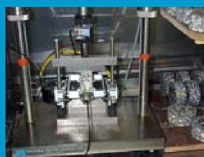
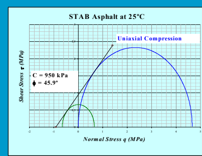
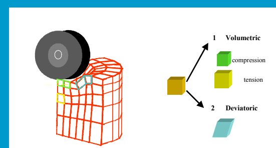
Developments in Asphalt Pavements Research

- from Science to Practical Applications -







Prof. dr. ir. André Molenaar

September 21, 2006

Topics

- History of pavement design
- Mechanistic empirical design methods
- Short comings of existing methods
- Fascinating world of modeling
- Micro – and Meso level
- Practical implications
- The road to the future

History of pavement design

• Good quality roads have always been essential for economic development, military action and official business.

• With increasing nr of vehicles and loads, good quality pavements became more and more important.

In the old days grandpa had a serious problem, the road was not designed to carry his car …….

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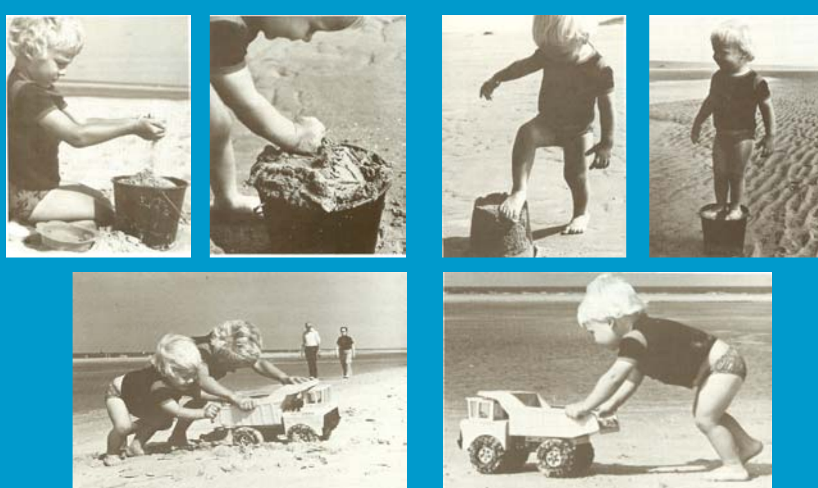
… and according to this picture little has changed since then !

Kids are excellent road engineers by birth



Pavement design: traditional approach

- Select thickness of covering layers such that stresses in subgrade are reduced to such an extent that subgrade deformations are limited.
- Select materials for covering layers such that no excessive deformation takes place there.

- Designs were based on limiting shear stresses in unbound layers.
- Thin surfacings were used to provide smoothness for driving comfort.

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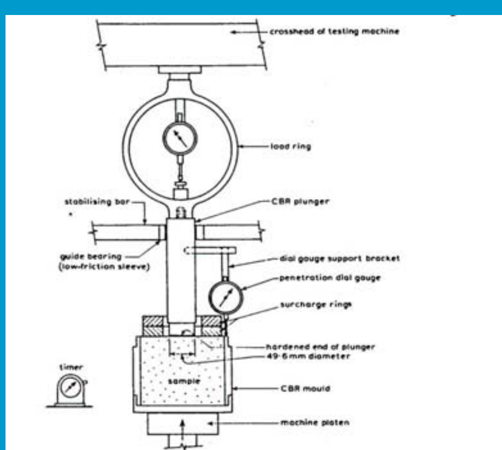
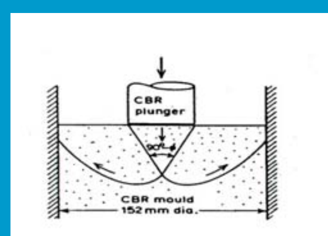
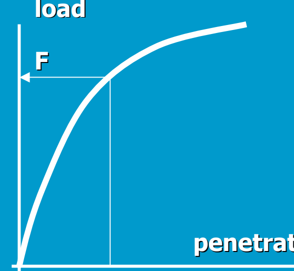
CBR (penetration) test



$CBR = F/F_{ref} * 100\%$





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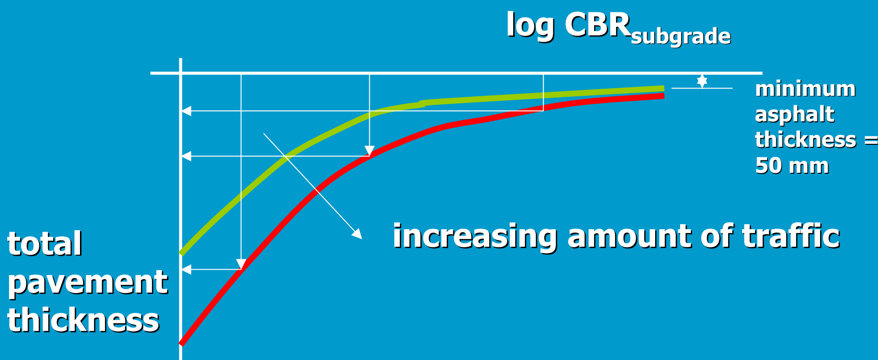
Empirical design charts allowed to determine thickness and CBR of granular base and thickness asphalt layer given $CBR_{subgrade}$



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CBR designs however are not always succesful

Bhutan

USA

Zimbabwe

Ghana

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Modern flexible pavement structures are much thicker and quite diverse ...

South Africa

- 5 cm asphalt concrete (4%)
- 15 cm high quality crushed stone
- 25 cm cement treated subbase
- CBR ≥ 15%

the Netherlands

- 5 cm porous asphalt concrete (>20%)
- 20 cm aspahlt concrete (6%)
- 30 cm unbound base of recycled material
- CBR ≈ 10%

... but they still suffer from damage.

permanent deformation of asphalt mixture

(fatigue) cracking of bound layers

Pavement damage is not only due to traffic (deformations due to settlements/frost/swelling soil)

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Settlements can also result in severe cracking

