Laboratoire Central des Ponts et Chaussées

Use of accelerated pavement tests (APT) for development and evaluation of performance models

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Introduction

LCPC activities on pavement design and modelling :

- Contribution to development and evaluation of French pavement design method
- **Development of models for**

  Low trafic pavements : Non linear behaviour of soils and unbound granular materials, prediction of rutting

  Bituminous pavements : visco-elastic behaviour, fatigue, visco-plastic behaviour (rutting)

  Rigid pavements : study and modelling of reflective cracking

Introduction

Development of models is in close relation with accelerated pavement testing activities (APT)

LCPC APT equipments :

-Fatigue test track – large circular test track (pavement length 120 m)

-“FABAC” Machines : mobile machines – simulation of full wheel loading on small length (2m)

LCPC Fatigue test track

Circular outdoor facility, built in 1984

Track width up to 6 m - length 122 m (radius 19.5m)

Radius of rotation : adjustable from 15 m to 20 m

Maximum speed 13.5 rpm (100 km/h at radius 19.5 m)

Transverse wandering of real traffic can be reproduced

Various types of loads from 8-ton single-axle to 30-ton multiple-axle (only a half-axle per arm)

3 test sites - one including a water table control system (pumping station)

Experiments performed in partnership with Road authorities or private companies

APT versus Performance Models

Advantages

- Well controlled pavement construction and experimentation conditions (load, traffic, temperature,...)
- Internal instrumentation and detailed monitoring of pavements
- Response in relatively short time owing to the acceleration of traffic
- Possibility to make comparative tests

Limits

- Not representative of real traffic & climatic variations
- Missing the ageing of materials
- AT LCPC : difficulty to pursue long term “research programs” due to cost and compatibility with “external demand” from private partners

Examples of evaluation of models using APT

- Experiment for the evaluation of fatigue behaviour
- Development and evaluation of a model for the prediction of rutting of unbound pavement layers SAMARIS project
- ALT experiment on airfield pavements

Experiment
on fatigue behaviour

Objectives of the experiments

- Comparison of fatigue behaviour of different bituminous materials, with different binders
  - in the laboratory, using different fatigue tests
  - in pavements
- Evaluation of the French fatigue design approach for bituminous pavements

3 full scale experiments on the LCPC test track

Third “fatigue” experiment

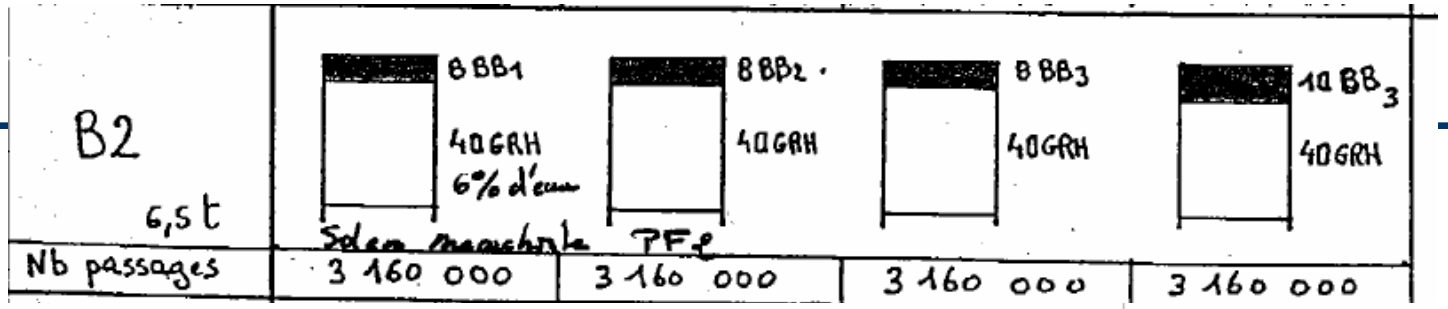
4 structures : 8 or 10 cm thick bituminous layer
40 cm thick granular base
clayey subgrade : E = 30 to 40 MPa

3 bituminous materials:

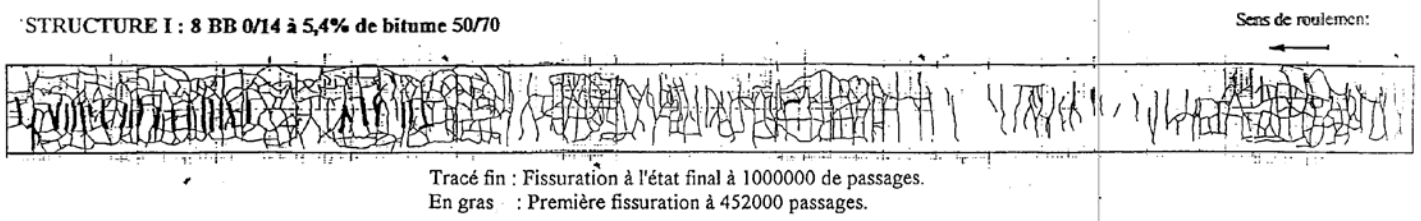
BB_B : Bituminous concrete with 50/70 grade bitumen (reference)
BB_S : Bituminous concrete with 50/70 polymer modified bitumen
EME : high modulus bituminous mix, with 10/20 grade bitumen
2 structures – 8 and 10 cm thick

Loading conditions :

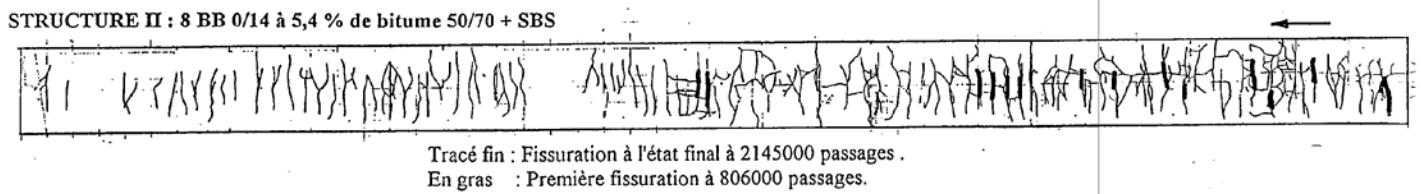
65 kN dual wheel load, 72 km/h
3.2 million loads applied



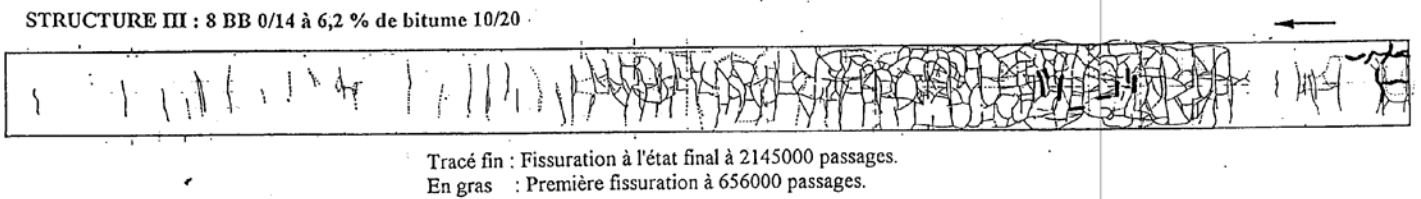
S1 (BB_B)



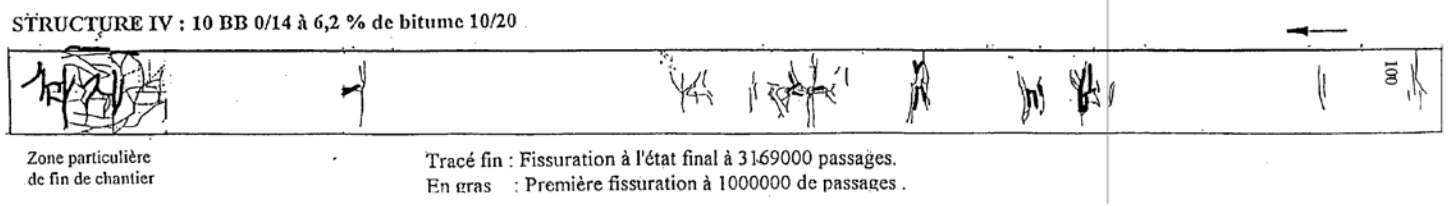
S2 (BBs)



