Towards enriched mechanical models (modelling of discontinuities, crack initiation and deflection evolution)

3D numerical modelling of road pavement damage using the M4-5n model:

Course cracking & Interface disbonding

Development of the calculation tool

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This topic is part of the DVDC theme on

- "the development of models of changes in the structural condition of road pavements and their application to estimating the residual road lifespans"

There are 2 main approaches in this theme, depending on the scale of the study:

- ► Multi-kilometre scale of road routes: statistical approach, formulation of laws of evolution of road conditions based, in general, on road network investigations

- ► More local scale (multi-metric): "mechanistic" approaches based on the use of mechanical models to take account of damage developing in road pavements

Work presented here → approach 2

- **Concerns**

  adaptation and use of the M4-5n mechanical model, based on a "stack of plates" type description of road pavement structures

- **Benefits of the model in relation to the objectives of the DVDC NP**

  ability to take into account the presence of cracks (particularly vertical cracks) or disbonding surfaces within multi-layer structures

- **Advantages of the model compared with conventional approaches (3D):**
  - Facilitates the geometric description of discontinuity surfaces (cracks, disbonding)
  - M4-5n mechanical field values remain limited to the vicinity of geometric singularities

And nonetheless makes it possible to model cracks developing in a 3D environment, and therefore to better approximate heterogeneous road pavement degradation mechanisms (e.g. localised cracks in the traffic lane)



- Purpose of the work presented: to develop a tool for advanced modelling of road pavement behaviour

- Examples of potential applications:
  - Interpretation at a given moment of investigation measurements and the local structural condition of road pavements
  - Forecast changes over time in the structural condition of damaged road pavements
  - Assessment of the effect of maintenance work
  - Support for the development of innovative technologies



WORK OBJECTIVES FOR THE DURATION OF THE DVDC NP

- Carry out the necessary developments to take into account, in the M4-5n approach, cracks and disbonding occurring and propagating within road pavement courses or at their interfaces → EF calculation code (Freefem++)

- Application of the tool to examine an initial case of crack growth in a road pavement

  (inspired by a scale 1 accelerated test (FABAC) carried out on a test bed at the Gustave Eiffel University)



WORK OBJECTIVES FOR THE DURATION OF THE DVDC NP (CONT.)