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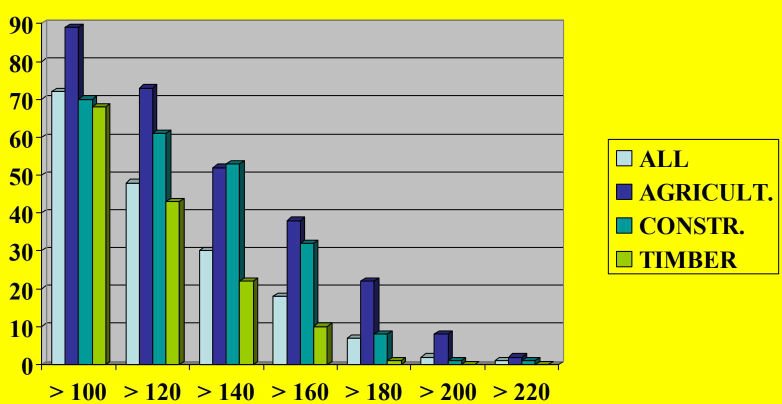
But traffic is a main source of problems and these loads come in different sizes and shapes

Overloading is a serious issue in many countries



Consequences of overloading are enormous

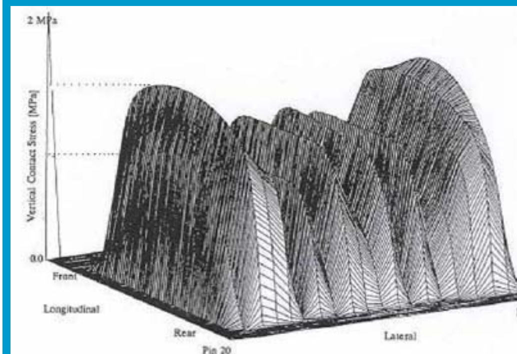
191 kN AXLE

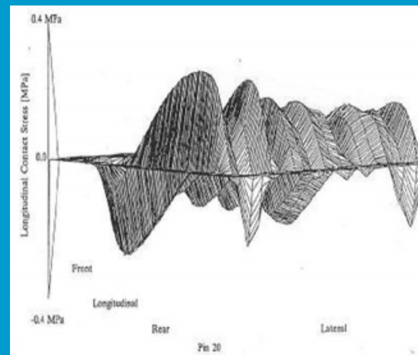
40 kN 56 kN 5 kN 90 kN

Legal wheel load = 25 kN
Damage due to violator (90 kN) equals $(90/25)^4$ = 169 times legal wheel load

Dual wheels, super super single and super single

Contact pressure distributions





Vertical **Lateral**

pressure distribution

Critical stress and strain locations

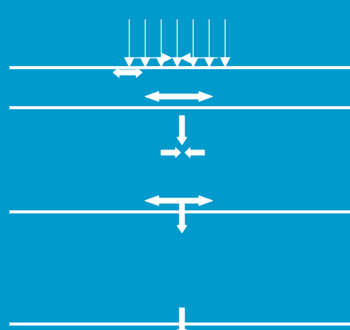
Load 50 kN, ϕ = 300 mm

Asphalt

Unbound or Bound Base

Subbase

Subgrade



1. **Tensile strain at pavement surface.**
2. **Tensile strain at bottom asphalt.**
3. **Compressive stresses in top unbound base.**
4. **Tensile strain at bottom bound base**
5. **Vertical compressive strain at top subbase.**
6. **Vertical compressive strain at top subgrade.**

Commonly used mechanistic approach

- Use linear elastic multi layer system, so characterise materials with E and μ.
- Assume full adhesion between the layers.
- Use static load(s).
- Calculate stresses and strains at critical locations.
- Use transfer functions (fatigue relations) to calculate pavement life.
- Drawbacks: materials are NOT linear elastic. They are non linear elasto-visco-plastic and often rate and temperature dependent.

Required transfer functions

- Fatigue and crack resistance of asphalt concrete.
- Resistance to permanent deformation of asphalt concrete.
- Resistance to permanent deformation of unbound base materials.
- Resistance to permanent deformation of subgrade materials.
- Fatigue and crack resistance of bound base and subbase materials.

Fatigue of asphalt mixtures

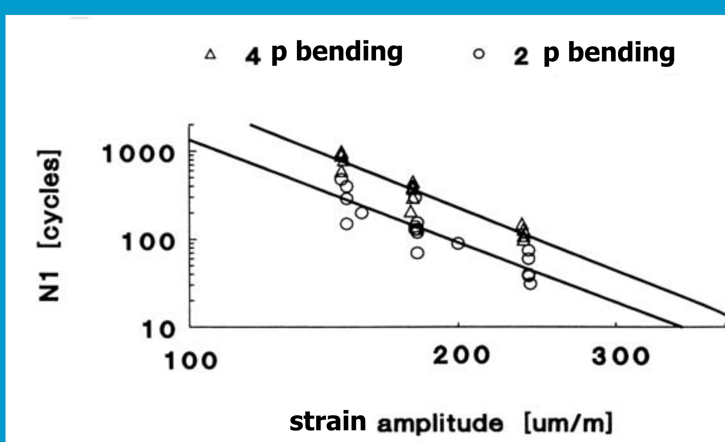
indirect tension

4 p bending

2 p bending

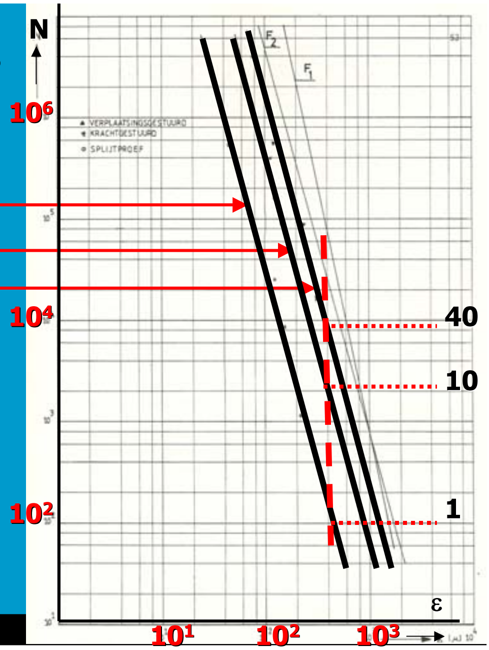
direct tension

Fatigue resistance is a specimen, not a material property

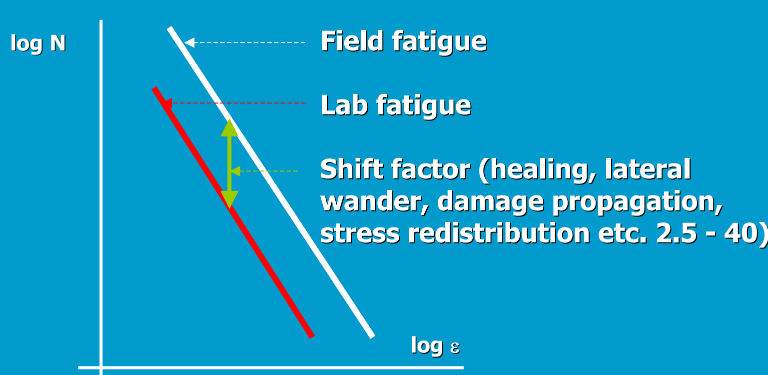


Fatigue resistance is a specimen, not a material property

indirect tension load contr.
4 p bending load contr.
4 p bending displ contr.