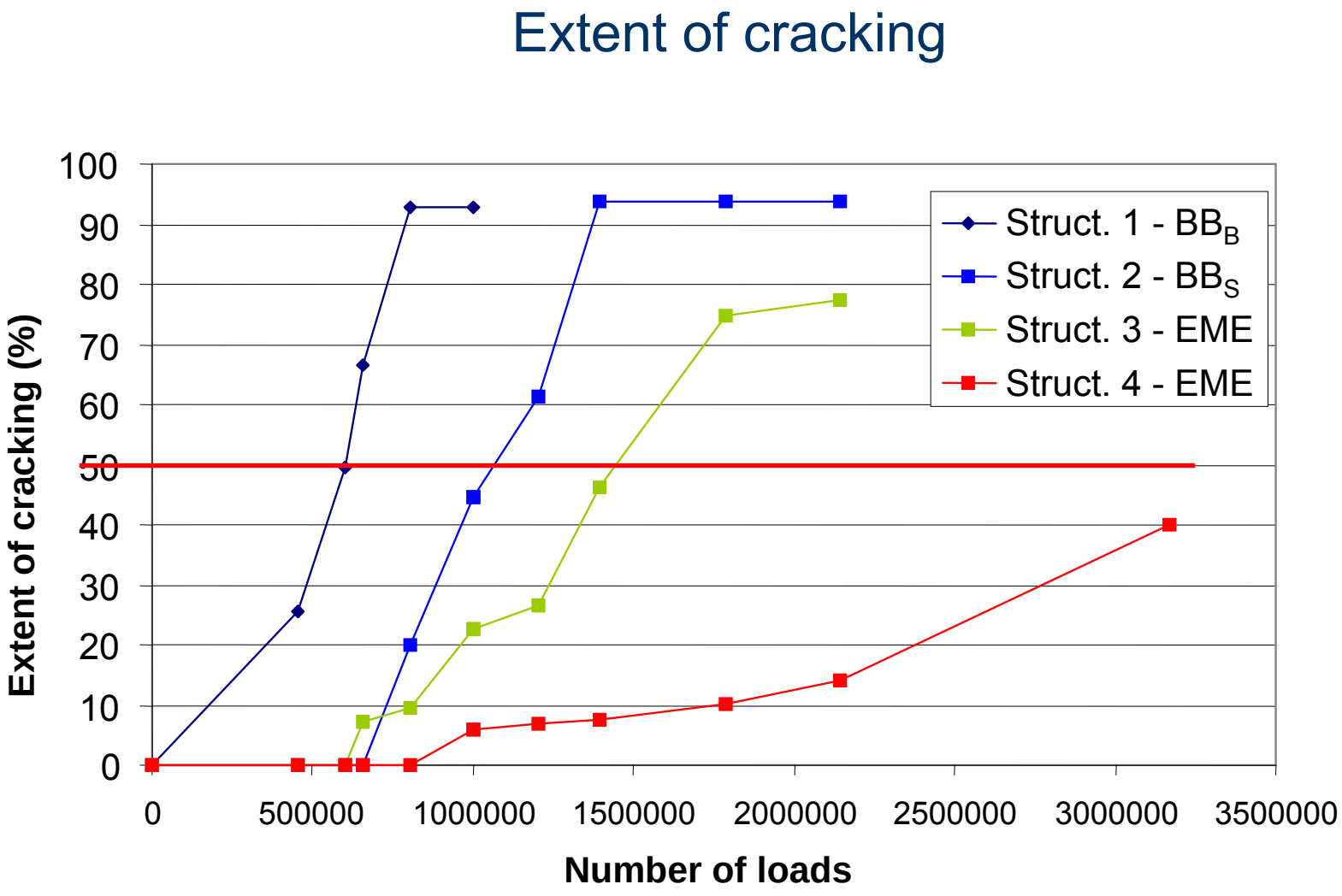
S3 (EME) 8 cm



S4 (EME) 10 cm



In situ performance of the 4 structures



Laboratory fatigue tests

5 different test procedures

Procedure	θ (°C)	f (Hz)	Type of loading
Controlled displacement test			
1	10	25	ε 3 levels of 8 samples
3	20	40	ε 3 levels of 8 samples or 12 samples
5	20	40	ε 1:10 3 levels of 8 samples or 6 samples
Controlled force test			
6	20	40	σ 3 levels of 8 samples or 12 samples
10	20	40	σ 1:10 3 levels of 8 samples or 6 samples

Fatigue design method

Criterion on maximum tensile strain :

$$\varepsilon_{tad} = \varepsilon_6(\theta, f) \cdot \left(NE/10^6\right)^b \cdot k$$

$\varepsilon_6(\theta,f)$: Strain leading to failure for 10^6 cycles, depending on temperature θ and frequecy f

NE : number of standard axle loads

b : parameter

k : various coefficients of correction, taking into account the risk of failure, the bearing capacity of the soil, the difference between the model and observed pavement behaviour

Predicted pavement life:

$$NE = 10^6 \cdot \left(\frac{\varepsilon_t}{k \cdot \varepsilon_6(\theta, f)}\right)^{1/b}$$

Results of laboratory fatigue tests

Values of failure strain ε_6 or failure stress σ_6

Fatigue test procedure	BB_B	BB_s	EME
3 – strain control Continuous – ε_6 **(μstrain)**	147	237	133
5 – strain control, with rest periods - ε_6 **(μstrain)**	227	292	187
6 – stress control, continuous - σ_6 **(MPa)**	0.62	0.82	
10 – stress control, with rest periods - σ_6 **(MPa)**	1.18	1.41	2.3

Improved fatigue resistance of the polymer modified bitumen material

Improved fatigue life with rest periods

Different relative behaviour of the EME in stress or strain controlled tests

Comparison of design predictions and field performance

Calculation of correction coefficient k

(k = 1 ⟶ exact prediction of pavement life)

$$NE = 10^6 \cdot \left(\frac{\varepsilon_t}{k \cdot \varepsilon_6(\theta, f)} \right)^{1/b}$$

Fatigue test procedure	S1 BB_B	S2 BB_s	S3 EME 8 cm	S4 EME 10cm
3 – strain control Continuous	1,58	1,28	1,14	1,20
5 – strain control, with rest periods	**1,04**	**1,03**	0,8	0,8
6 – stress control, continuous	3,21	2,57		
10 – stress control, with rest periods	1,73	1,49	**1,10**	**1,08**

Conclusions – “fatigue experiment”

- Large differences in fatigue life predictions from different fatigue test procedures
- fatigue tests with rest periods seem more representative of in situ behaviour
- Correction between in situ and lab behaviour dependent on the type of material (BB/EME)
- For the high modulus material (EME), the stress controlled fatigue test seems more representative of in situ behaviour.

Model for the prediction of rutting in unbound pavement layers

Developped in European project SAMARIS (2002-2006)

SAMARIS

- **SAMARIS : European project of the 5th PCRD**
  - 2002-March 2006
  - Pavement and Structure Streams
- **Task 5** : Development of a performance-based approach for the prediction of rutting of unbound pavement materials
  - Selection of permanent deformation models for unbound granular materials
  - Development of a structural method of calculation of rutting of unbound pavement layers
  - Comparison with results of ALT full scale pavement experiment

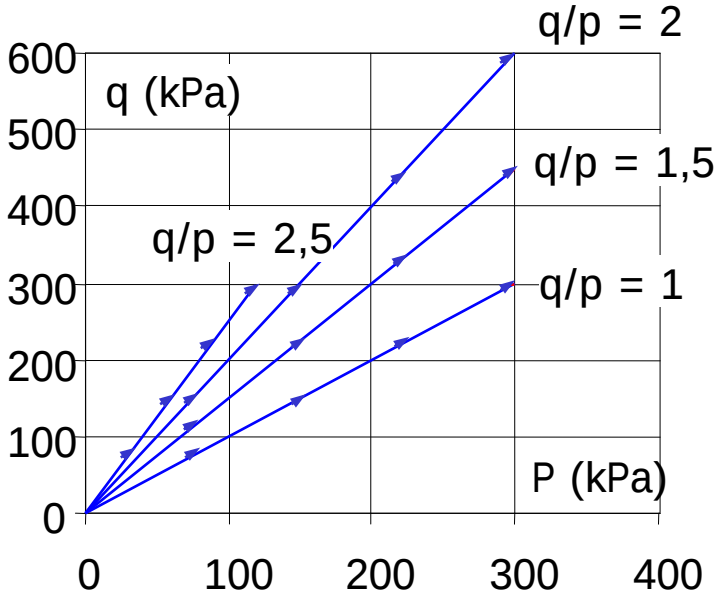
Laboratory study of permanent deformations

Test method : cyclic triaxial test

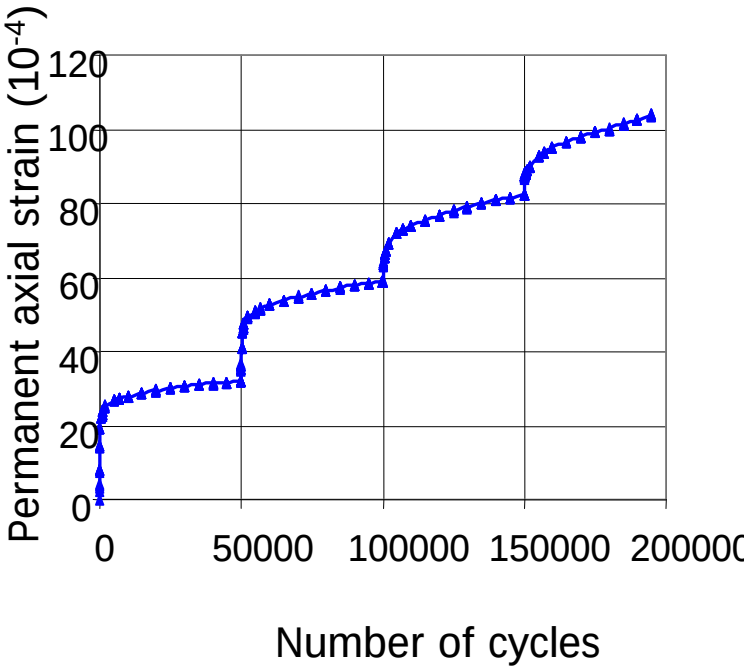
Advantages : realistic simulation of « stress paths » due to traffic loading

Test equipment

Test procedures



$p = (\sigma_1+2\sigma_3)/3 \quad q = (\sigma_1-\sigma_3)$



Selected permanent deformation models

2 modelling approaches :

- **Routine level** : utilizable for design

  Empirical permanent deformation model

$$\varepsilon^{p}_{1}(N) = f(N).g(p_{max}, q_{max})$$ Gidel (2001)

- **Advanced level** : for research or analysis

  Elasto-plastic model with isotropic and kinematic hardening

  Chazallon (2000)