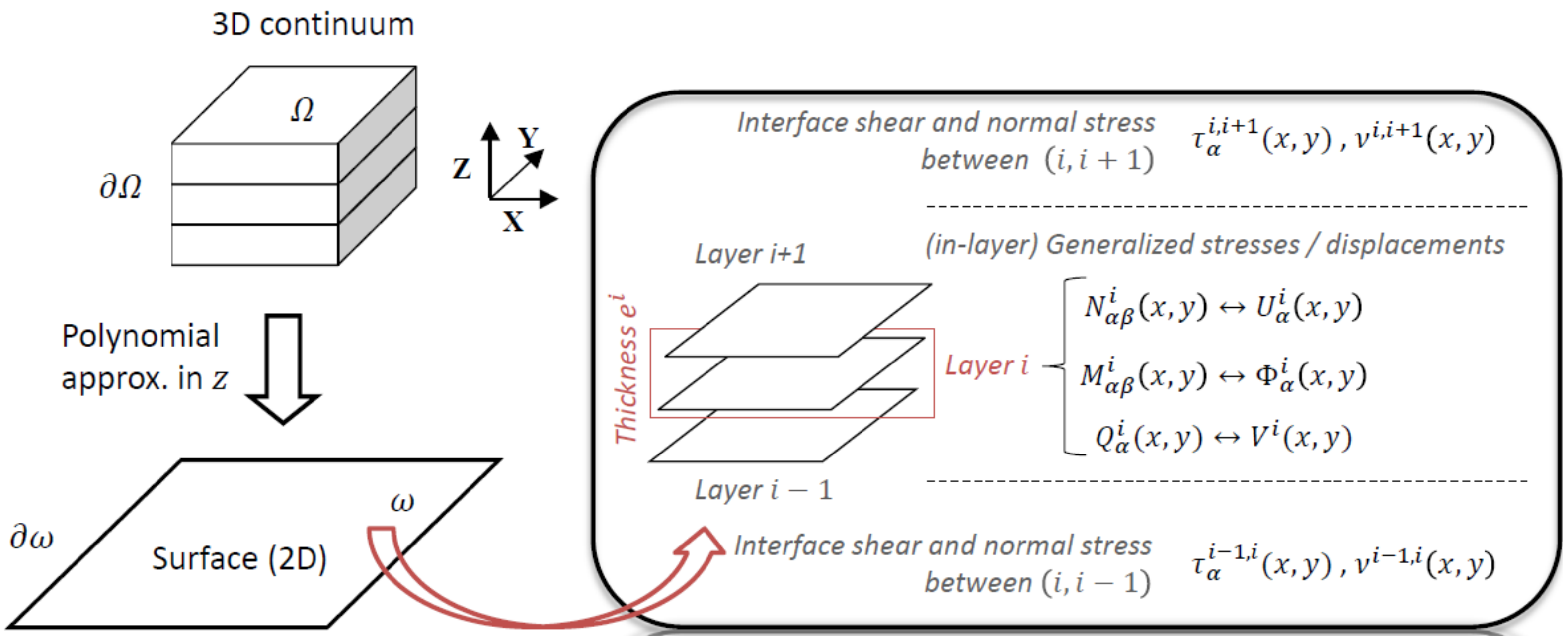
Starting points: M4-5N finite element tools developed in H. Nasser's thesis ((2016)) and earlier work on M4-5n (A. Chabot)

3 stages in the numerical developments carried out

- Generalise the technique of taking into account vertical cracks or horizontal disbonding surfaces initiated in H. Nasser's thesis
- Determine the energy restitution rates associated with the propagation of cracking or disbonding surfaces using the M4-5n approach
- Link these quantities to a "Paris law" type law of evolution that can be used to predict the fatigue damage kinetics of a road pavement under rolling load traffic



▶ Simplified description



For layers 1 and $n+1$ → surface loading in terms of interface stresses

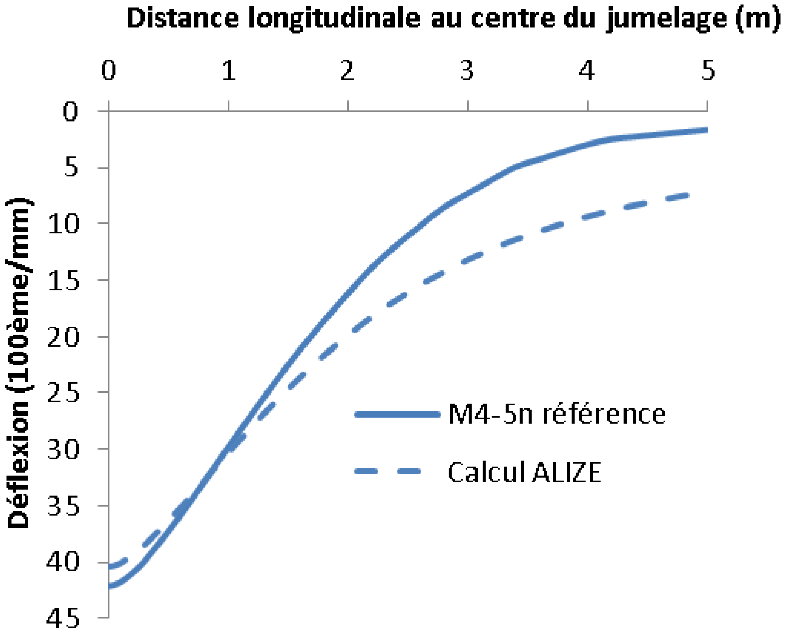
On $\partial\omega = \partial\omega_U \cup \partial\omega_T$ → boundary conditions per layer

