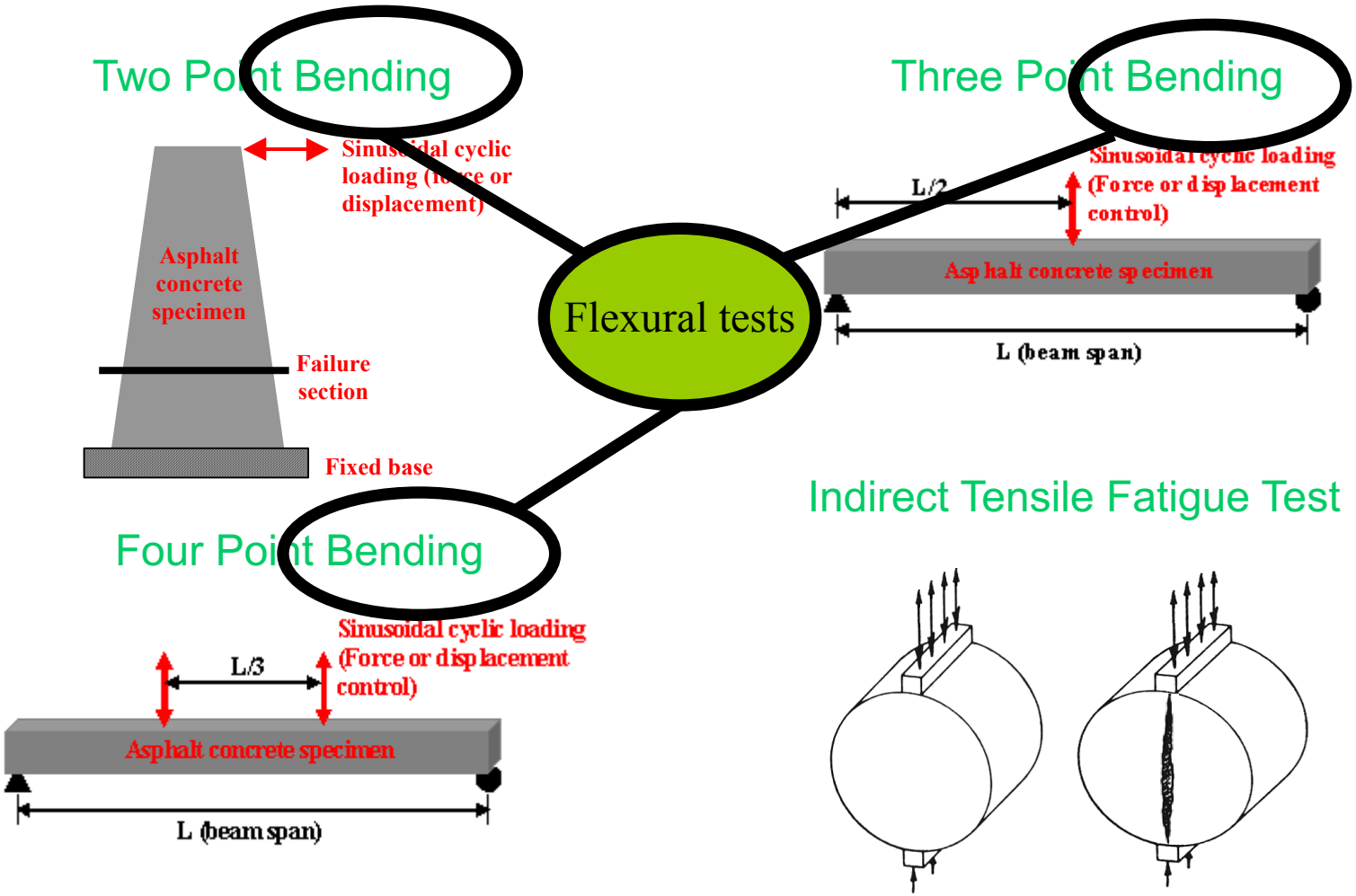


Fatigue cracking

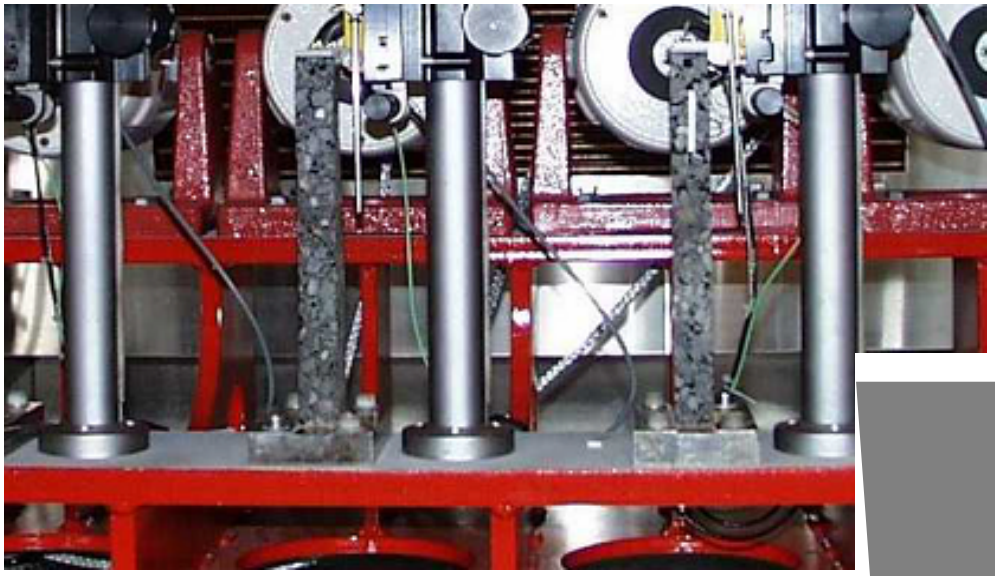
Fatigue mechanism

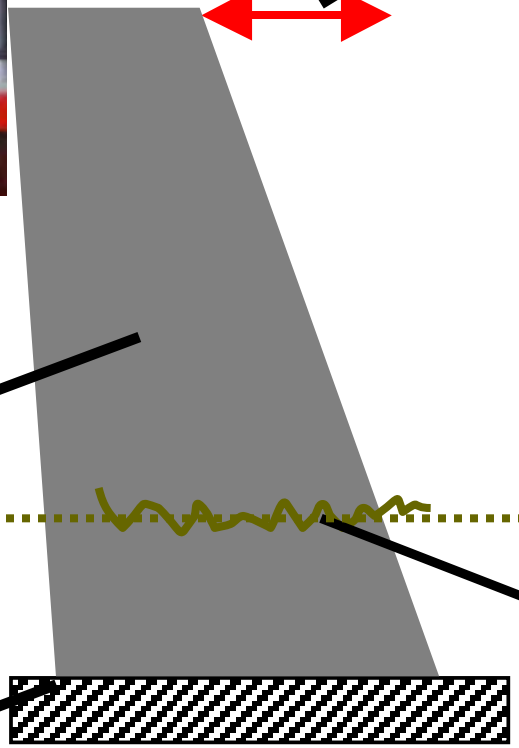


Fatigue testing approaches

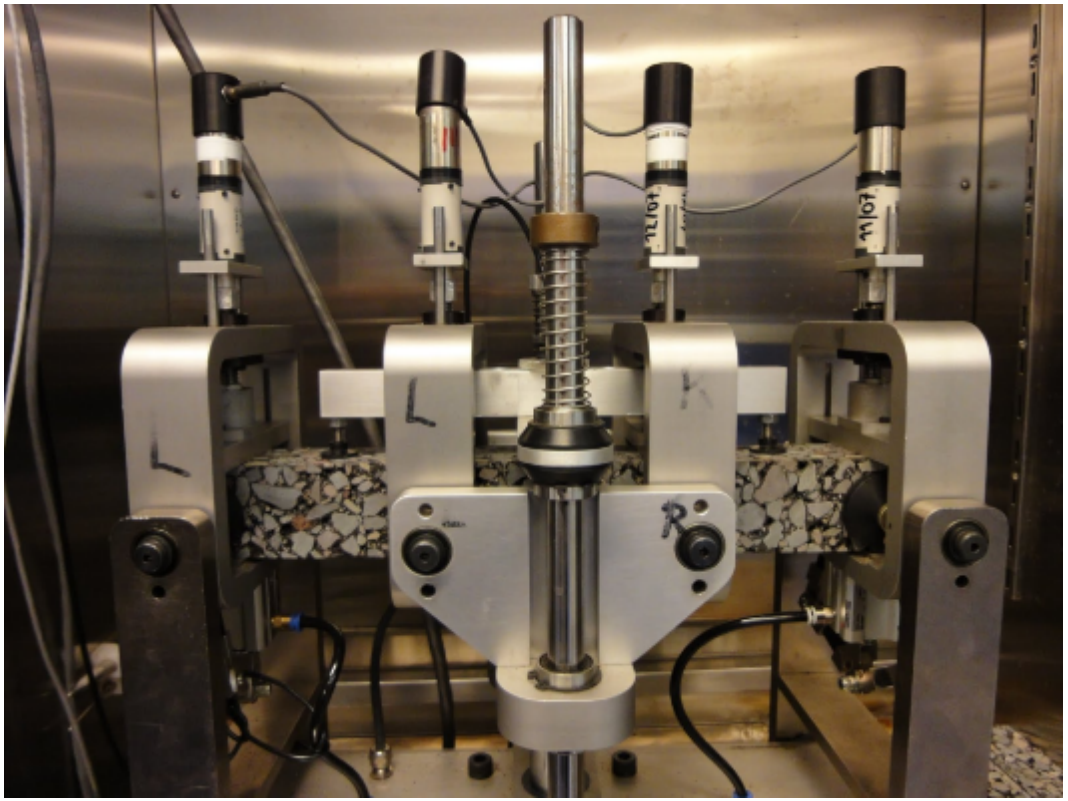


Fatigue tests – 2-point bending