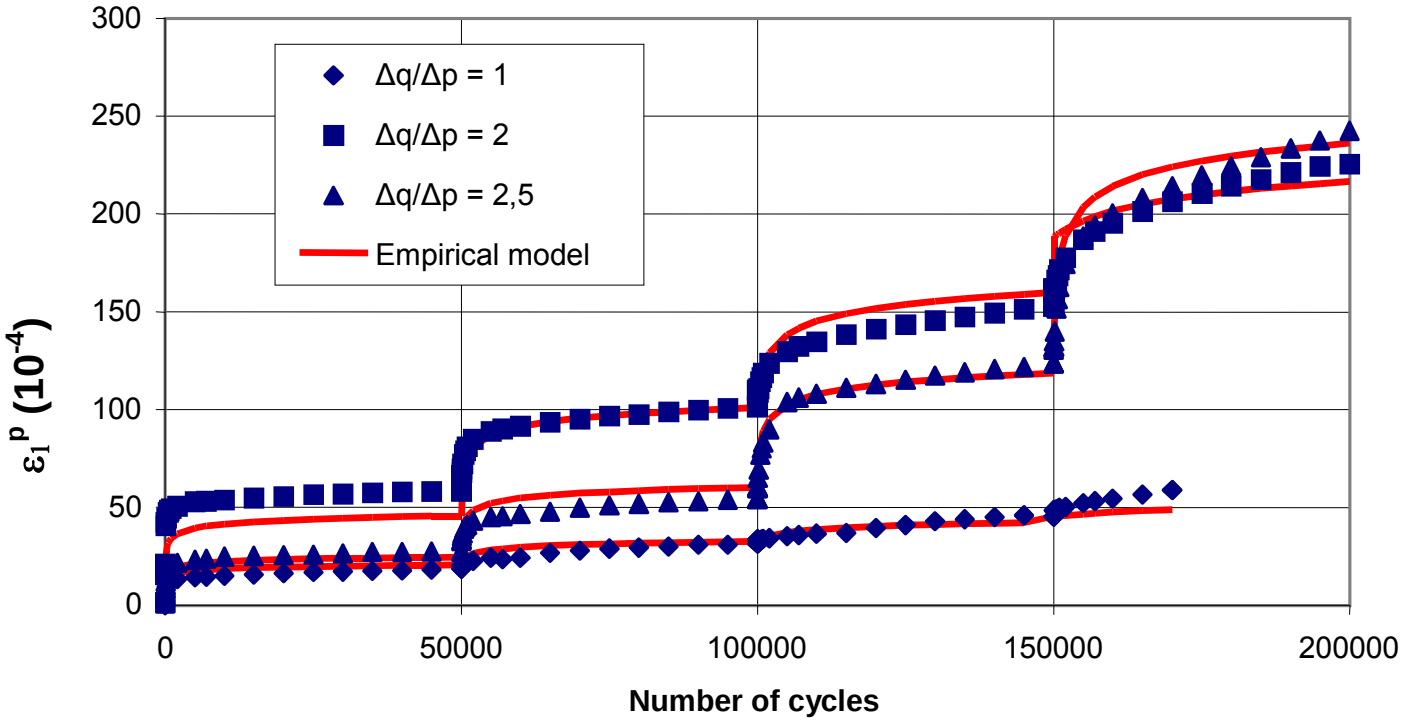
Example of calibration of empirical permanent deformation model

$$\varepsilon_1{}^p(N) = \varepsilon_1{}^p{}_0 . \left[1 - N^{-B}\right] . \left[\frac{L}{p_a}\right]^n . \frac{1}{\left(m + \frac{s}{p_{\max}} - \frac{q_{\max}}{p_{\max}}\right)}$$

Gidel (2001)

Maraichère UGM

Cyclic Triaxial Tests at w = 5 %



Structural modelling approach

Main hypothesis : For one cycle $\delta \underline{\underline{\varepsilon}}^p << \underline{\underline{\varepsilon}}^e$

→ Separate modelling of resilient behaviour and permanent deformations

Three steps :

1. 3D Finite Element calculation of the stress fields in the pavement structure using the resilient behaviour (non linear elastic, visco-elastic models)
2. Use of the stress fields and stress path to calculate permanent strains at the different points of the pavement in the vertical transversal plane
3. Calculation of the displacement field (rutting)

- FEM method (program ORNI) : 3D structural calculation.
- Simplified method: integration of ε_1^p in the vertical direction

Modelling of a full scale experiment

Experiment performed in 2003 on the LCPC fatigue test track

5 low traffic pavement structures (each 25 m long)

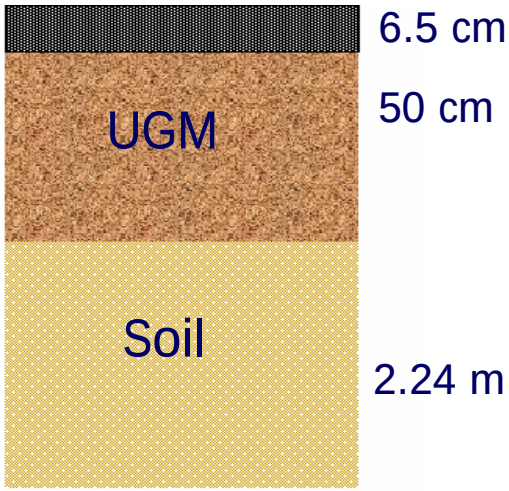
Full scale loading conditions : 65 kN dual wheel load, 72 km/h

1.5 million loads applied

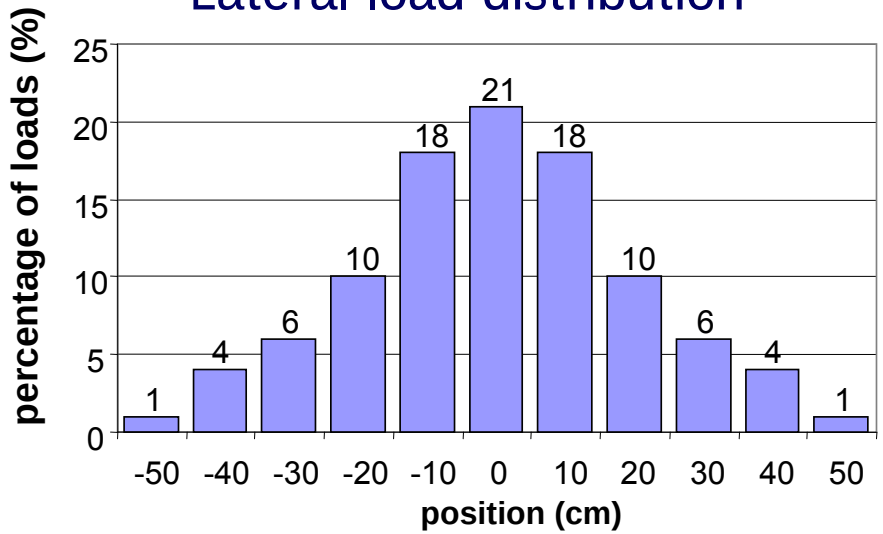
Low water table level (–2.6 m)