- Modelling of a 3D road pavement based on a "stack" of elastic plates working in bending/shear and possibly in compression → 2D formulation in generalised fields (course and interface); facilitates geometric treatment of defects
- Winkler springs to represent the soil
- Equilibrium equation, law of behaviour, kinematic compatibility, etc.
- From a numerical point of view: solving a 2D EF problem



▶ Alizé vs. M4-5n on a new road pavement structure (BBG3/BBG3) under reference load (standard twinning, p=0.662 MPa)

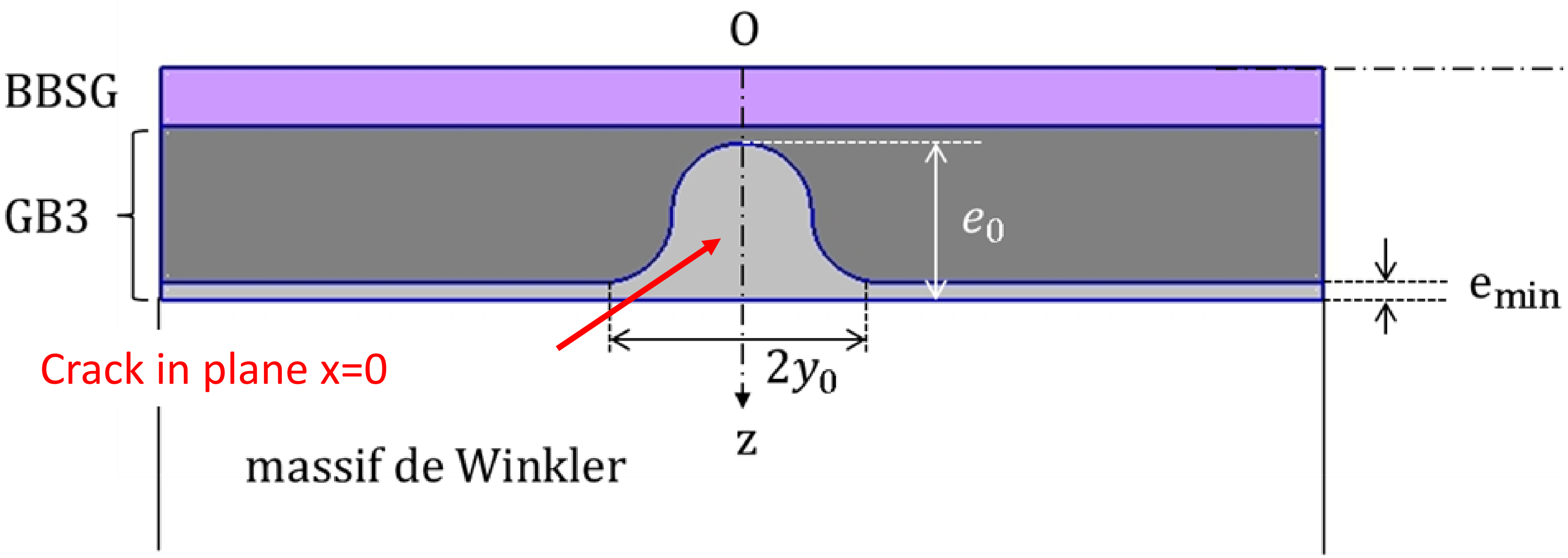
Matériau	Epaisseur (m)	Module d'Young (MPa)	Coefficient de Poisson
BBSG3	0,08	7000	0,35
GB3	0,13	9000	0,35
GB3	0,13	9000	0,35
Plate-forme	Infini	50	0,35