Substantial corrections needed to match lab result with practice



Fatigue performance

- Field fatigue ≠ lab. fatigue
- Nevertheless we need lab. fatigue tests to get an idea about fatigue performance.
- Fatigue testing is time consuming and costly.
- Therefore fatigue is not suited as a performance related specification.
- Can we estimate fatigue performance of mixtures?

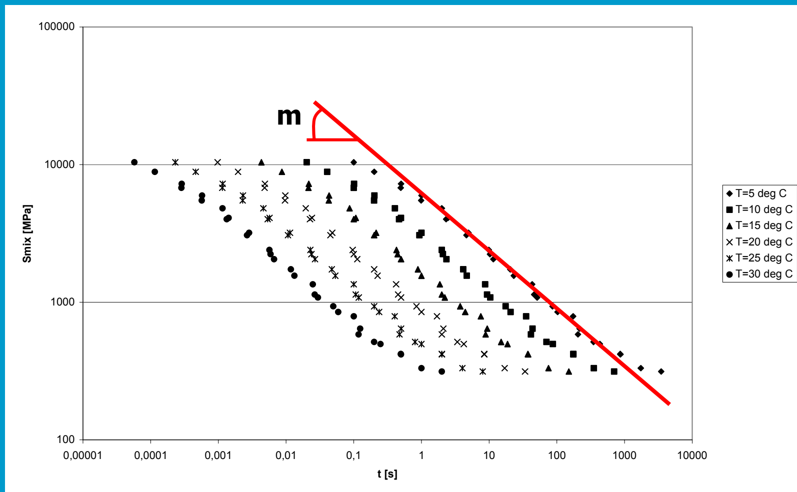
Theory on crack growth in visco-elastic media is of help

- Crack growth law: $dc/dN = AK^n$
- $A = f(S_{mix}, m, \sigma_t, \Gamma)$
- $n = f(2/m$ and void content$)$
- Fatigue law: $N = k_1 (\varepsilon)^{-n}$
- $k_1 = f(A, m,$ specimen geometry$)$

=

- m is slope of master curve !

Mixture stiffness in relation to temperature and loading frequency



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Slope of the master curve m is extremely important parameter

- Gives information about fatigue behaviour
- Gives information about resistance to permanent deformation.
- The lower m and the higher S_{mix} the better the resistance to permanent deformation!
- Stiffness measurements are very important !

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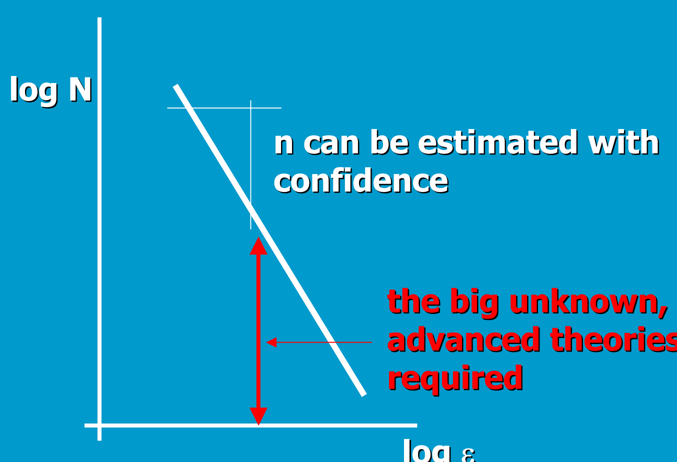
Stiffness measurements using repeated load itt

From the lab to the field

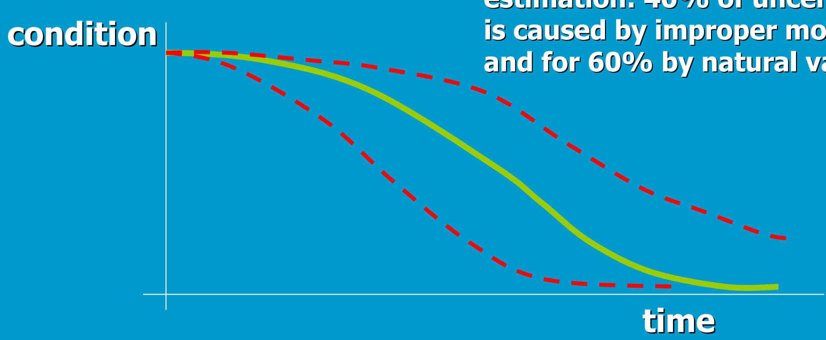


Challenge

- Fatigue analysis is still highly empirical.
- k_1 is the big unknown.
- How do we deal with damage propagation and redistribution of stresses.
- Improved models are needed in order to be able to analyse effects of new generation loads, benefits of better materials etc.

Performance predictions have a high degree of uncertainty

estimation: 40% of uncertainty is caused by improper modelling and for 60% by natural variation.

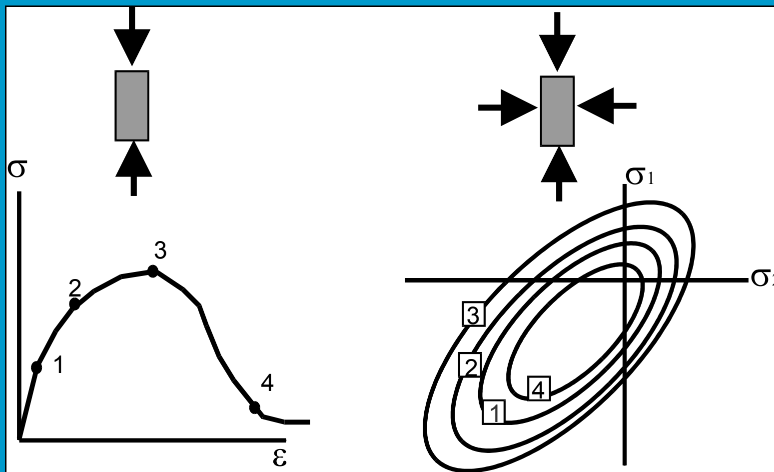


Uncertainties

- Uncertainties in predictions can be balanced by experience.
- We have enough knowledge to make succesful thickness designs for traditional structures using known materials.
- But what if traditional structures and materials cannot do the job ?
- What if risks have to be quantified for contractual purposes ?
- Better modelling is a must !