Modelling of structure 4

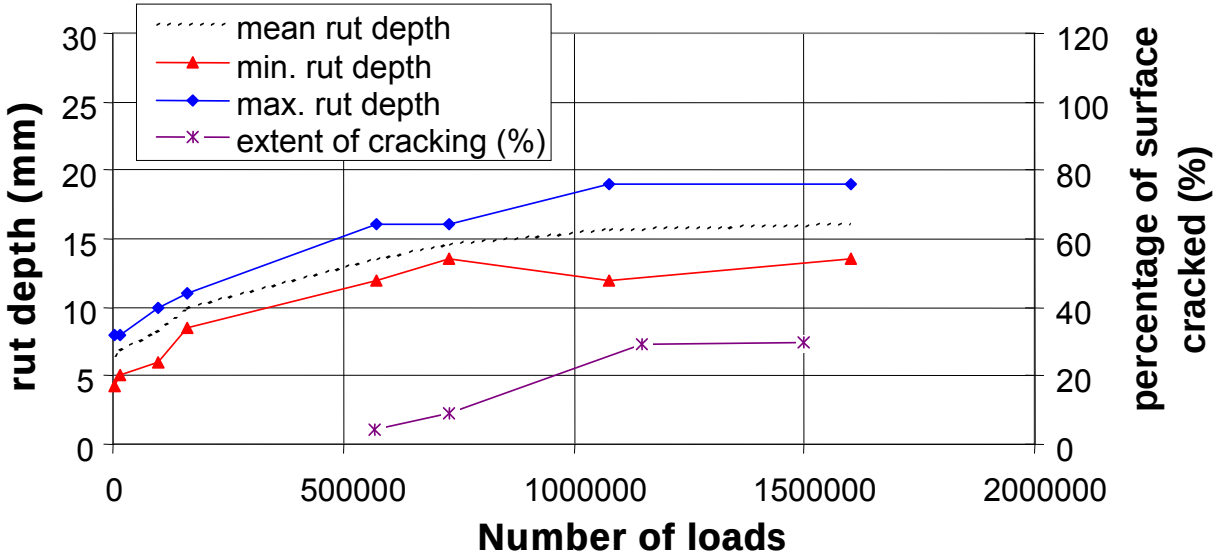
Structure 4



Lateral load distribution



Evolution of rutting and cracking

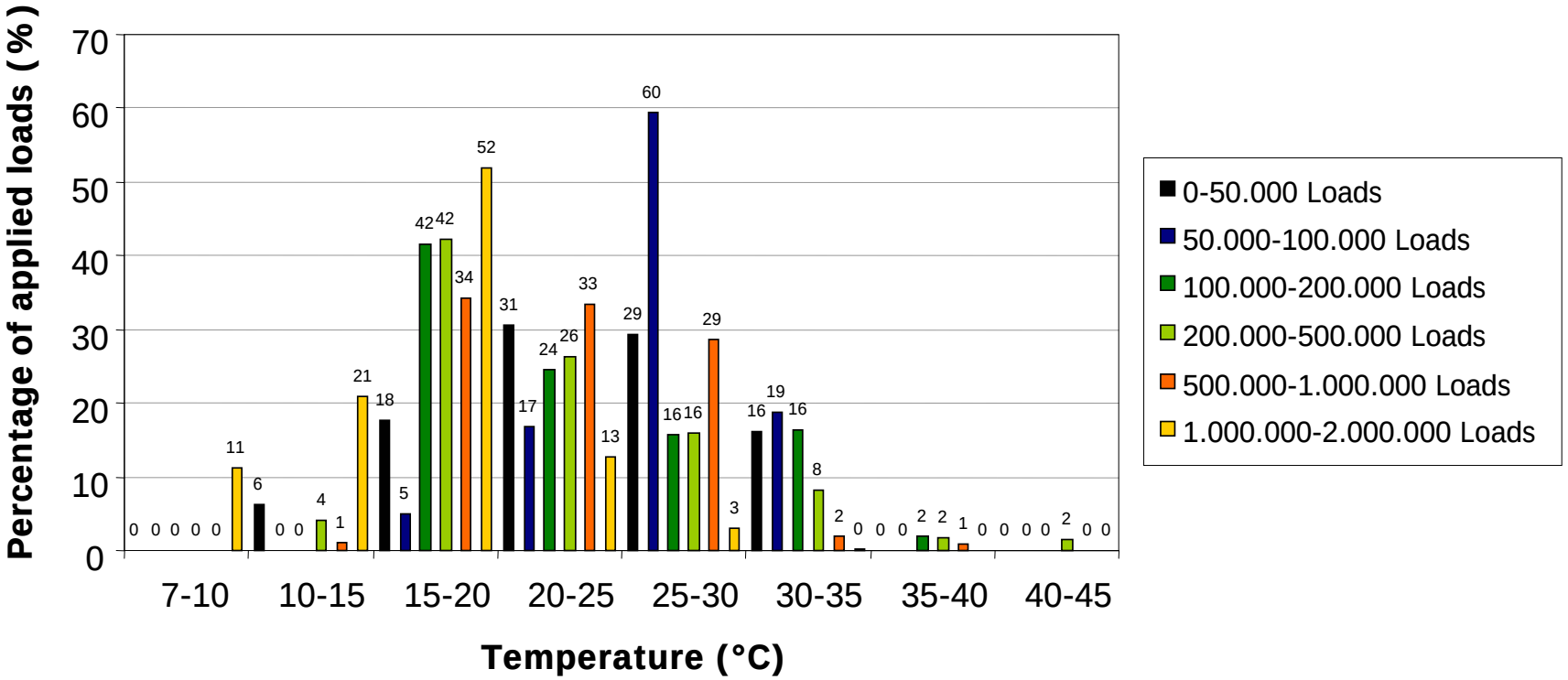


Modelling hypotheses

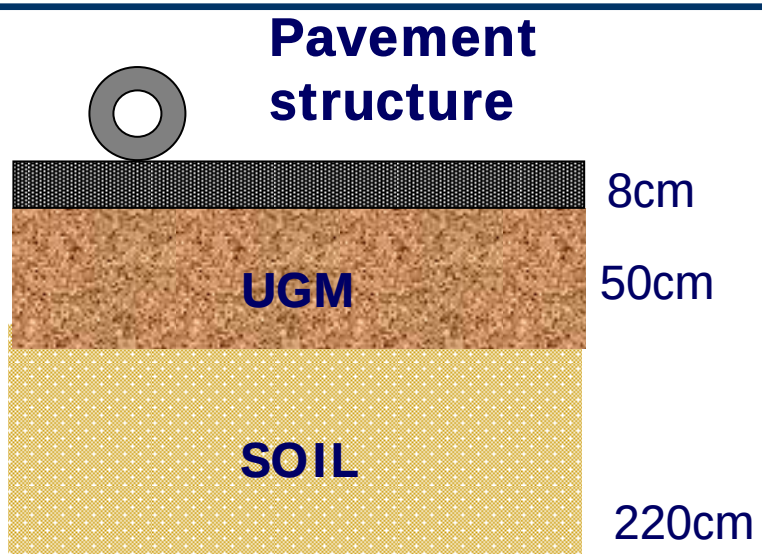
Modelling of rutting of UGM layer and subgrade (empirical model)

Simulation of load wandering and variations of temperature with traffic

Temperature distribution used for calculations



Examples of rut depth calculations



Loading : 65 kN load (single or dual wheel)

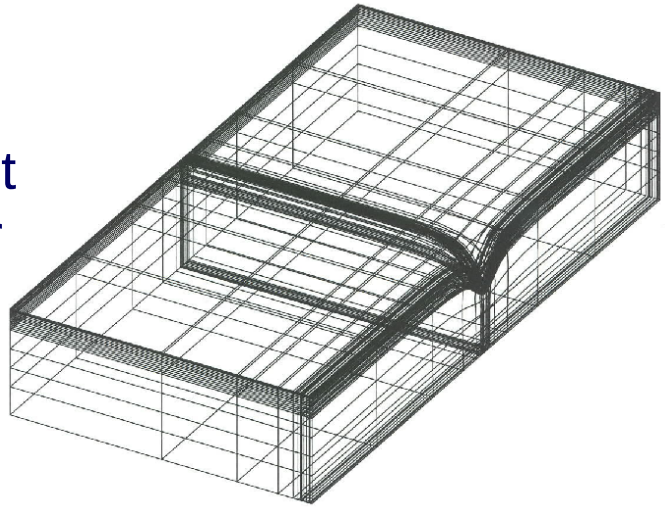
1.5 million loads - Constant temperature

- Bituminous concrete : linear elastic
- UGM : non linear elastic

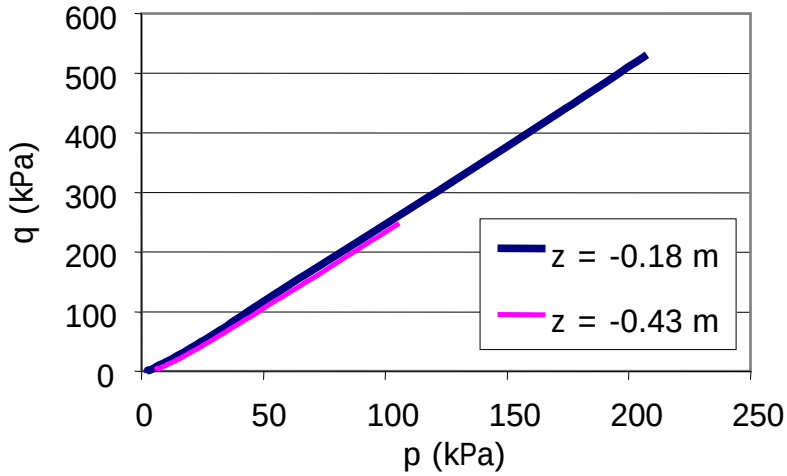
+ empirical permanent deformation model

- Soil : linear leastic E = 100 MPa, n = 0,35

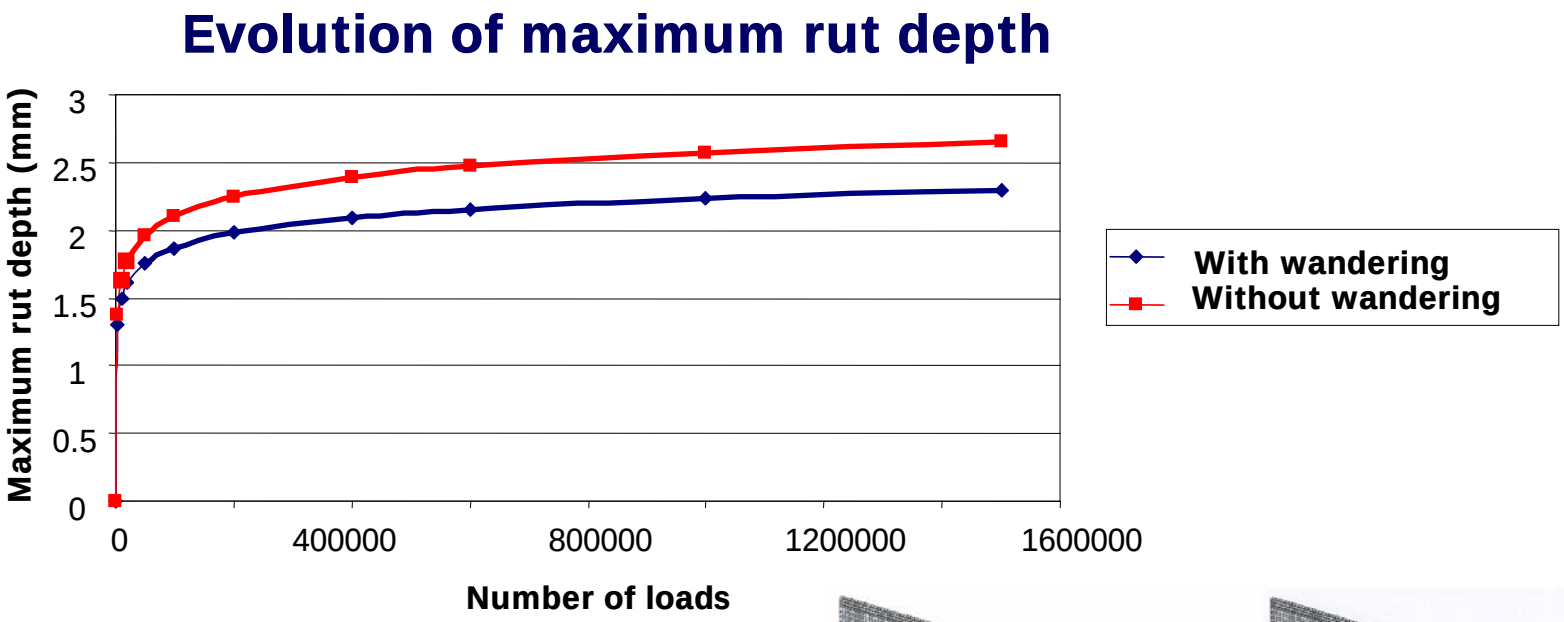
3D mesh modelling of resilient behaviour