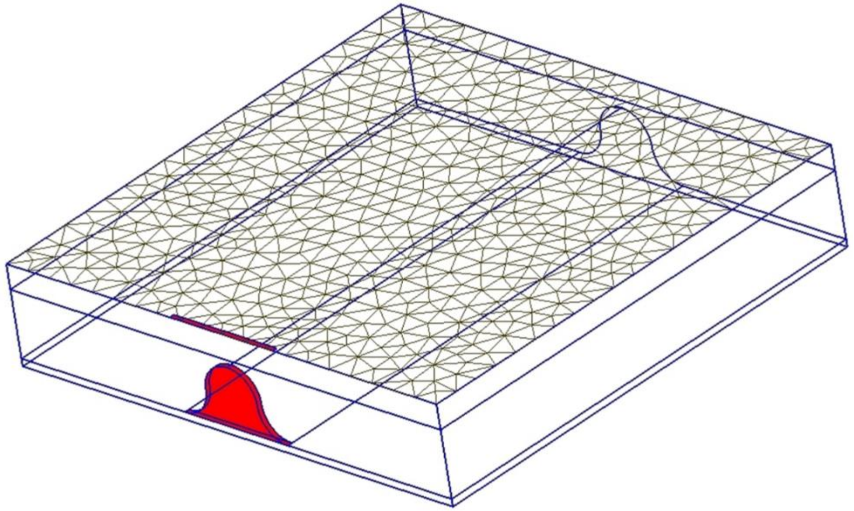
- Good general agreement between the calculated deflections
- Differences in shape due to differences in the modelling of structures (deliberate simplification of the GNT course and the soil in M4-5n; a more precise description could have been given)
- The same applies to strains and stresses



► Same calculation but with the presence of a vertical crack in GB3 (given state of cracking)