Elasto-visco-plastic models describing behaviour under 3D stress conditions are the future

Principle of the model



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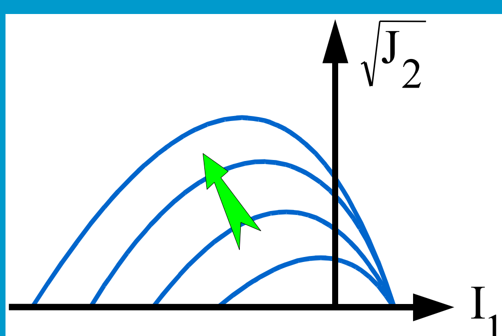
Principle of the model



Curves indicate stress conditions where change in material condition occurs, e.g. end of elasticity etc.

$$f = \frac{J_2}{p_a^2} - \frac{\left[-\alpha \left(\frac{(I_1 - R)}{p_a^2} \right)^n + \gamma \left(\frac{(I_1 - R)}{p_a^2} \right)^2 \right]}{\sqrt{1 - \beta \cos(3\theta)}} = 0$$

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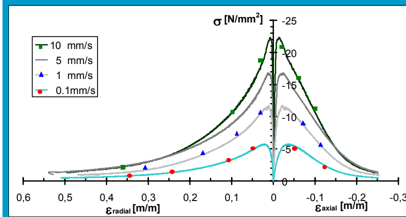
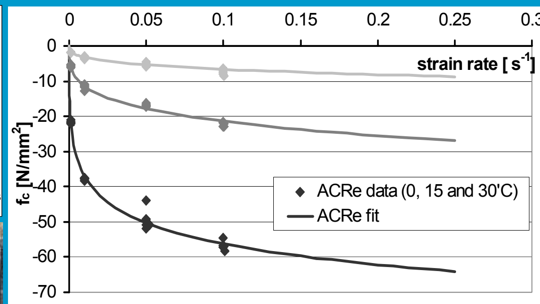
Compression test





$$f_c = -108\left(1-\frac{1}{1+\left[\dot{\varepsilon} * e^{\left(-86.3+\frac{24260}{T}\right)}\right]^{0.32}}\right)$$

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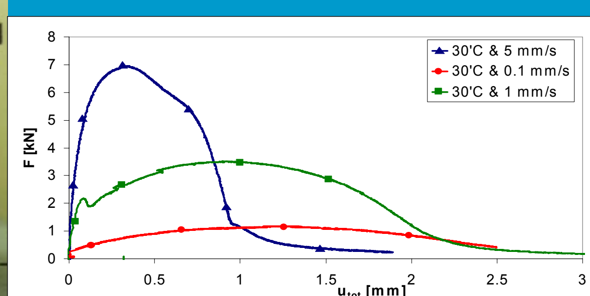
Tension test



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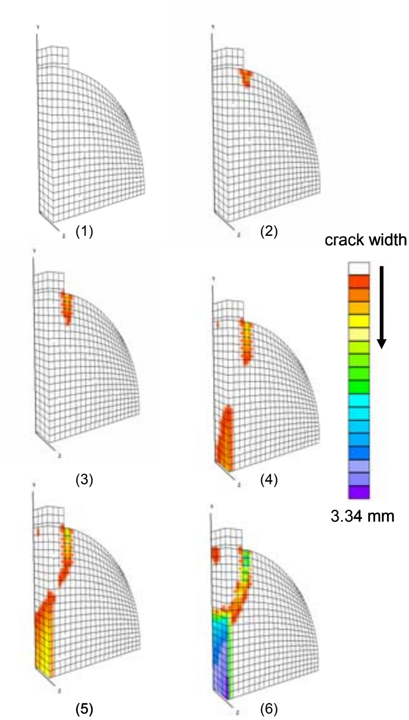
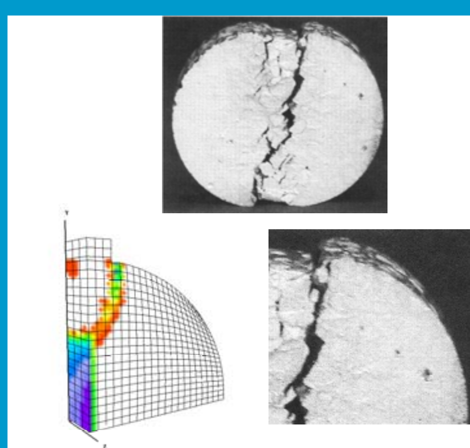
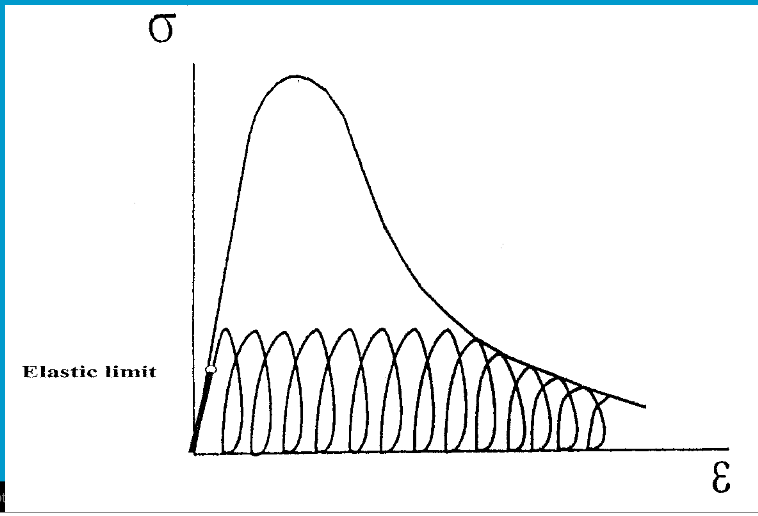