Stress paths in UGM layer



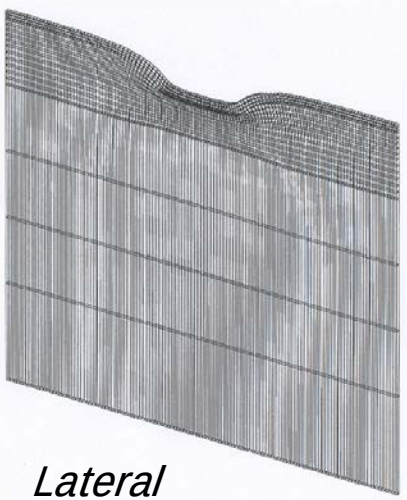
Calculation : influence of lateral load wandering



Rut profiles after 1.5 million loads (single wheel) :

⇨ Low influence of lateral wandering

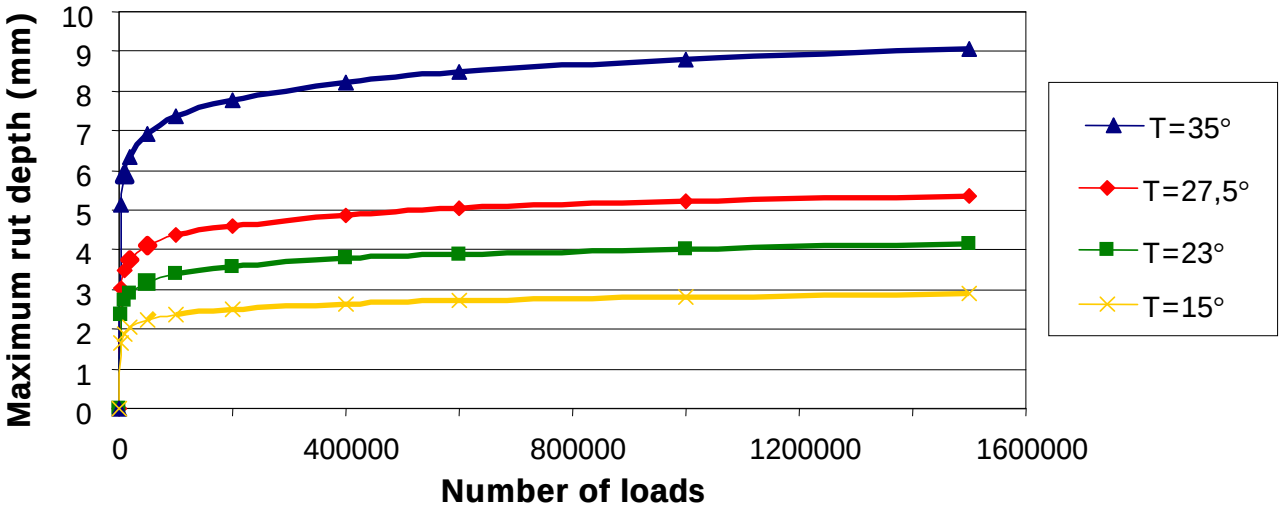
No lateral wandering



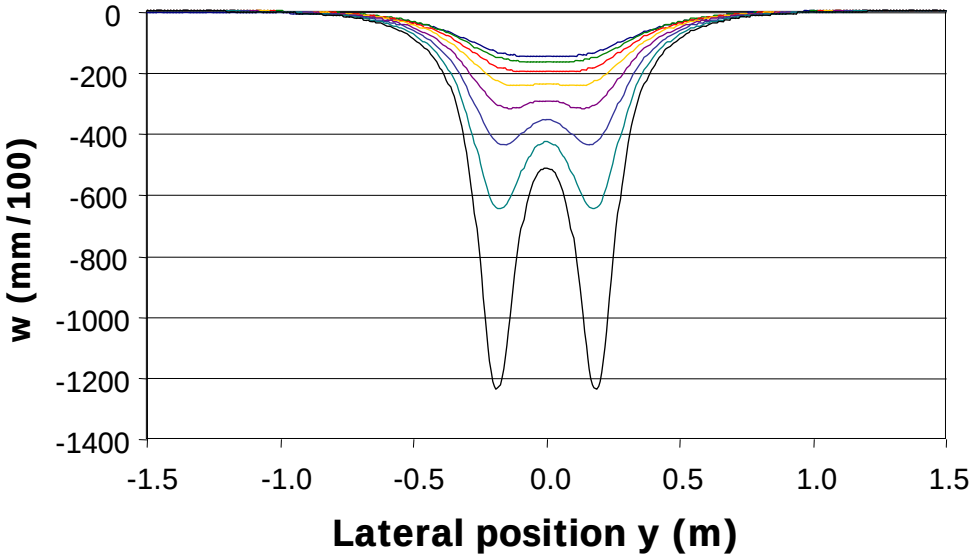
Lateral wandering (11 positions)

Influence of wearing course temperature

Evolution of maximum rut depth for different temperatures :



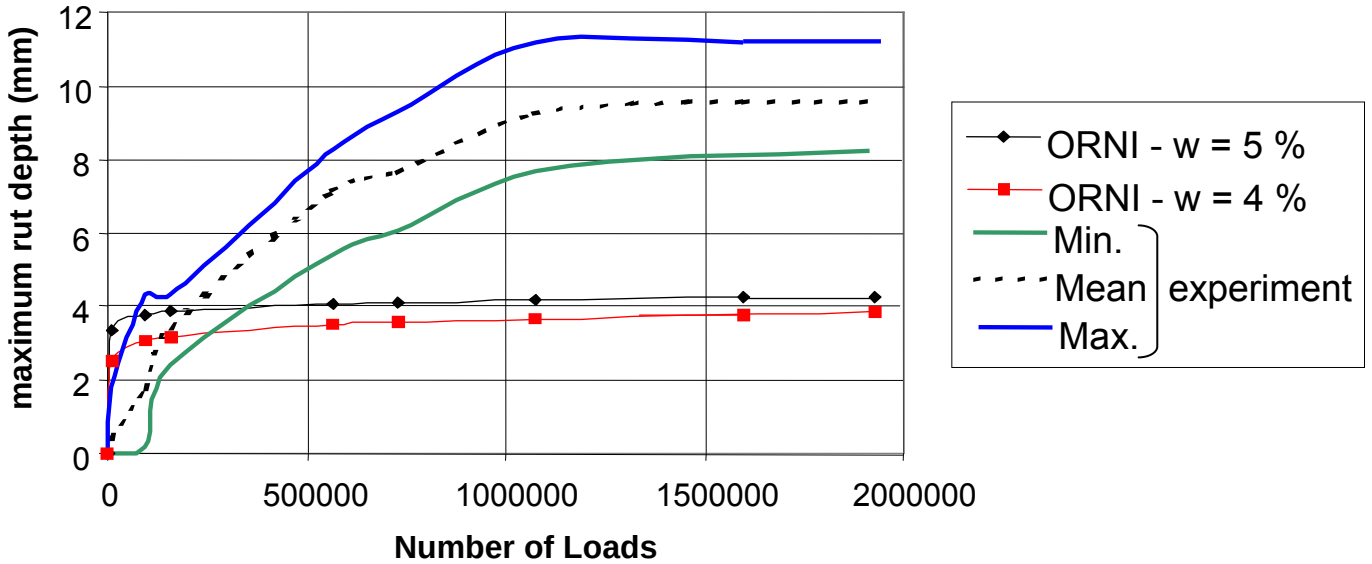
Rut profiles for different Temperatures (8.5 to 42.5°C)

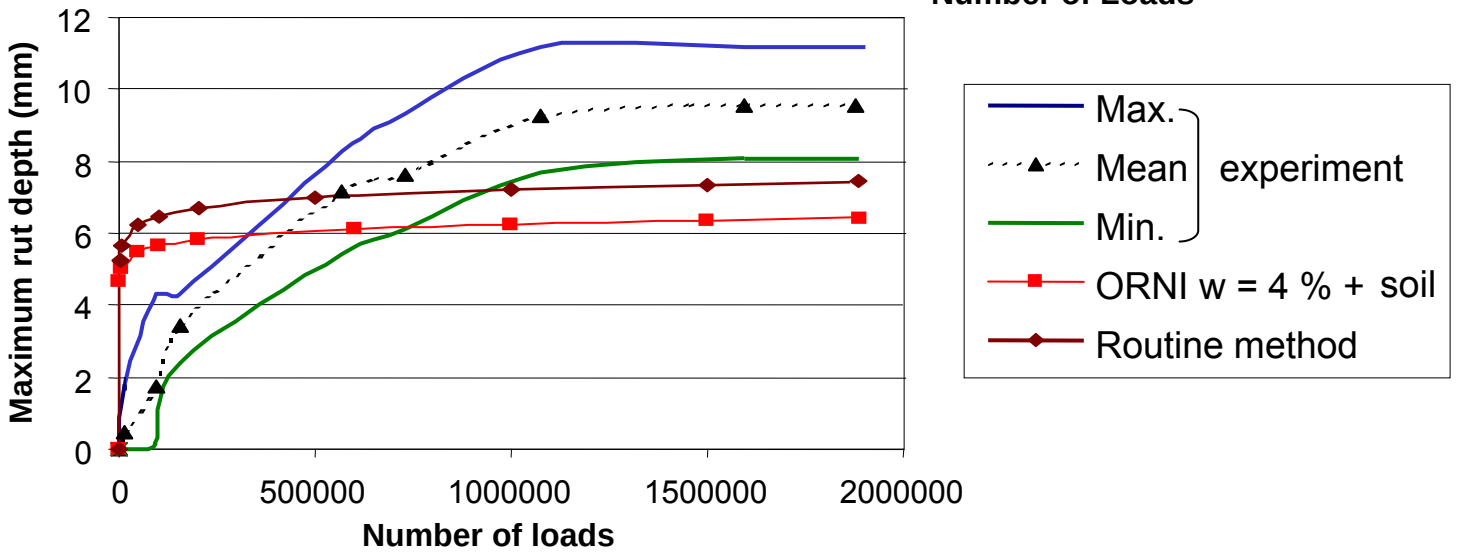


⇨ Large influence of temperature

Comparison of model with experiment

Rutting of UGM only





Rutting of UGM + soil

Conclusions – Modelling of rutting

• First results encouraging but difficulty to simulate real in situ conditions (temperature and moisture variations...)