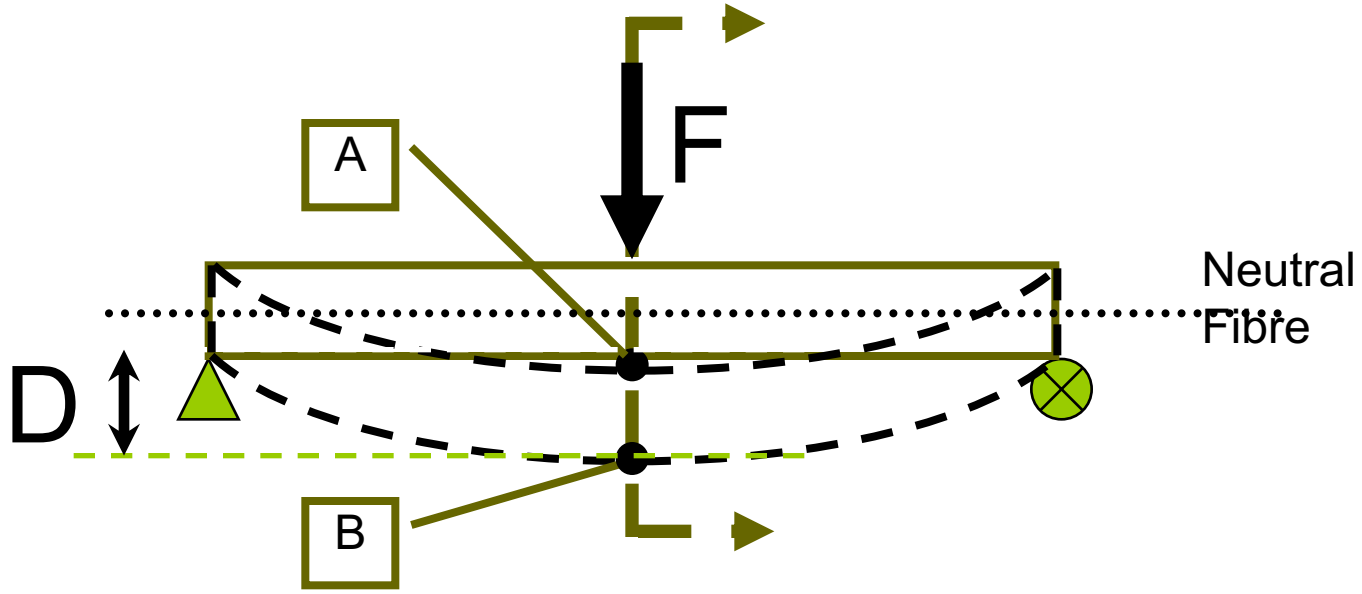




Fatigue tests – 4-point bending



Fatigue test – Flexural tests



(A) MAX. CONTRACTION (B) MAX. EXTENSION

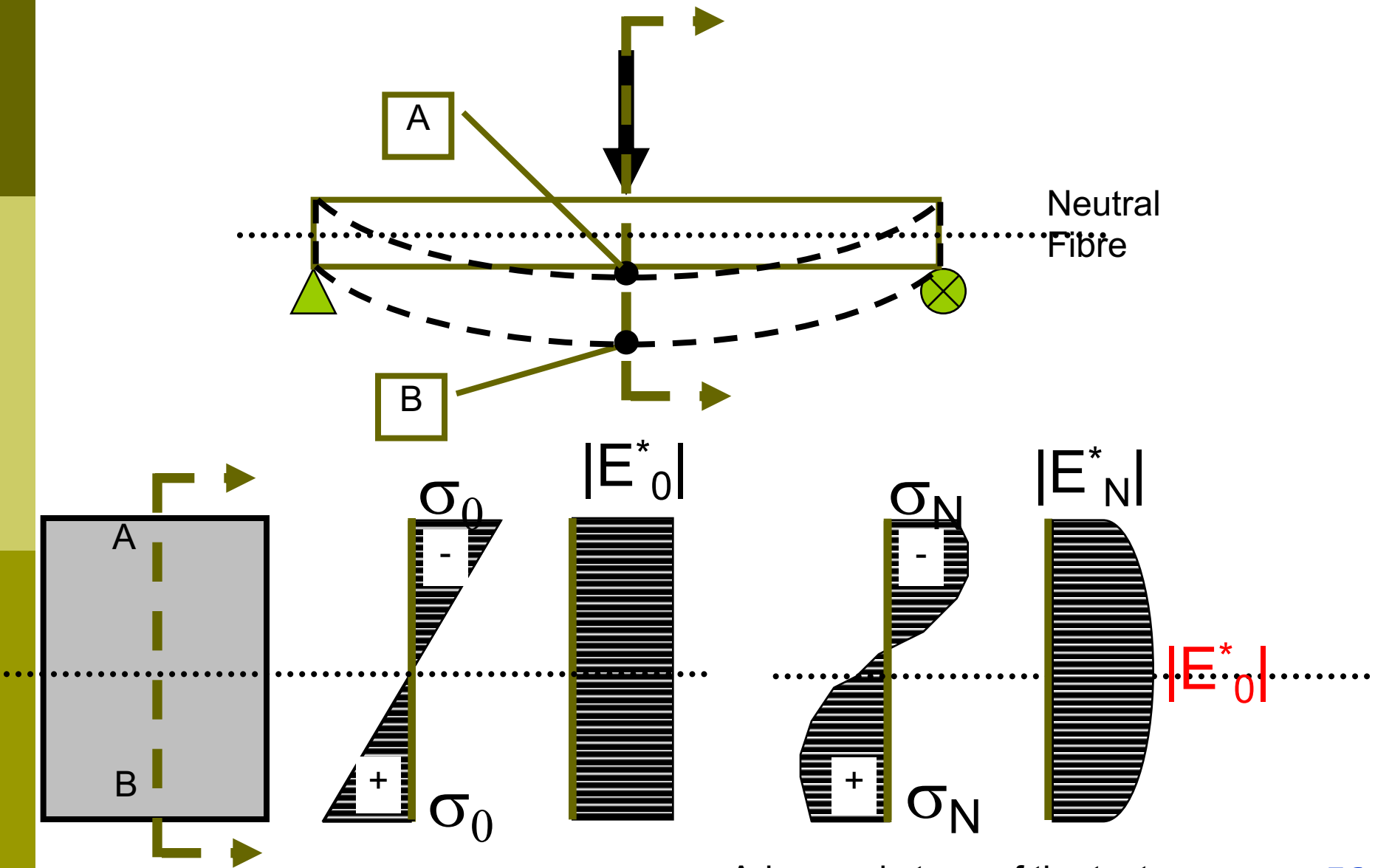
How to calculate stress and strain from force and displacement values?