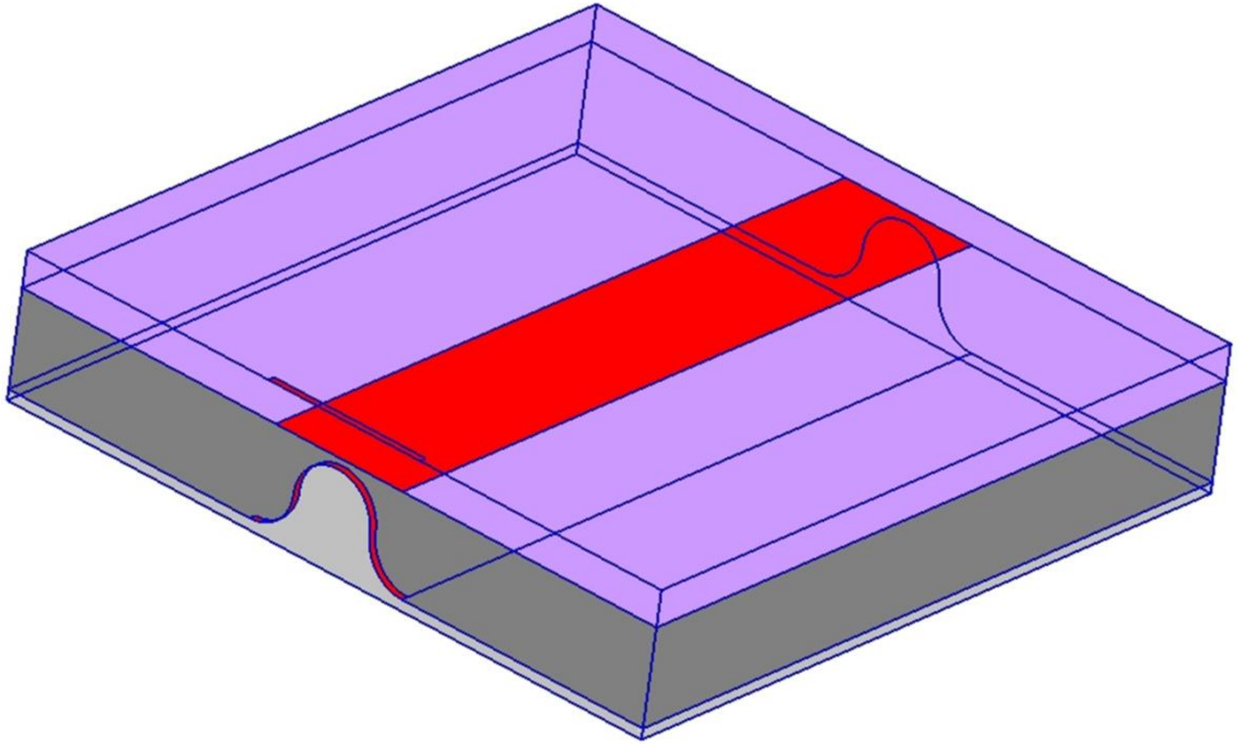


- The crack profile considered has little impact on deflection compared with the previous calculation (42/100 mm)
- On the other hand, there is a sharp increase in deformation and stress (ε_{xx} and σ_{xx}) at the base of the SCAS



3D view of the structure and associated M4-5n mesh (2D)

► Calculation with cracks and disbonding of the SCAS/BBG3 interface



- Still low impact on deflection (here 42/100 mm)
- Sharp increase in deformation and stress (ε_{xx} and σ_{xx}) at the base of the SCAS due to the crack
- Discontinuity of deformation ε_{xx} on either side of the disbonding surface ($z = 0{,}08m$).



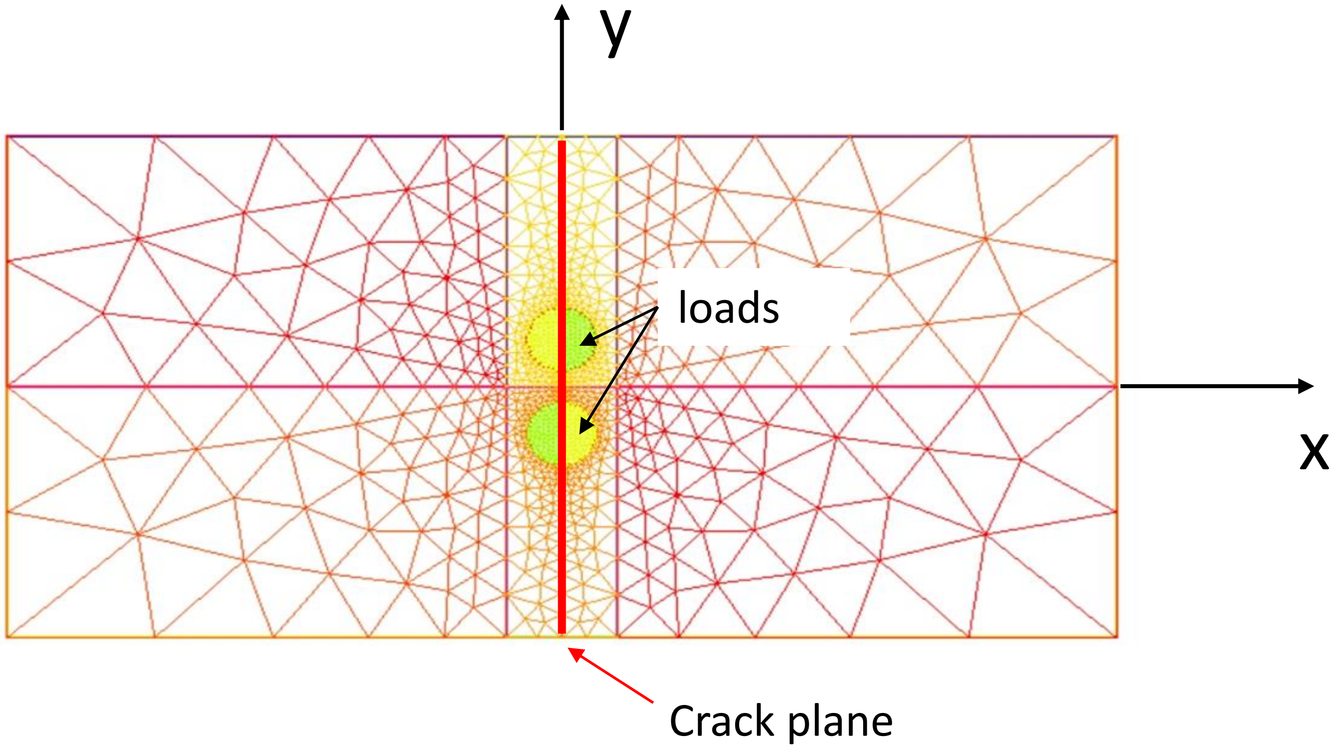
- Crack propagation → predicting the fatigue damage kinetics of a road pavement under traffic
  - Determination of energy restitution rates for M4-5n (cracking/disbonding) + link with "Paris law" type law of evolution
  - Validation and calibration vs. other tools on a simple 2D case