• Models predict a too fast stabilisation of permanent deformations

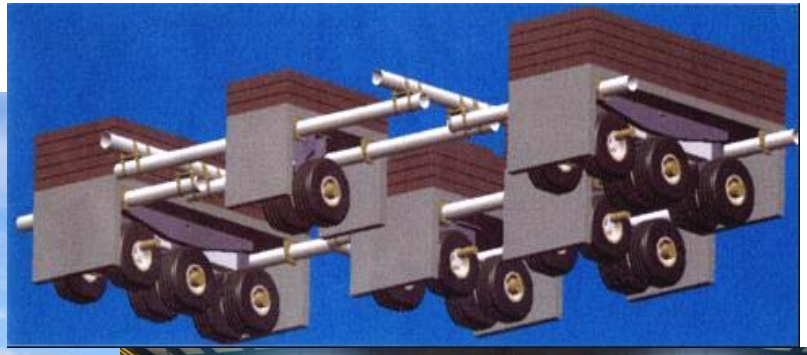
Perspectives :

- more detailed evaluation of ORNI

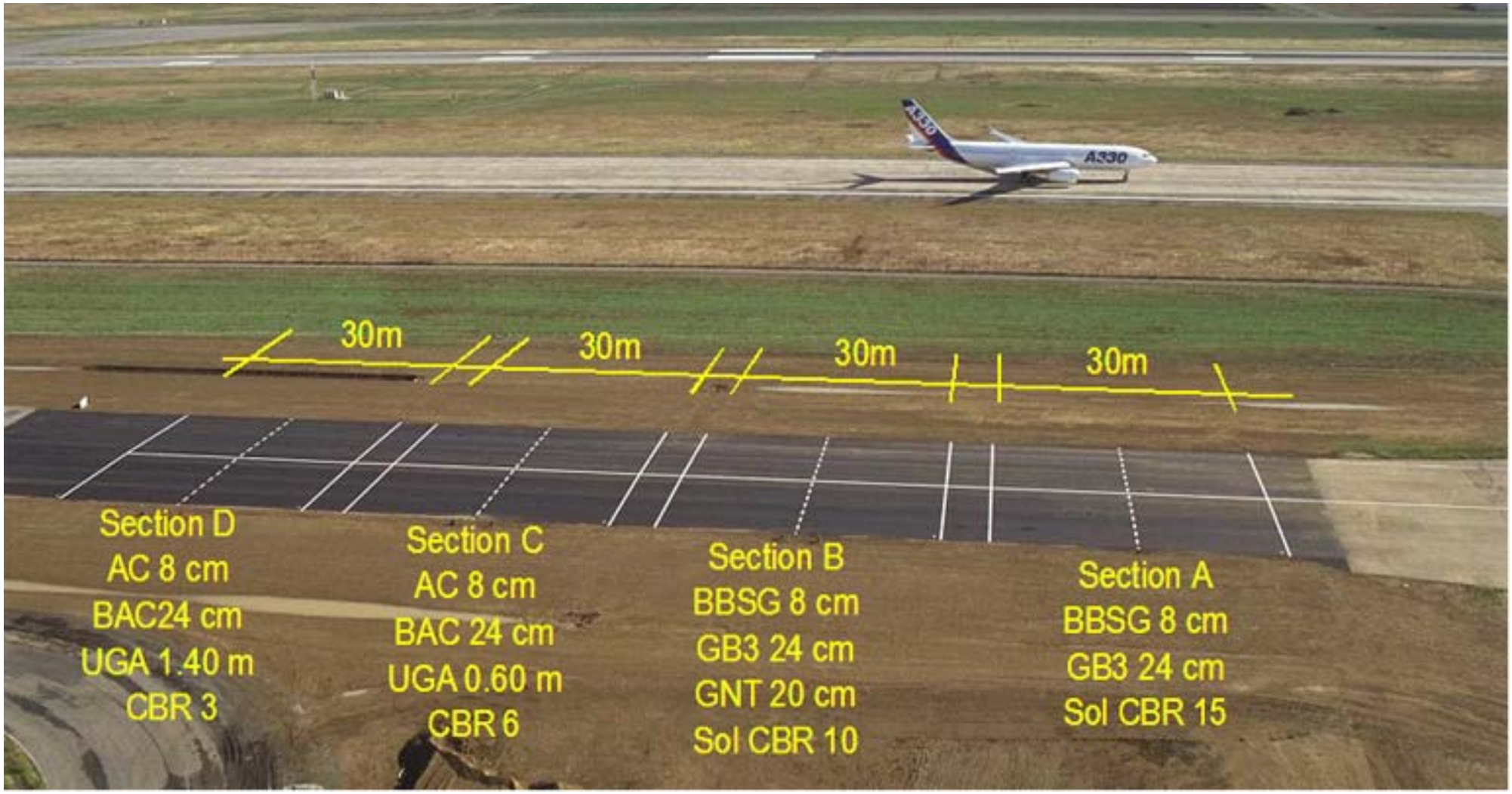
- Improvement of the models for unbound materials

- Modelling of permanent deformations of bituminous materials

Application of ALT to PM for airfield pavements



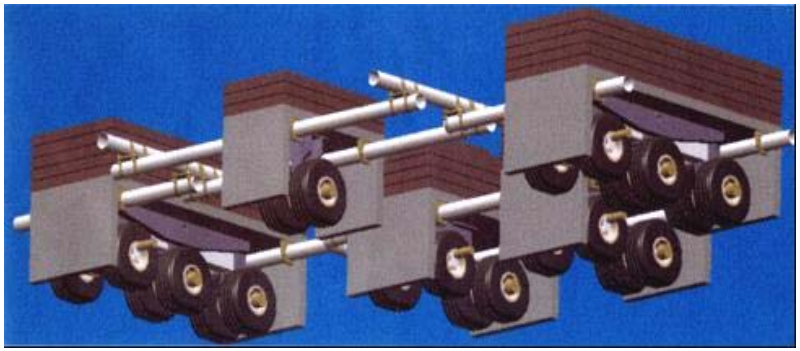
Airbus experimental program on flexible pavements – 1998-2003



Objectives of the Airbus experimental program

Tests on 4 instrumented pavement structures with soils of different bearing capacity (CBR 3 to 15)

Simulation of loads of different aircrafts , using a load simulator



Objectives :

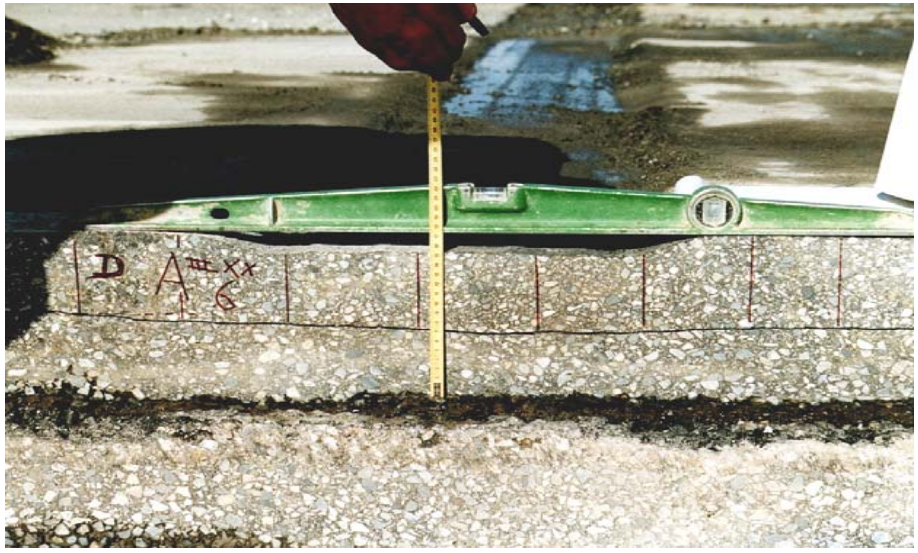
Study of the behaviour of flexible airfield pavements under heavy aircraft loading conditions

Evaluation of the possibility of applying the french road pavement design method to flexible airfield pavements