Simulation of an indirect tension test

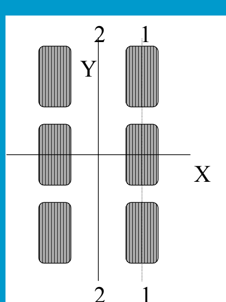
Simulation of failure in an indirect tension test



Principle of damage analysis



Simulation passage B 777

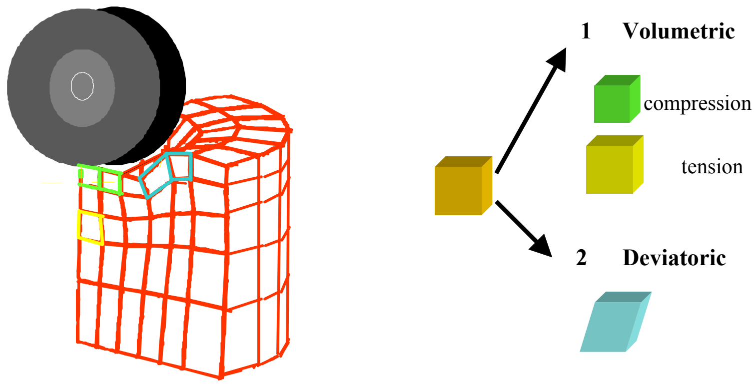


200 mm Asphalt
E = 3000 MPa

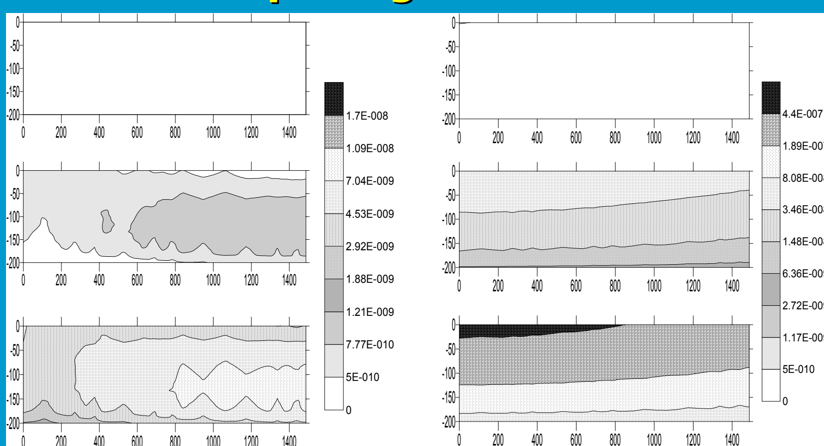
400 mm Base
E = 300 MPa

Subgrade
E = 100 MPa

Volumetric and deviatoric damage



Simulation passage B 777



Devatoric damage | Total damage

Damage @ sec. 2-2 after 1, 500 and 4000 cycles

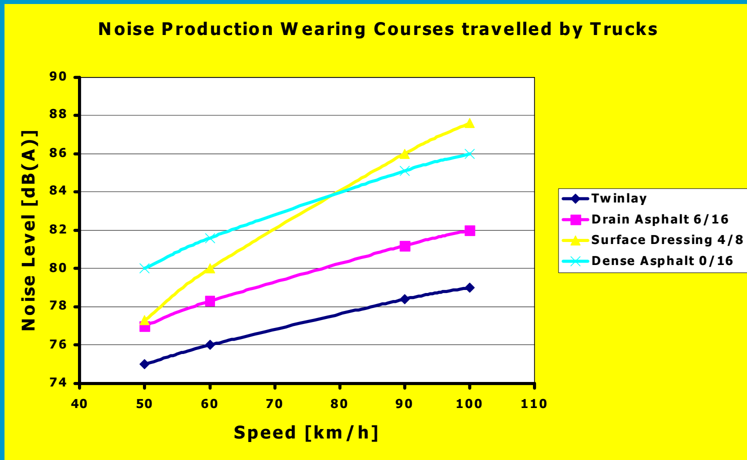
Exiting developments in surface materials

- Noise reduction
- Intelligent pavement
- Energy production
- Rapid repair and maintenance

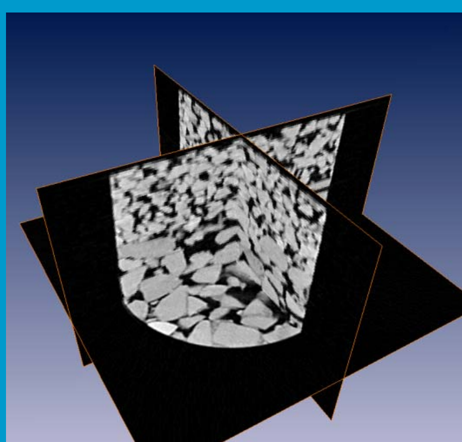
Wearing courses

- Modelling on macro scale not good enough.
- Meso scale (grain size) and Micro scale (molecular level) are becoming important.
- Problem layers:
  - porous asphalt concrete
  - thin noise reducing wearing courses