- Application example
  - Structure: EME (5cm) / EME (6cm) + GNT (33 cm) + soil
  - Loading: standard half-axle (without sweeping)
  - Study of the growth of a crack profile initiating at the base of the high modulus asphalt
  - Load placed vertically above the crack plane $x = 0$ (position considered to be the most detrimental to crack growth)

- The crack propagation calculation simulates the effect of repeated loading on the pavement



Some calculation data



M4-5n mesh of simulated road pavement (top view of 3D road pavement)

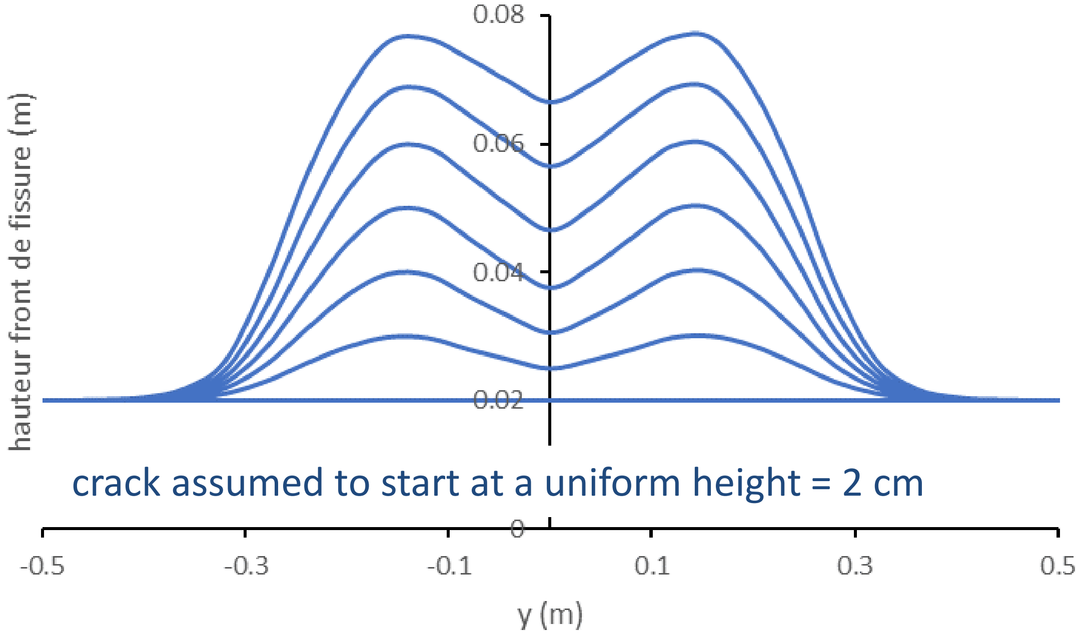
	E (MPa)	ν
High modulus asphalt	15150	0.35
Untreated gravel	260	0.35
Winkler springs	$k = 60\ Mpa/m$	