We need to assume a behaviour law

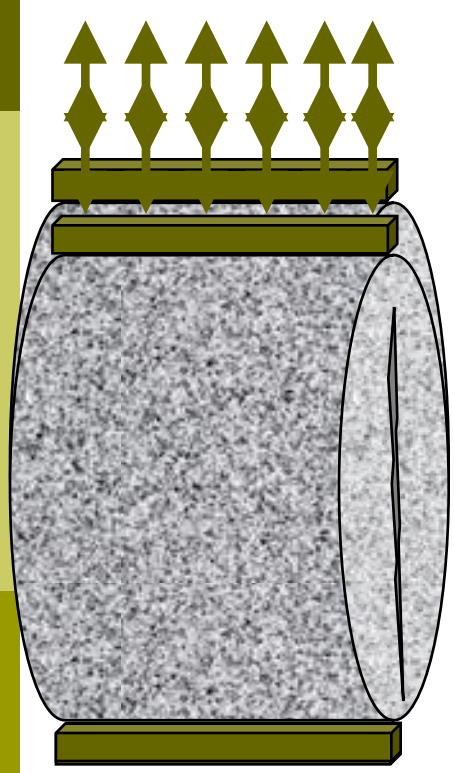
Example (Elastic low)

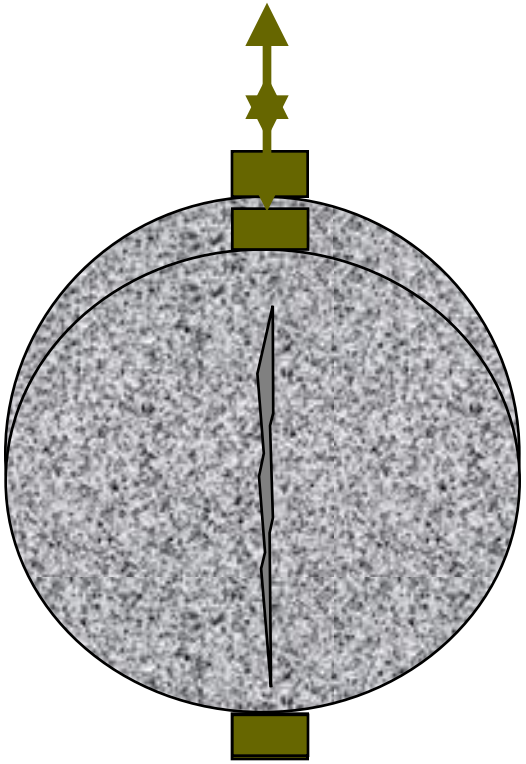
$$\sigma = M/I \cdot y$$

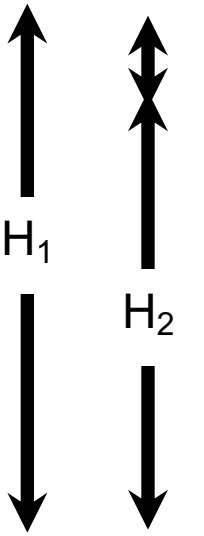
Fatigue test – Flexural tests



Fatigue tests – Indirect Tensile Test

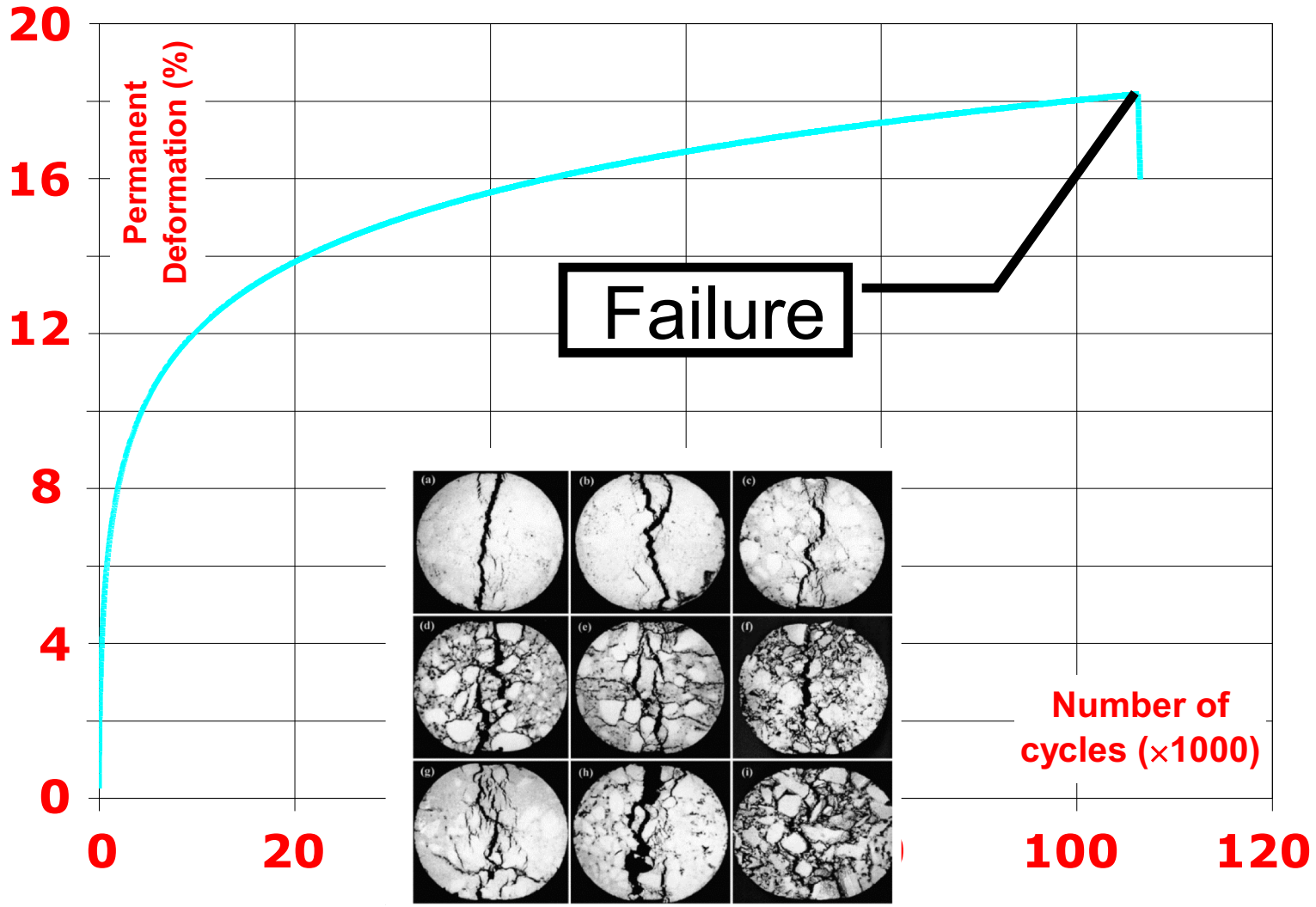






$$\frac{DH}{H_1} \times 100\% = \varepsilon p$$

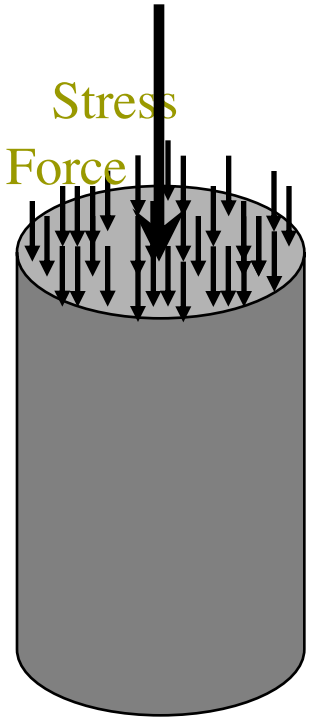
Fatigue tests – Indirect Tensile Test



Hartman et al., 2001

Fatigue tests – Tension Compression

Homogenous tests



- The pressure is the value of the Force (F) distributed on the transversal section (A)