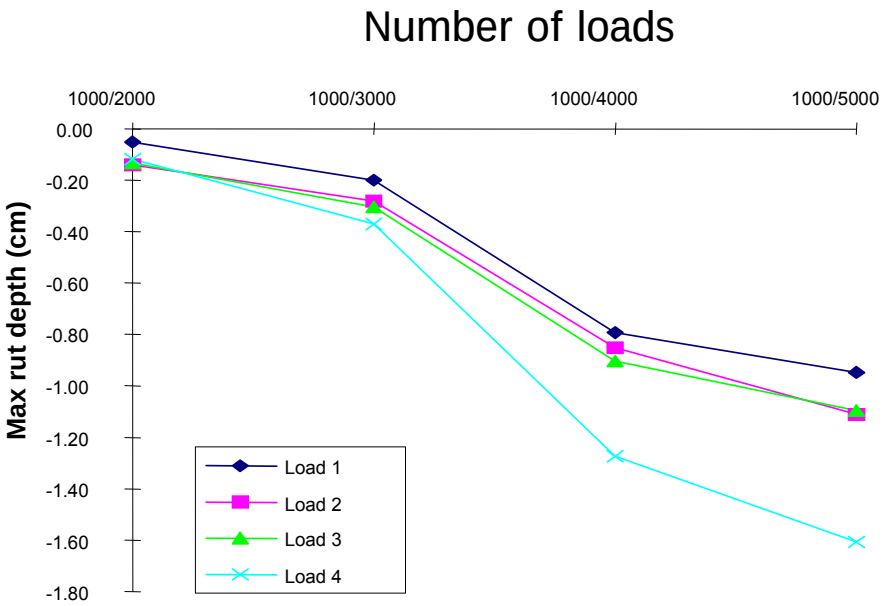
Observed pavement performance

Main mode of distress of the flexible pavements = **rutting**

No fatigue cracking - densification of the bituminous layers under heavy loading

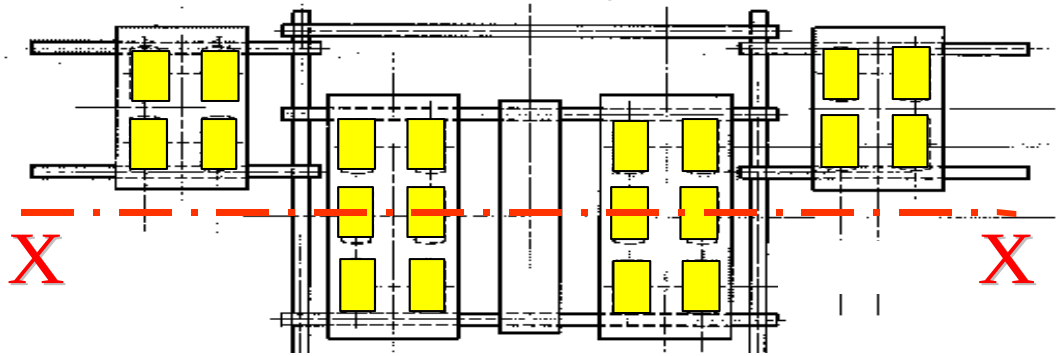


Evolution of rutting Section C – CBR 6



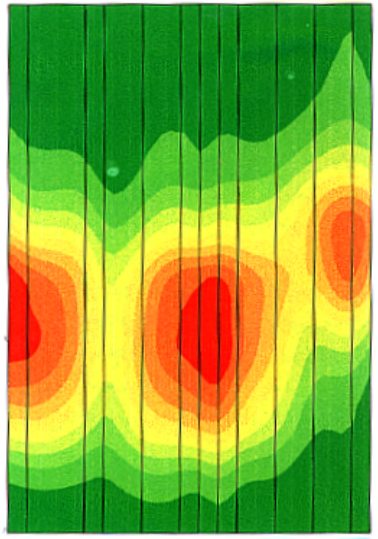
Linear elastic calculations (ALIZE Software)

A380 Load configuration

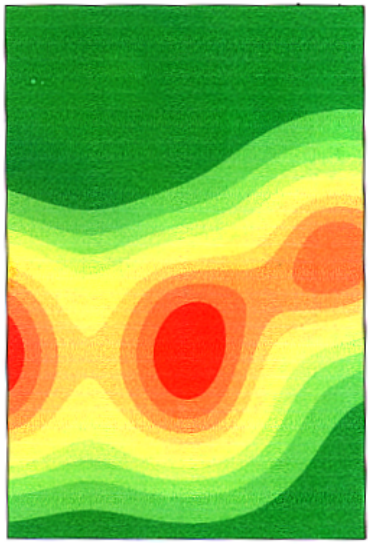


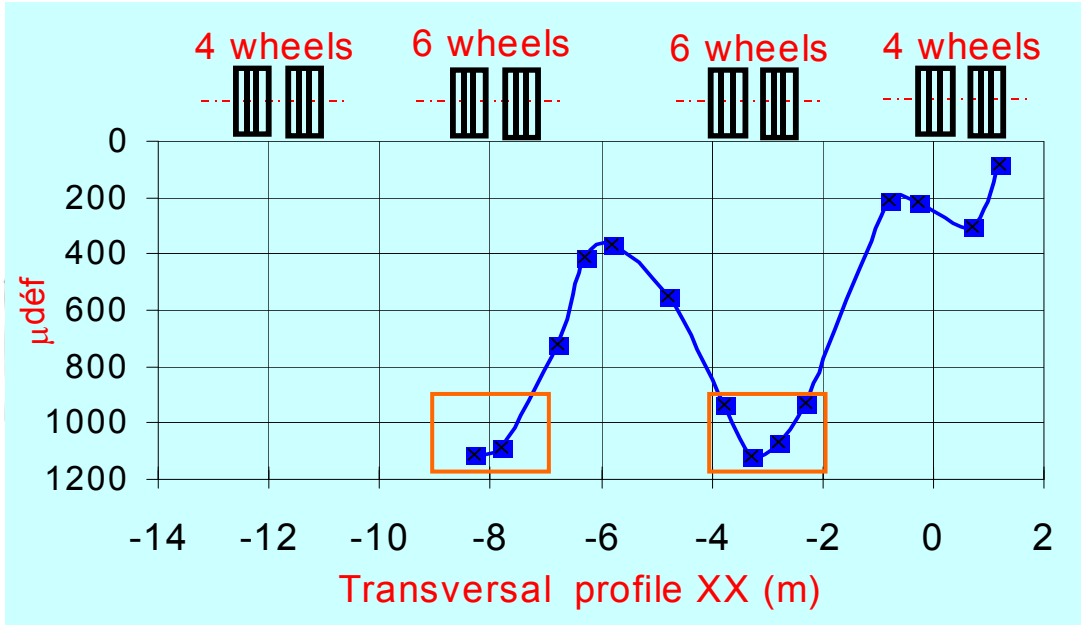
Prediction of vertical strains at top of subgrade (structure C)

Measurement



Alizé software





Results of linear elastic calculations

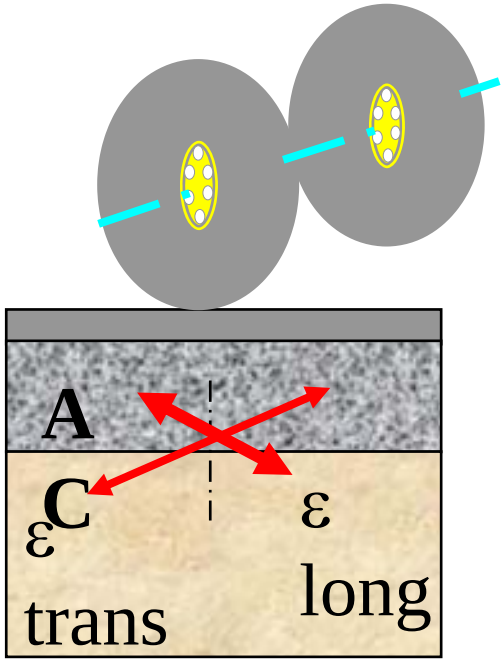
Good prediction of vertical strains in granular layers and subgrade

Poor prediction of maximum tensile strains at bottom of bituminous layers :

- Maximum values poorly simulated
- Discordance in directions of maximum tensile strains ε_t:

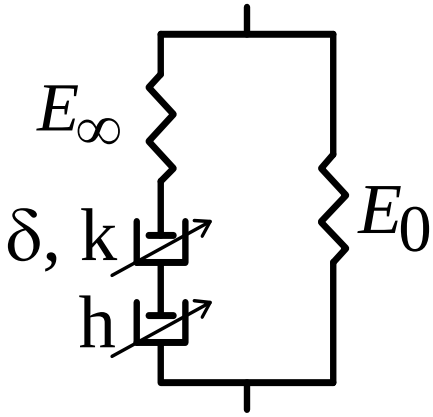
Measurements : ε_t transversal > ε_t longitudinal

Calculations : ε_t longitudinal > ε_t transversal



⇒ **Attempt to take into account viscoelastic behaviour**

Visco-elastic model for bituminous materials

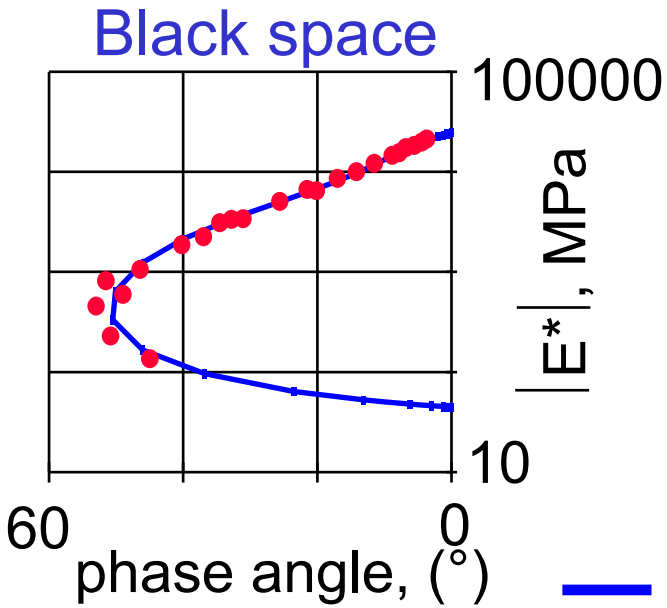


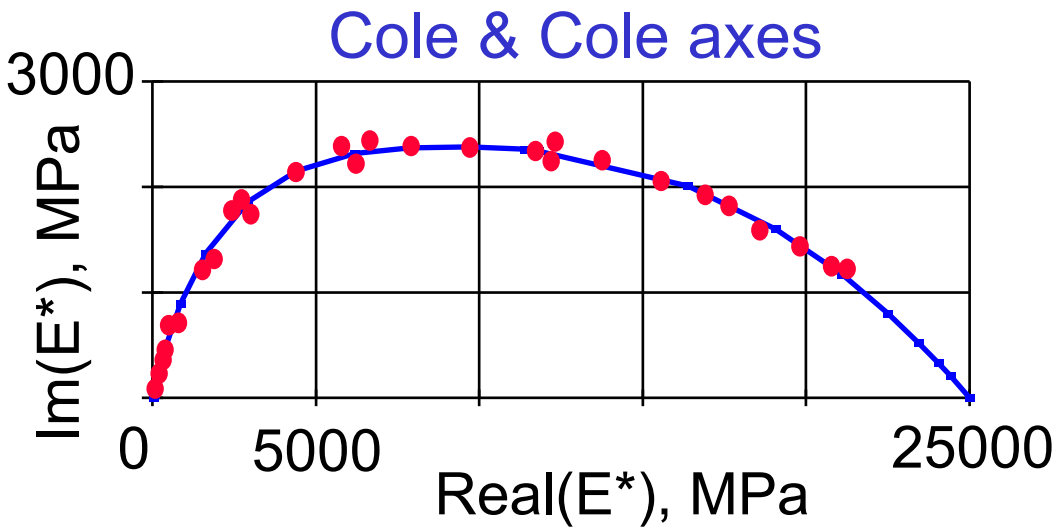
HUET - SAYEGH MODEL (1965)