Porous asphalt concrete (PAC) for noise reduction



Double layer porous asphalt concrete



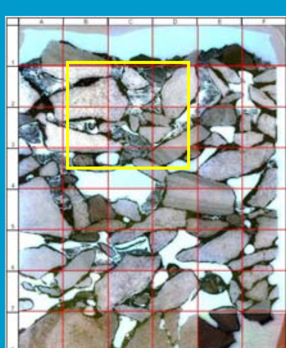
Ravelling is the main problem of PAC

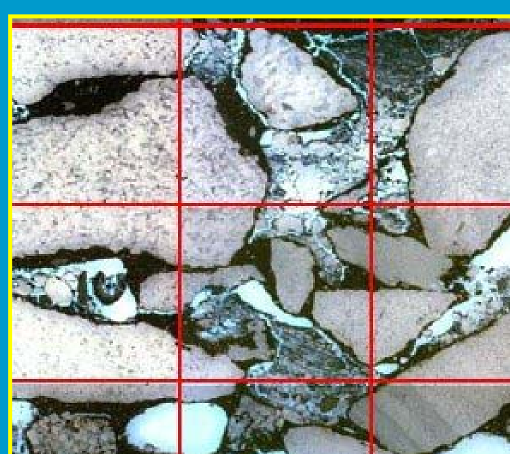
Ravelling

Model to predict ravelling

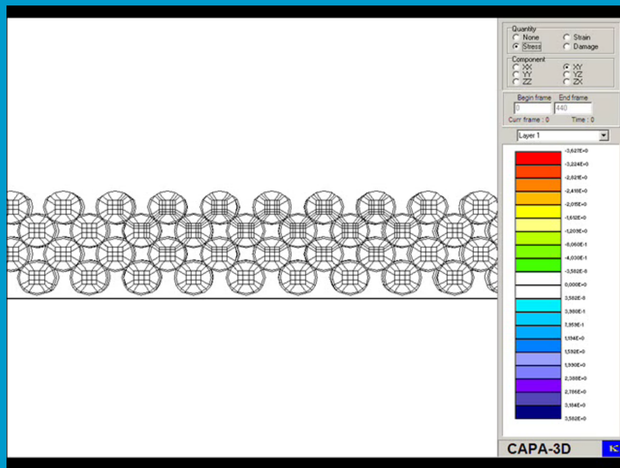
- Discrete FEM.
- Characterisation of bituminous mortar (stiffness and fatigue).
- Characterisation of adhesion (fatigue).
- Effects of Temperature, Oxygen, UV radiation and moisture should be taken into account.
- Validation with test track experiment.

Transform skeleton into FE mesh





Modelling of PAC



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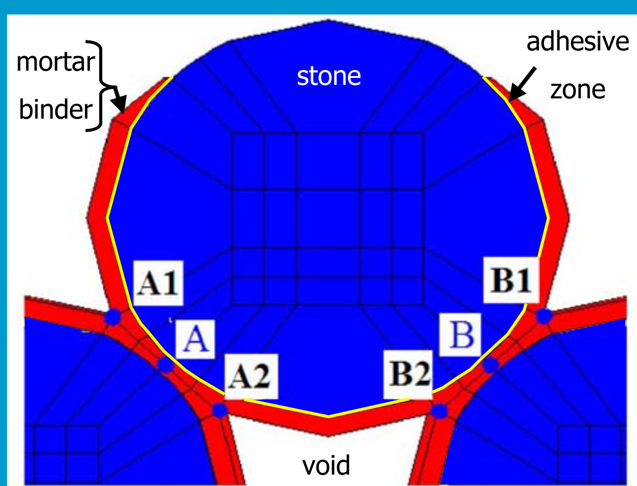
Detail PAC model



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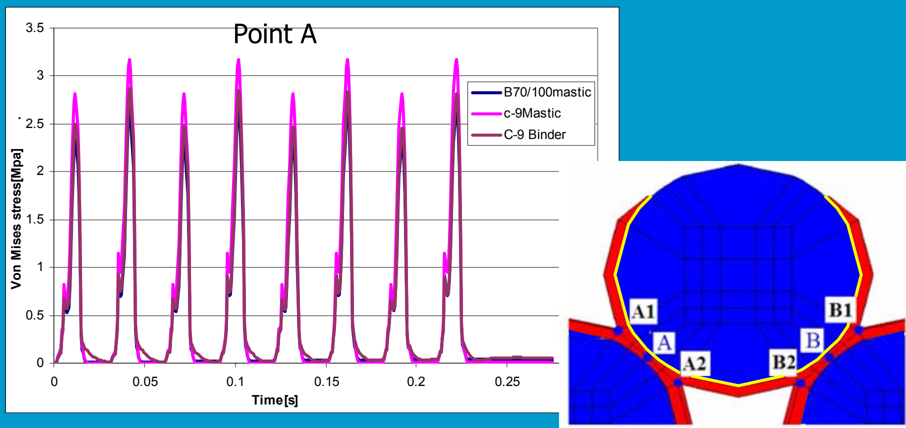
Higher stress due to stiffer mortar



Fatigue testing binder using DSR

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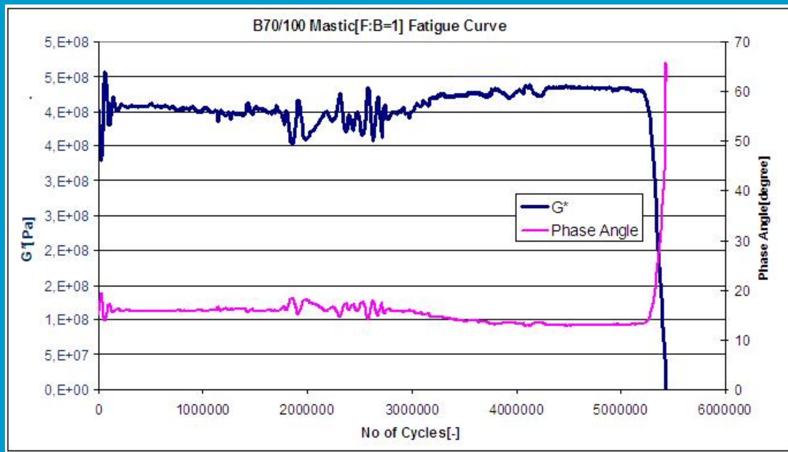
Fatigue of bituminous mortar 44 Hz, 20 °C, f/b = 1



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Tension test on interface aggregate – bituminous mortar

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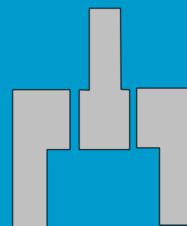
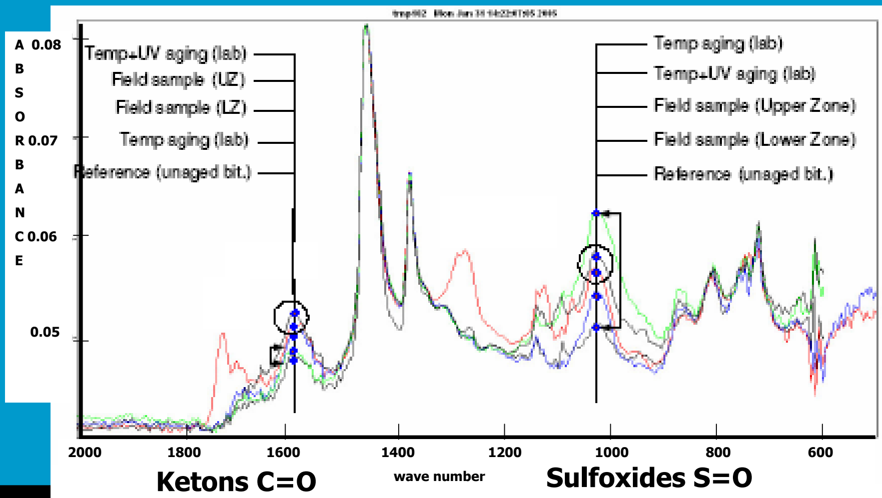
Shear testing on interface aggregate – bituminous mortar