$$p = F / A$$

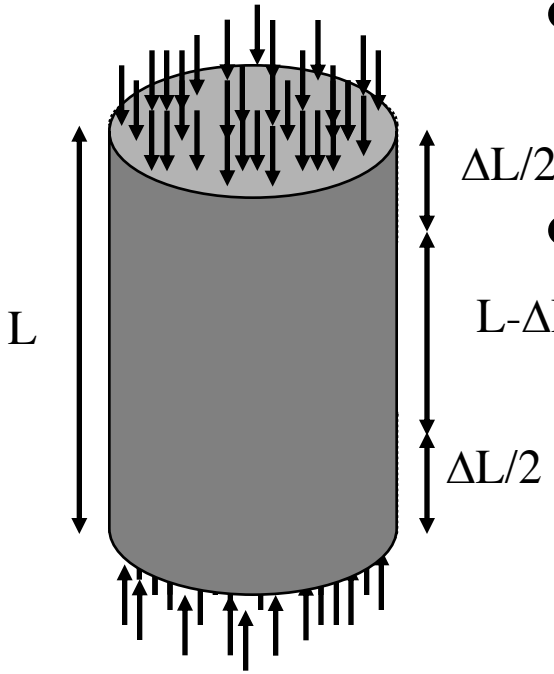
- The normal stress is equivalent to pressure in homogenous conditions

Pressure = Stress

$$\sigma = p$$

Fatigue tests – Tension Compression

Homogenous tests



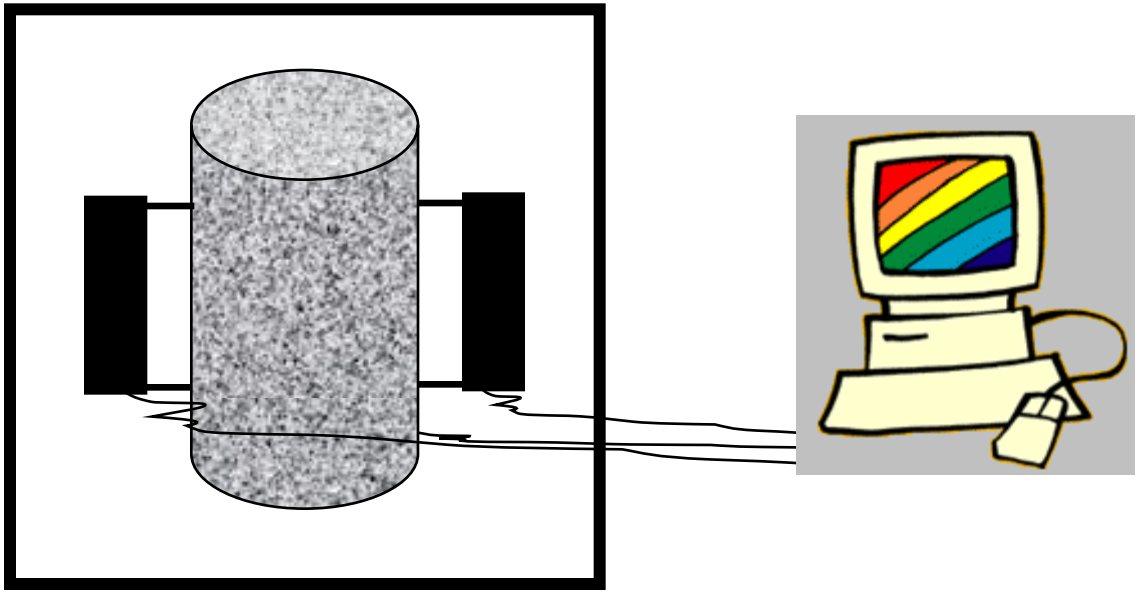
- ΔL is the displacement of the material
- The strain is the percentage of total displacement of the original height