$$E^*(\omega,\theta) = E_0 + \frac{E_\infty - E_0}{1+\delta(i\omega\tau(\theta))^{-k} + (i\omega\tau(\theta))^{-h}}$$

$$E_\infty = 25000\ MPa\,;\ E_0 = 45\ MPa\,;$$

$$\delta = 2{,}7\,;\ k = 0{,}27\,;\ h = 0{,}7$$

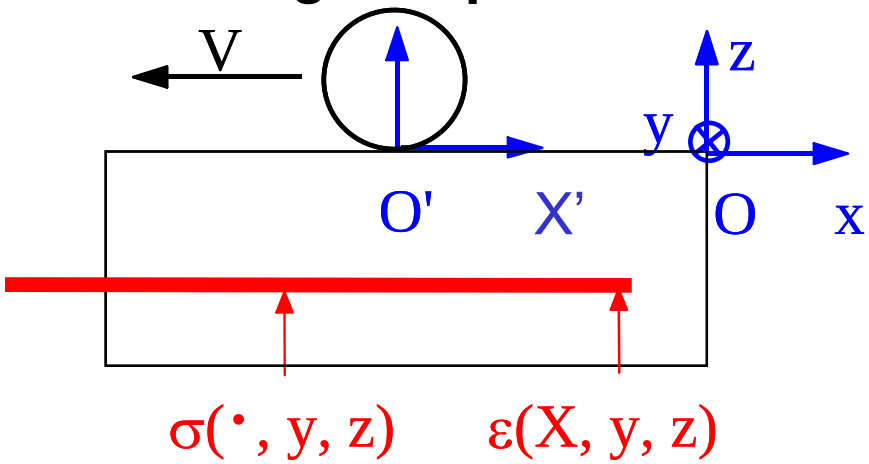




Huet-Sayegh's model ● measurements

Finite element model : module CVCR of CESAR-LCPC

Modelling of a pavement under moving wheel load (in 3D)



Hypotheses : Constant speed V

Constant properties along x

Calculation in the referential of the moving load (O', X', y ,z) X' = x +Vt

Static mechanical problem - no time steps

Modification of the visco -elastic law : becomes a non - local law

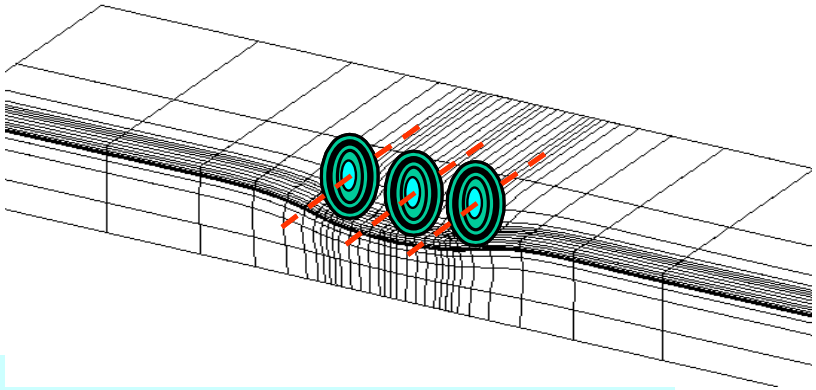
Models available in CVCR :

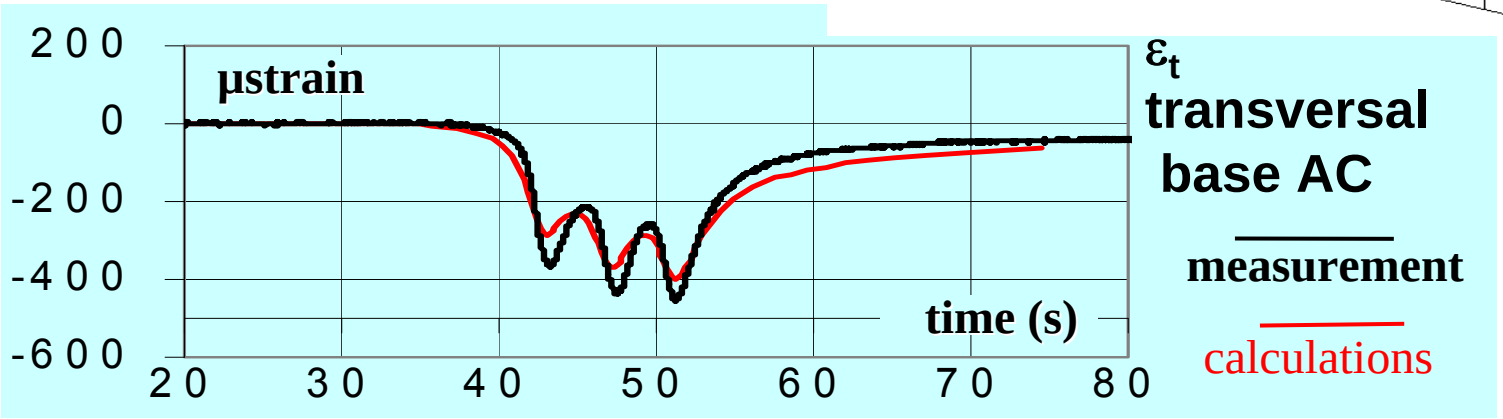
Linear and non linear elasticity (Boyce model, k-θ model)

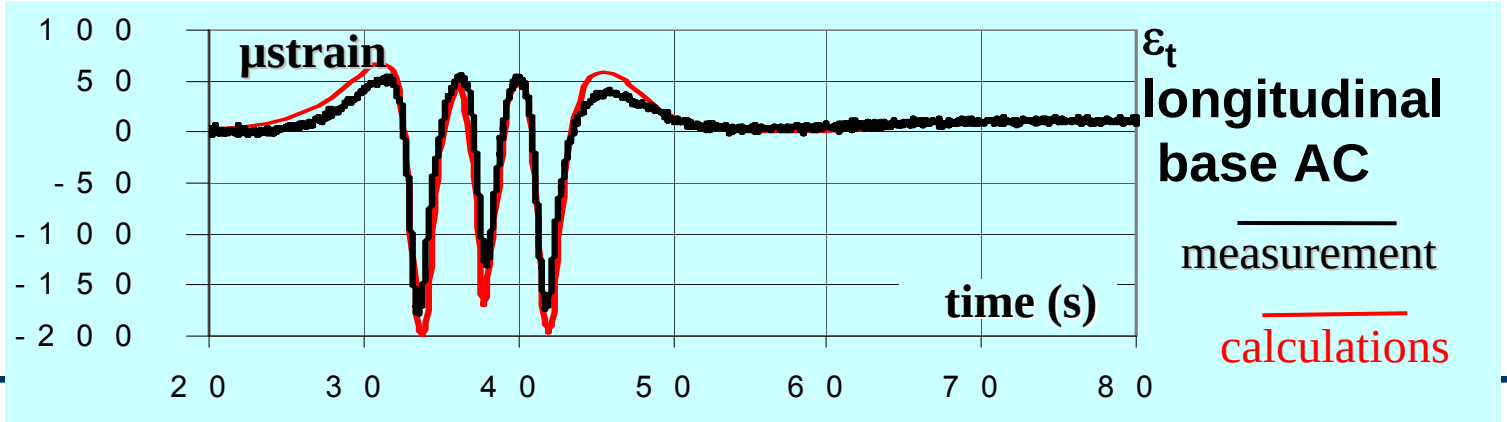
Huet-Sayegh visco-elastic model

Viscoelastic modelling of strains at bottom of bituminous layers

Load : 6 wheel bogie
240 kN per wheel







First conclusions of the Airbus experiment

Main mode of distress of the flexible pavements = rutting

No detectable fatigue of bituminous layers, despite high tensile strains

Modelling of resilient behaviour

- Reasonable prediction of vertical strains in subgrade with linear elastic calculations.
- Visco-elastic modelling necessary to predict correctly strains in bituminous layers

Modelling of fatigue

- Need to adapt the fatigue tests to aeronautical loading conditions

(high strain levels ≈ 400 μstrain, lower number of cycles (10^4))

Rutting :

Need to develop suitable design criteria and specifications for resistance to rutting of materials (bituminous and unbound)

General Conclusions

APT is a useful tool for :

- Identification of pavement deterioration mechanisms, and suitable models
- Validation of models

But validation on real pavement sections is also necessary

Recent research at LCPC on design /performance models focuses in particular on :

- Prediction of rutting
- Design of airfield pavements or special pavements (ex: industrial platforms) subject to heavy, complex loads

Conclusions

- Most models are “semi-rational” and do not describe perfectly in situ behaviour
- Determination of representative model parameters is essential (see fatigue experiments)
- Application of models to design is not straightforward :

  Need to apply “correction” factors or “safety” factors, based on comparisons with real pavement performance

  Need to develop better statistical approaches to take into account variability of

  - Pavement and material properties
  - Climatic conditions
  - Traffic