Weatherometer for aging of bituminous materials

Change in composition due to aging



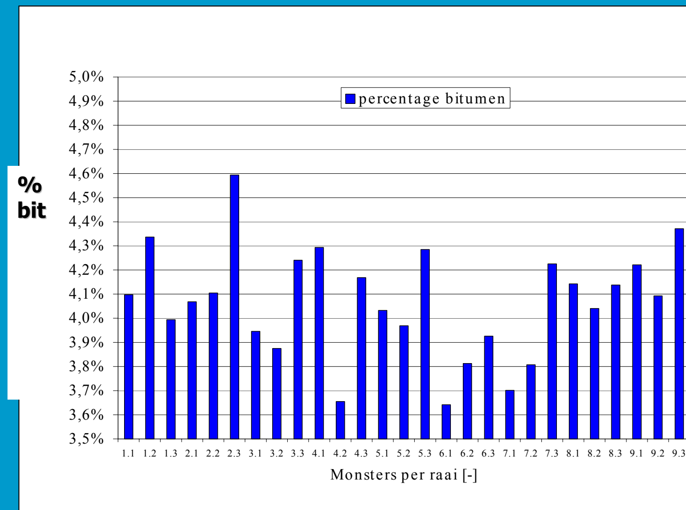
Test track experiment for validation

Quality of production and laying has enormous influence on perkormance

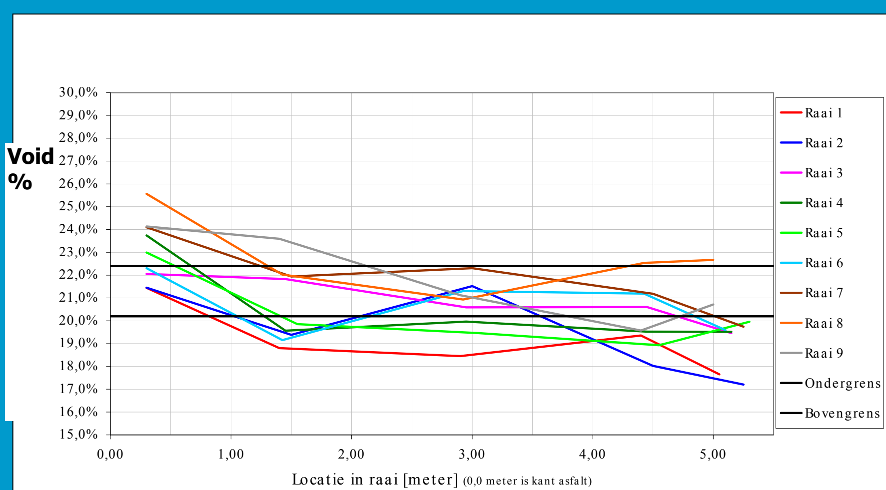
September 21, 2006

Influence of laying on pavement performance

Variation of bitumen content in PA

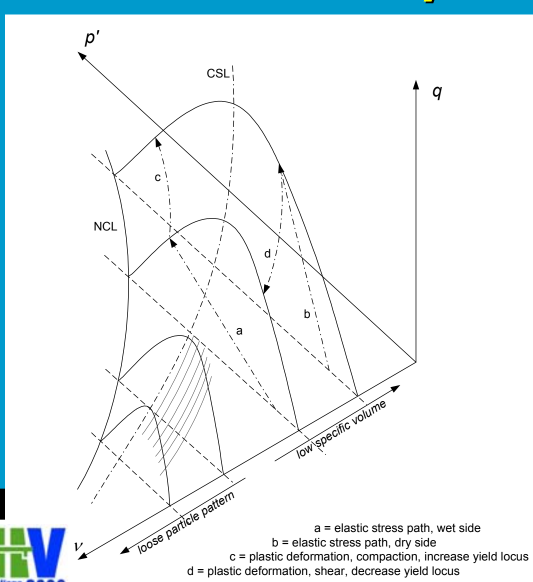


Variation in void content of PA



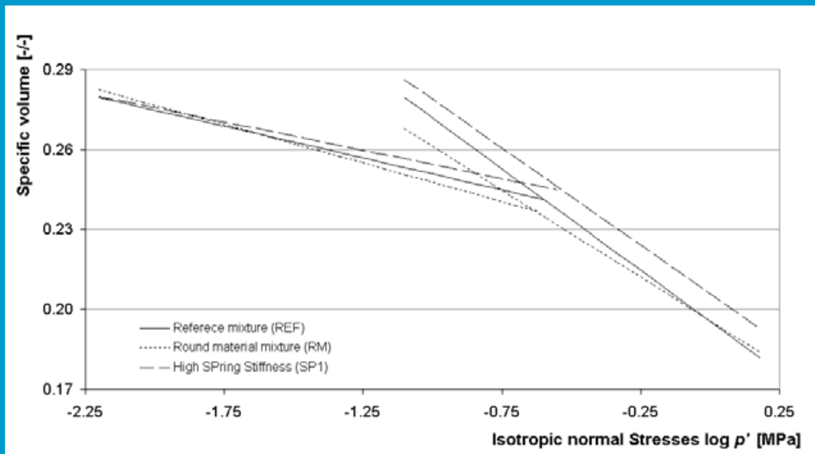
Influence of compaction on pavement performance