Strain = Relative deformation

$$\varepsilon = \Delta L / L$$

Fatigue tests – Tension Compression

Tension-Compression Fatigue Test



Fatigue tests – Tension Compression

Tension-Compression test

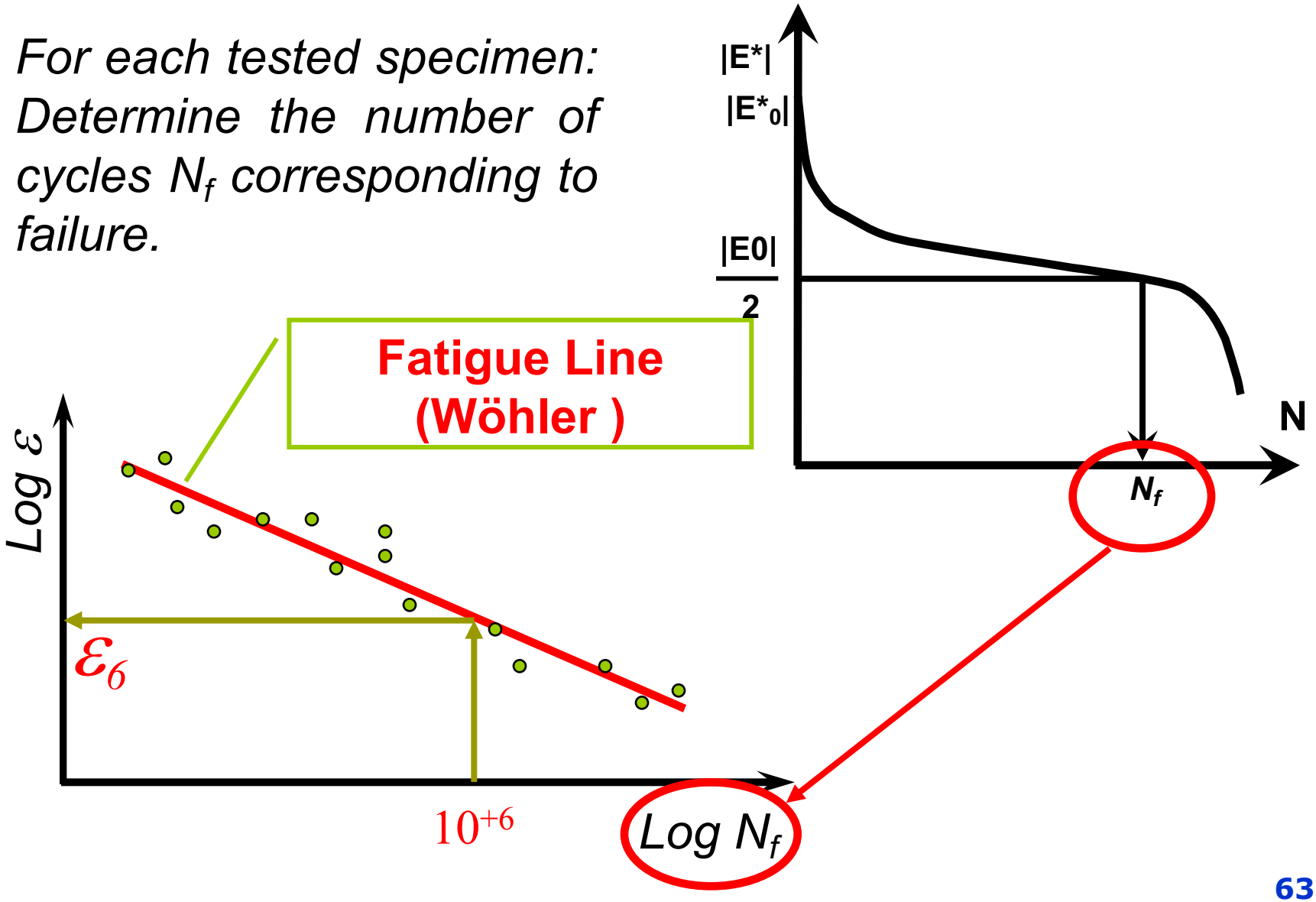
Destructive Test

Temperatures: 10 °C

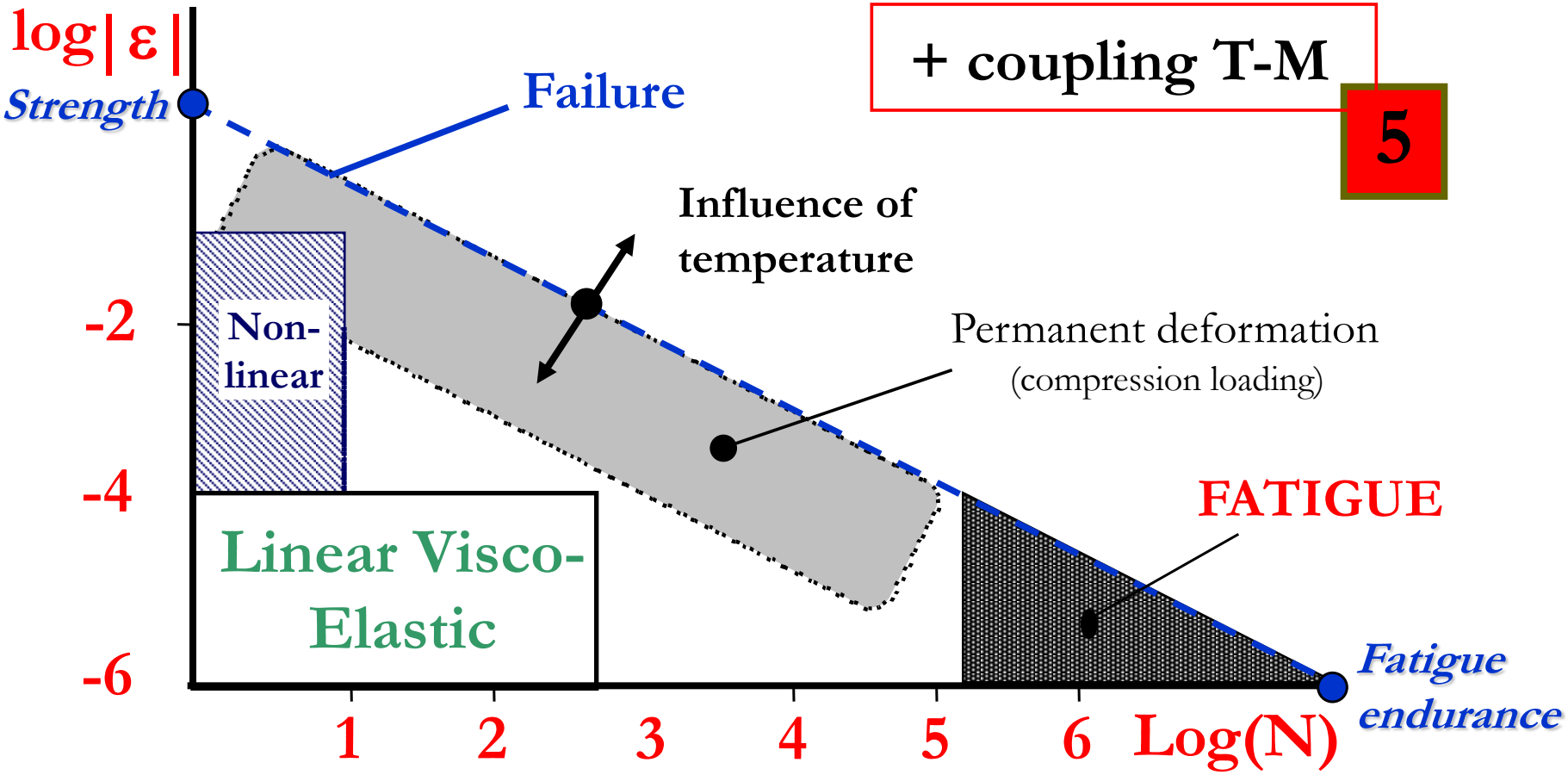
Frequency: 10 Hz

Classical fatigue criterion

For each tested specimen: Determine the number of cycles N_f corresponding to failure.



Behaviour of bituminous materials



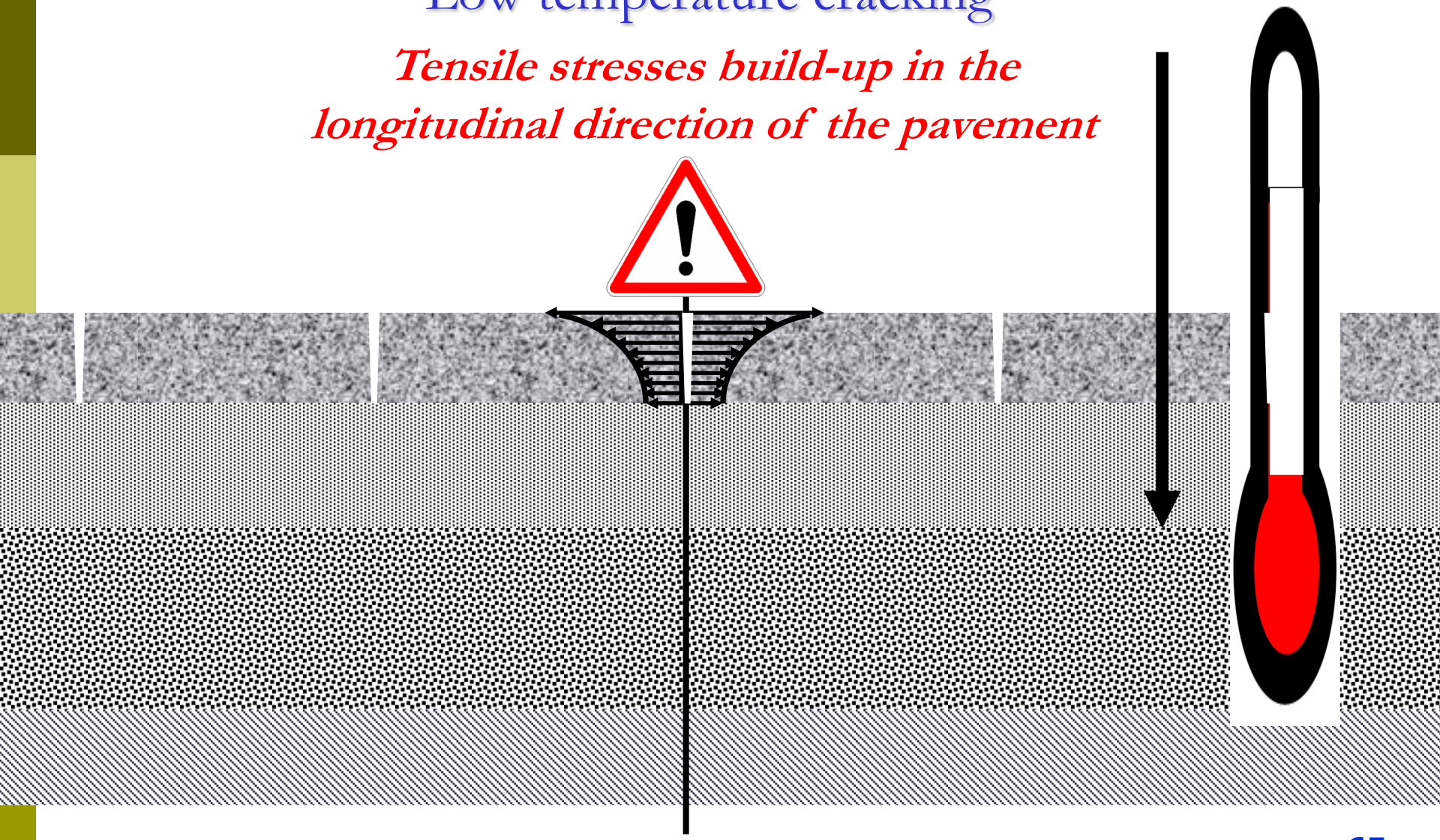
➢ *Importance of a « good » modelling for road design*

Di Benedetto (1990)