+ coefficients (2) for the Paris-type law of evolution based on M4-5n quantities

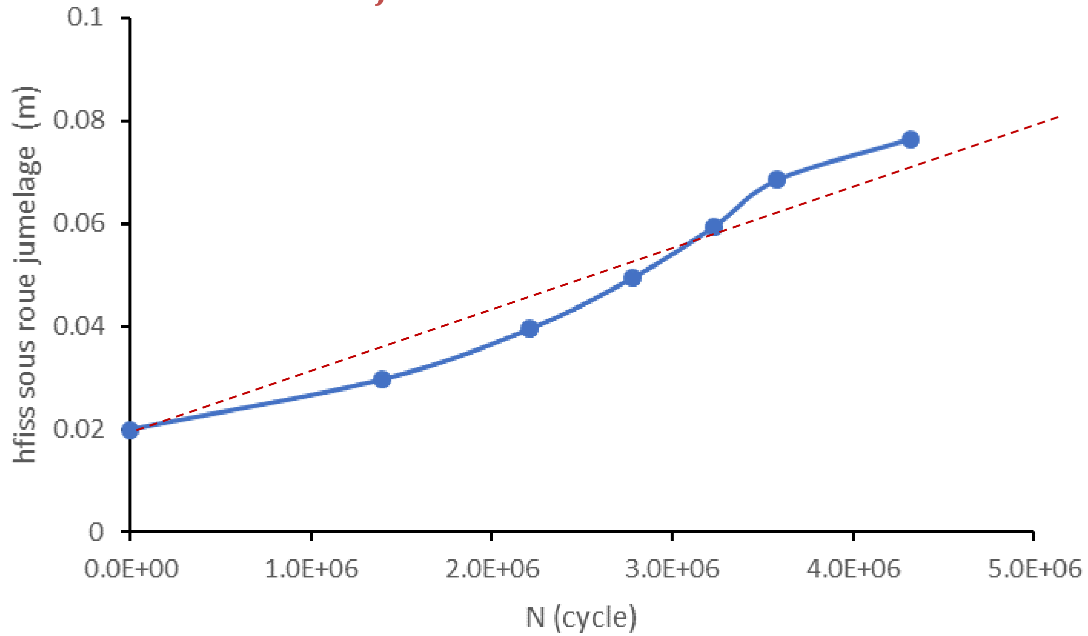
Calibration vs. "classic" 2D FE calculation of plane deformations in fracture mechanics and Paris law

SOME SIMULATION RESULTS FOR FATIGUE CRACK GROWTH

Evolution of the geometry of the crack front in the vertical plane (O, y, z)



Crack propagation kinetics vs. number of loads (h_{fiss} taken under the wheels)



- We find the expected symmetry of the cracking profiles, in relation to the median longitudinal axis of the road pavement
- h_{max} cracking under the wheels, then rapid decay on the outside of the traffic lanes

- The dots correspond to the profiles in the figure on the left
- The growth in cracks under the wheels appears to be approximately linear with the number of loads over the range of cracking from 2 to 8 cm



- The aim of this work is to propose a tool to numerically calculate the behaviour, on a metric scale, of a section of road pavement containing defects (cracks, disbonding surfaces); a tool based on the M4-5n model
- 1st part of the work for a given state of cracking – The examples of principle treated show the applicability of the developments made to the Mechanics of Road Pavements
- 2nd part of the work focused on modelling crack propagation and disbonding surfaces under repeated traffic loads – development of the mathematical formalism
- These developments were implemented in the form of a finite element calculation script in the Freefem++ environment



- This is the first example of the calculation of crack growth in a course of asphalt road pavement on a cracked surface to be presented
  - Simulations show the evolution of the geometry of the cracking front and its kinetics as a function of the number of load passages
  - The numerical results provide an estimate of the extent of the damaged area based on the location of the applied loads and loading cycles

- However, most of the practical applications of the numerical tool developed have yet to be defined and formalised

- The application of this work to more finalised uses will have to be carried out progressively by adapting, calibrating and improving the present tool