Modelling compaction by means of critical state theory

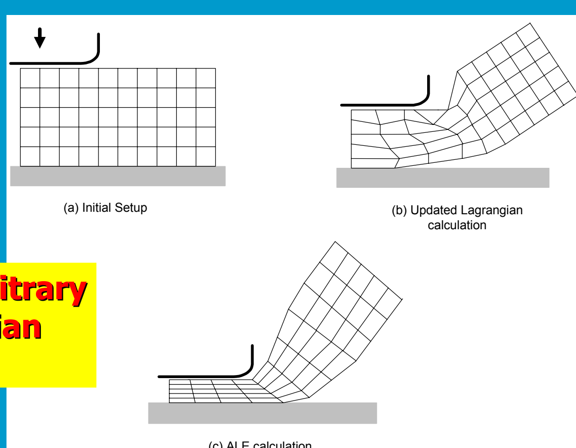


Modified Hveem stabilometer

Compaction characteristics

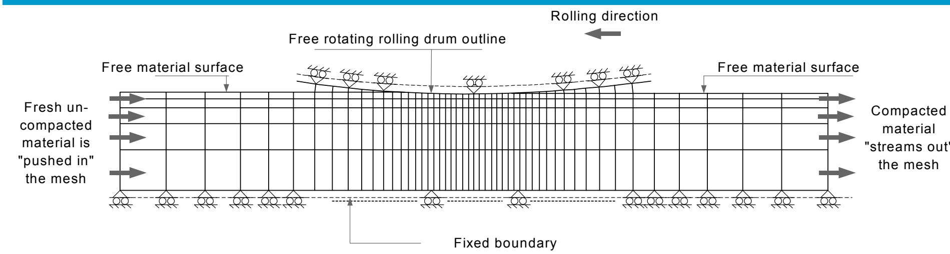


Due to large deformations, special fem should be used

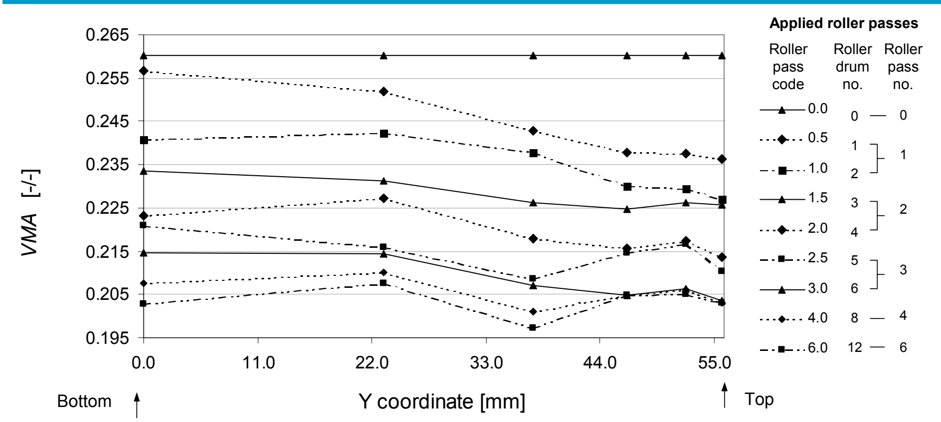


ALE = arbitrary Langrangian Eulerian

Finite element mesh for roller simulations



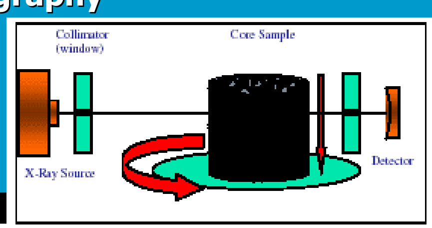
Decrease of VMA as a function of the nr of roller passes



Laboratory measurement techniques will change with changing emphasis from macro to meso and micro level

Laboratory tests for today and tomorrow

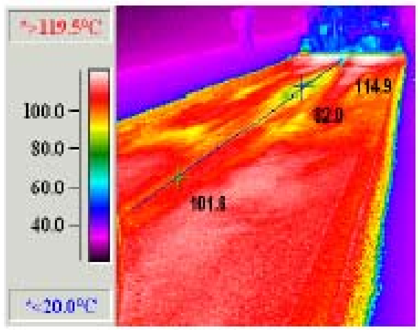
- Universal sorption device
- Wilhelmy plate
- Dynamic shear rheometer
- Tension and compression tests
- Sieve analysis
- X-ray tomography



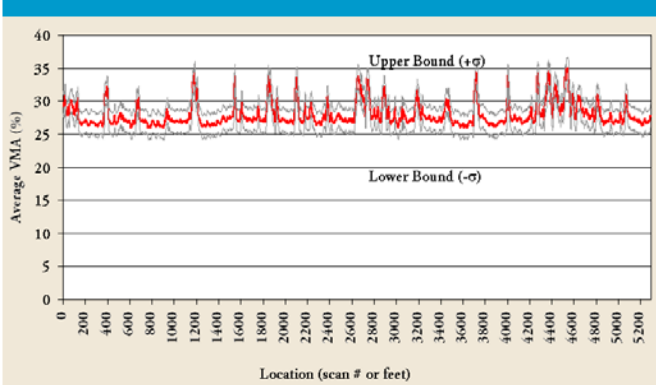
Great need for high speed non contact evaluation techniques providing detailed insight on quality of pavement

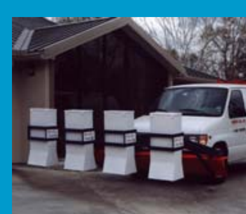
SASW (spectral analysis of surface waves)

Infra-red for detection potential weak spots

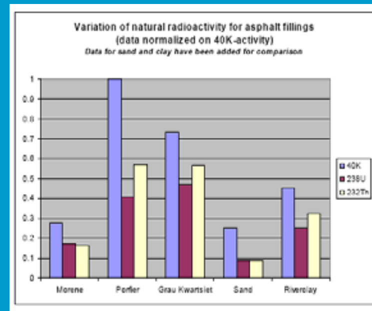


Radar for assessment bitumen content, VMA, h etc.

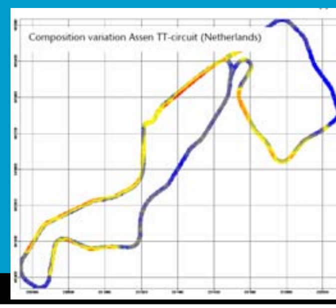


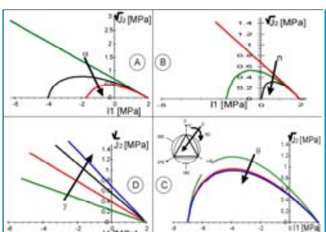


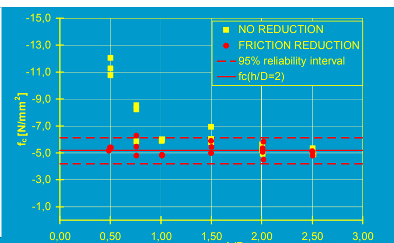
Medusa

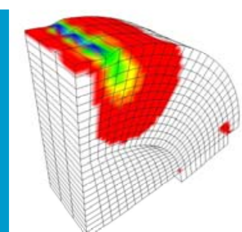


Measuring natural background radio-activity radiation allows assessment aggregate type









THANK YOU FOR YOUR ATTENTION