Low temperature cracking

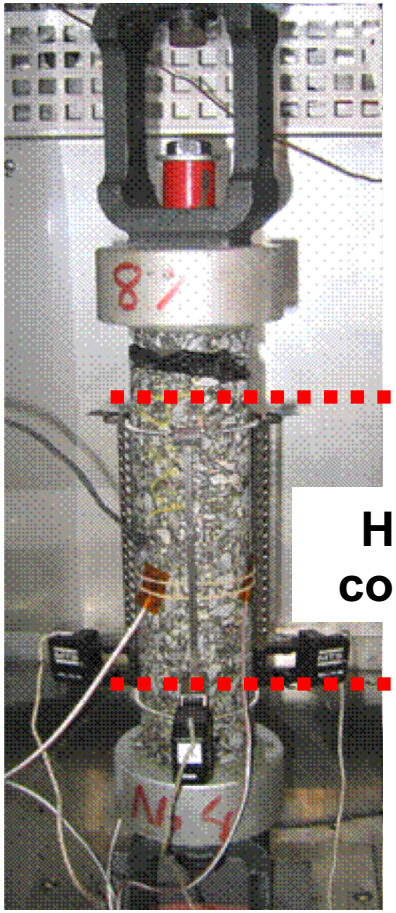
Low temperature cracking

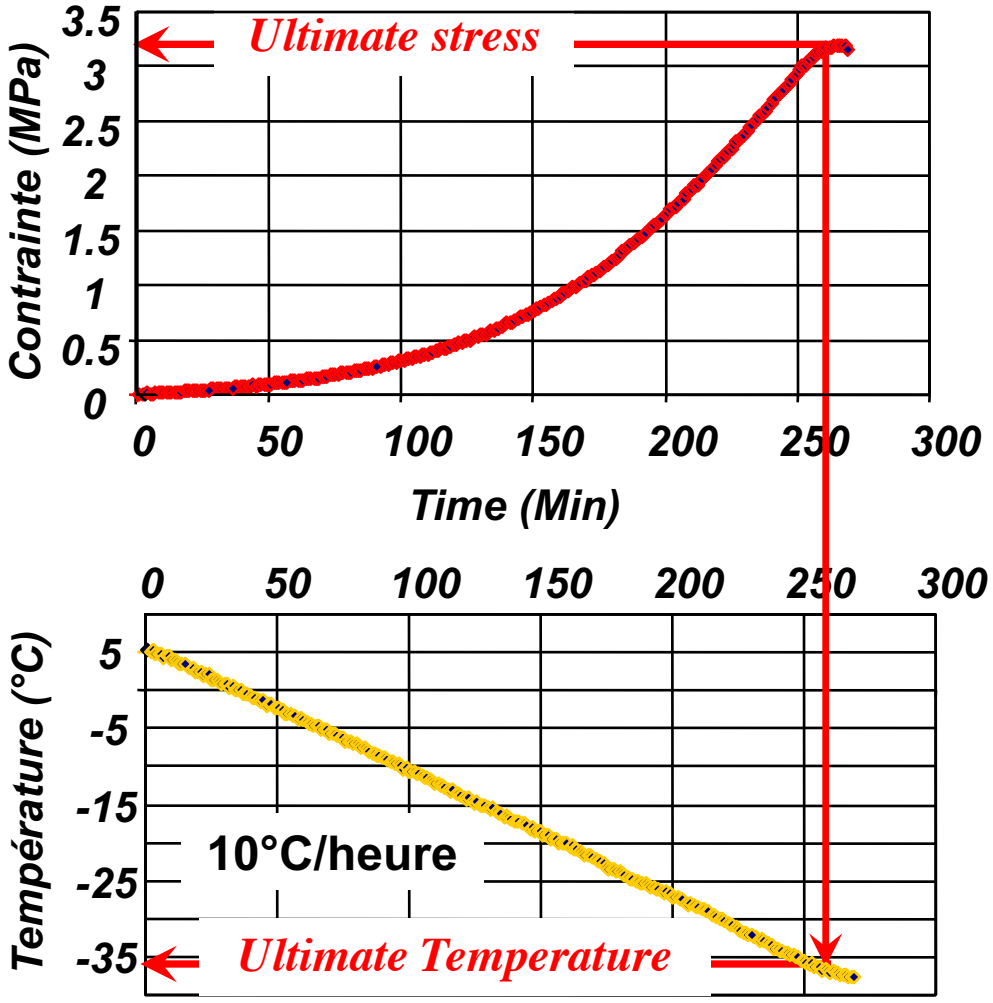
Tensile stresses build-up in the longitudinal direction of the pavement



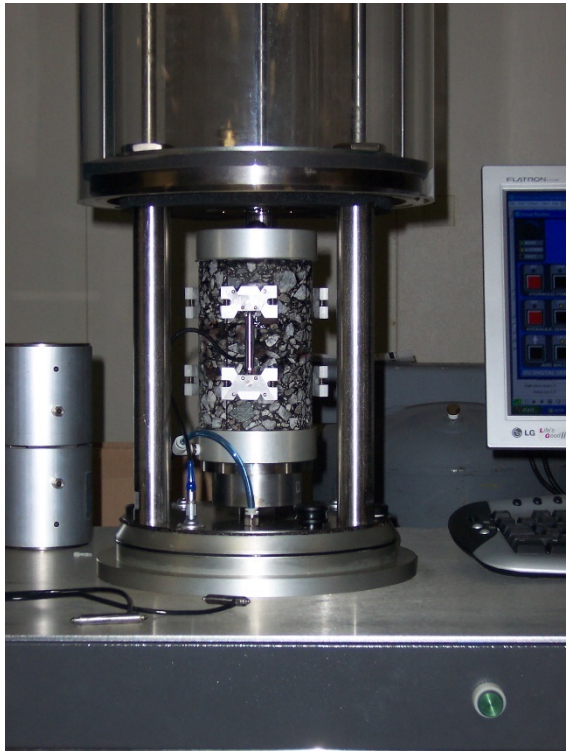
Low temperature cracking

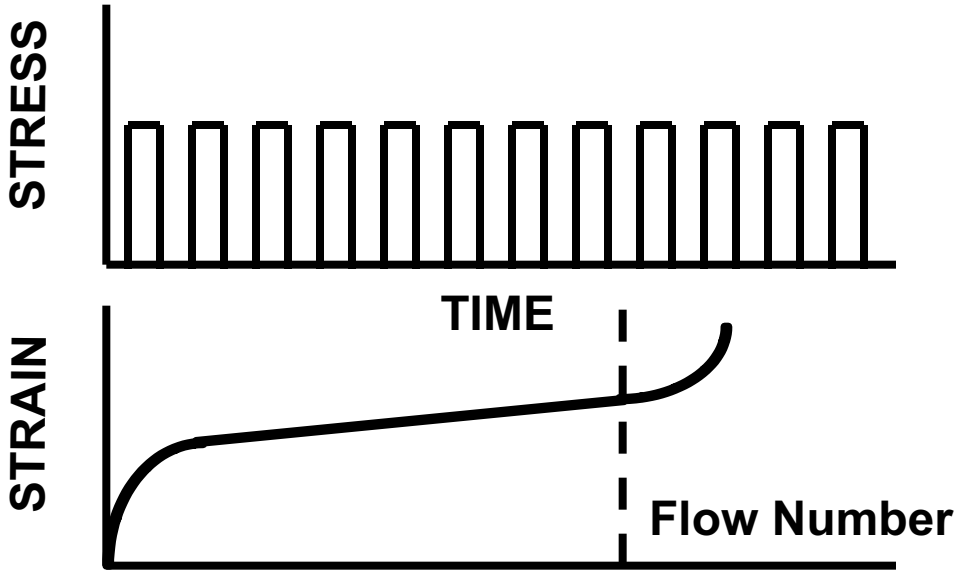
Low temperature cracking





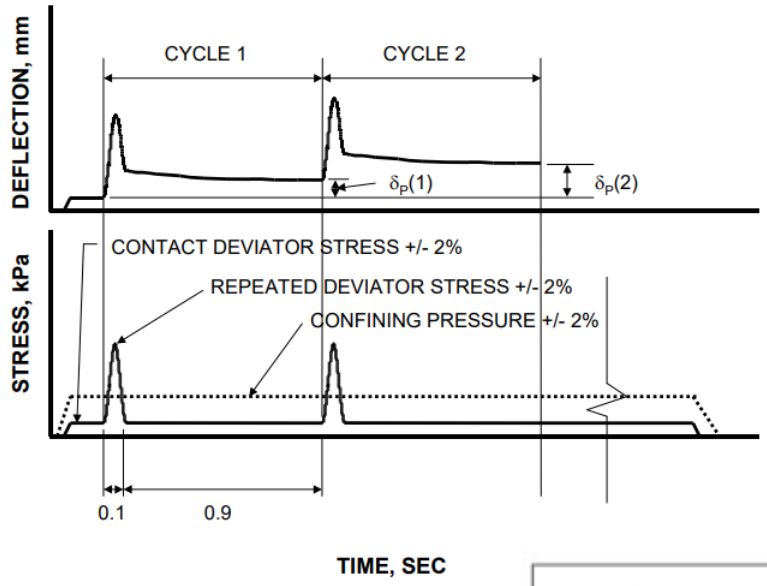
Repeated Load Test – Flow Number





- Rutting
  - Min FN at High Temp

Repeated Load Test – Flow Number



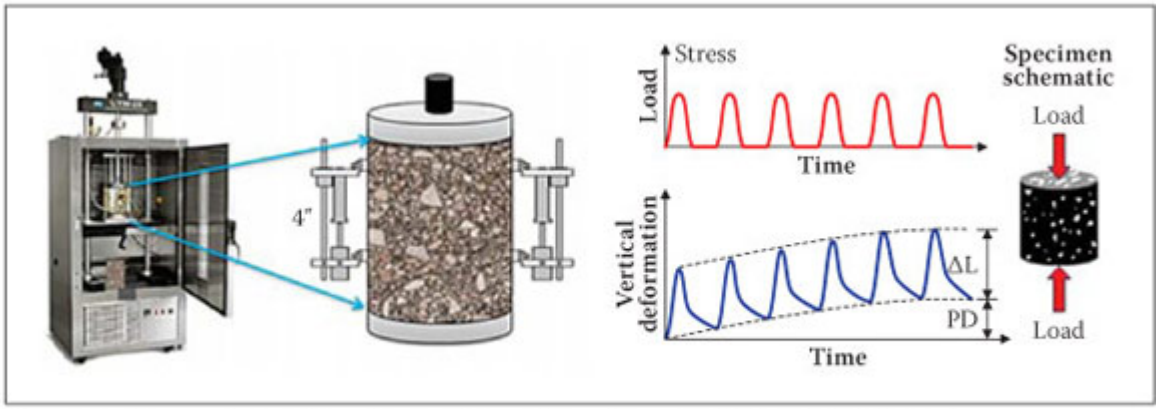


Figure 2 FN test setup and loading configuration using the UTM-25 (TxDOT 2004)

Repeated Load Test – Flow Number

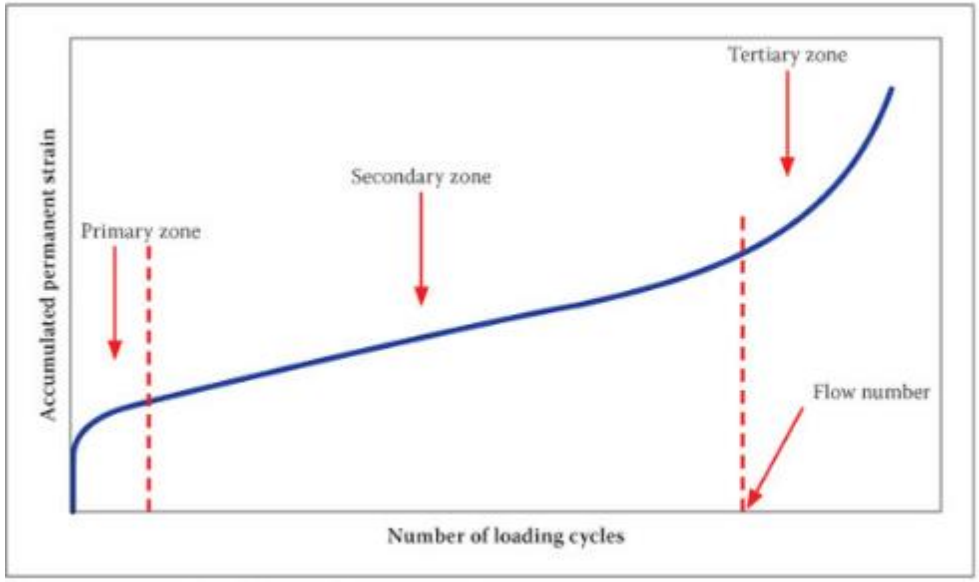


Figure 3 Graphical illustration of the FN (TxDOT 2004)

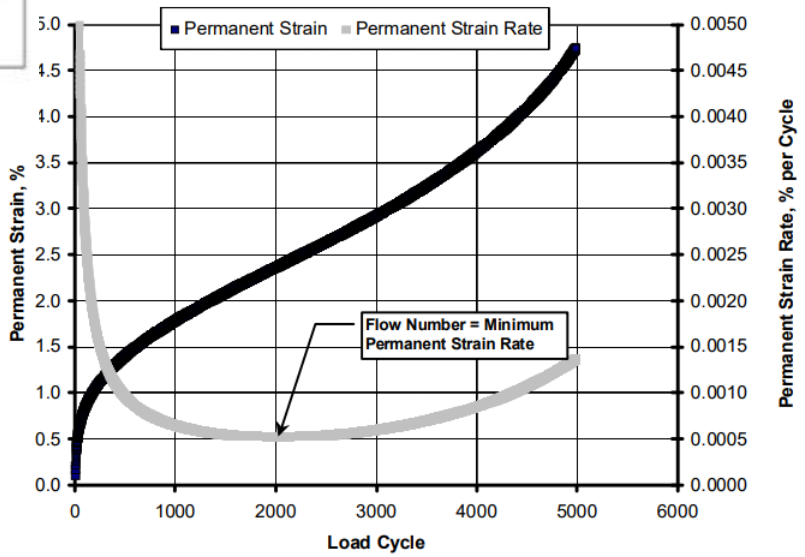


Figure 3. Example Flow Number Test Data.

Repeated Load Test – Flow Number

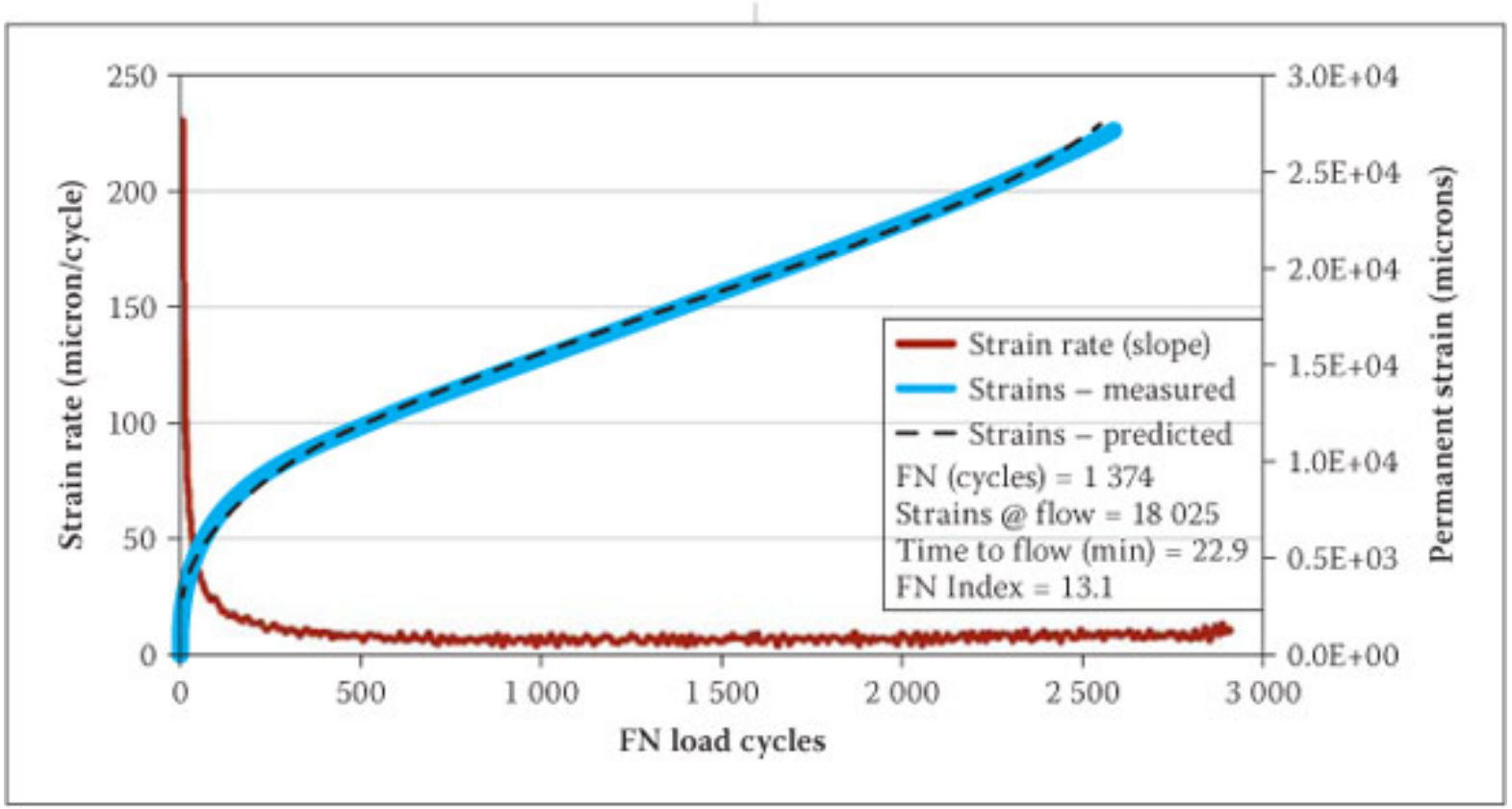
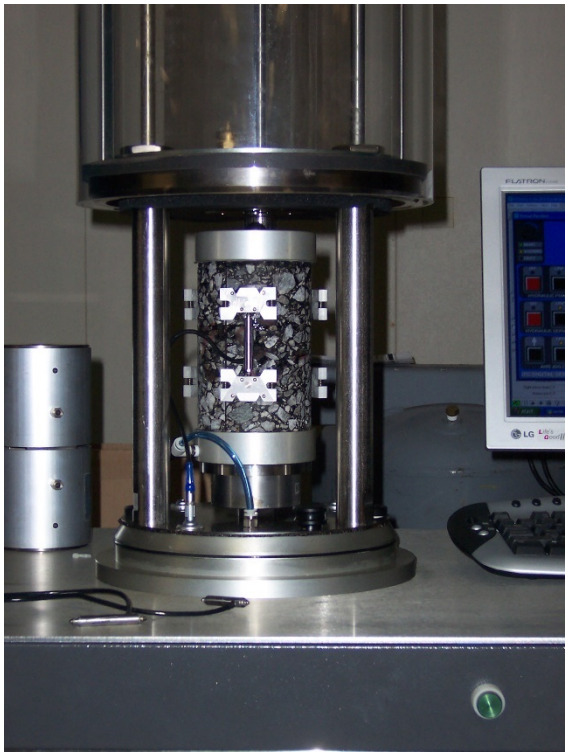
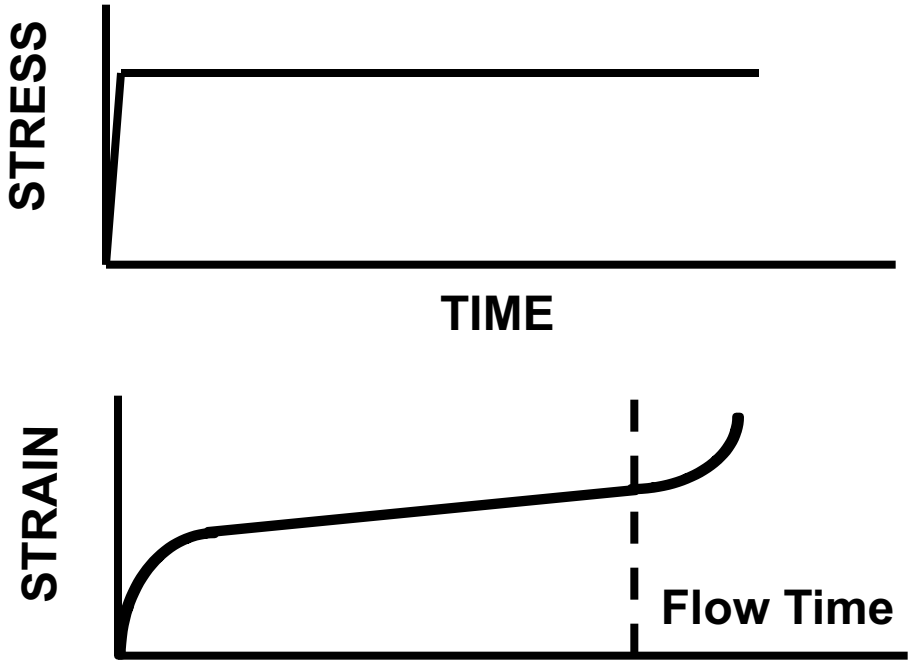


Figure 4 Accumulated permanent strain and strain rate as a function of load cycles

Creep Test – Flow Time





- Rutting
  - Min FT at High Temp

Outline

- About CPATT
- Introduction – What is "Performance" and why we need "Performance Testing"
- Performance Testing Fundamentals
- Behaviour of Bituminous Materials
- Behaviour Characterization vs. Performance Testing
- Performance testing of asphalt mixes
  - Low Temperature Cracking
  - Rutting
  - Fatigue
  - Complex (Dynamic Modulus)
  - Flow Number
  - Flow Time
- Closing Remarks

Closing Remarks

- Pavement performance is highly impacted by the performance of the building materials used in the pavement structure
- Asphalt concrete is the main material used in a flexible pavement structure and is exposed to traffic loadings, environmental conditions and other damaging factors
- The behaviour of asphalt materials is quite complex and asphalt testing requires good knowledge of this behaviour
- Testing conditions have significant impact on the quality of the results and the quality of the pavement design and performance prediction
- Performance-based mix design would be an excellent tool to improve the quality and the reliability of paving materials and increase the service life of the pavements

Closing Remarks

Performance-based design example: French Mix Design Approach

A **five level**, **performance-based design** approach:

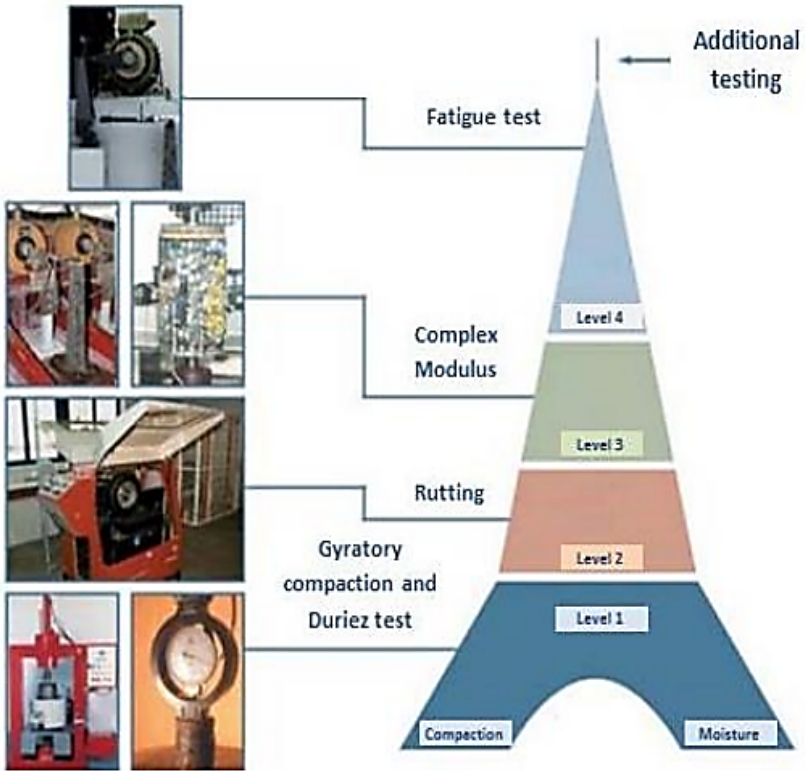
Level 0 - Determining the minimum binder content based on the gradation and richness factor.

Level 1 - Compaction ability and the moisture sensitivity assessment.

Level 2 - Evaluating the rutting resistance of the mix.

Level 3 - Determining the complex modulus values.

Level 4 - Evaluating the fatigue resistance of asphalt mixes and ε_6.

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