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

Models of structural deterioration

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Models of structural deterioration

Objectives:

Analyse the measurements of deflection basins in light of numerical mechanical modelling, in order to characterise the state of cracking of road pavement structures.

- Finite element approach: case of delamination and vertical cracking without propagation in 3D geometry

- Boundary element approach: case of 3D crack propagation

([1]): P. Gaborit, Comportement thermo-mécanique de structures de chaussées bitumineuse (*thermo-mechanical behaviour of bituminous pavement structures*), PhD thesis, ENTPE, 2015

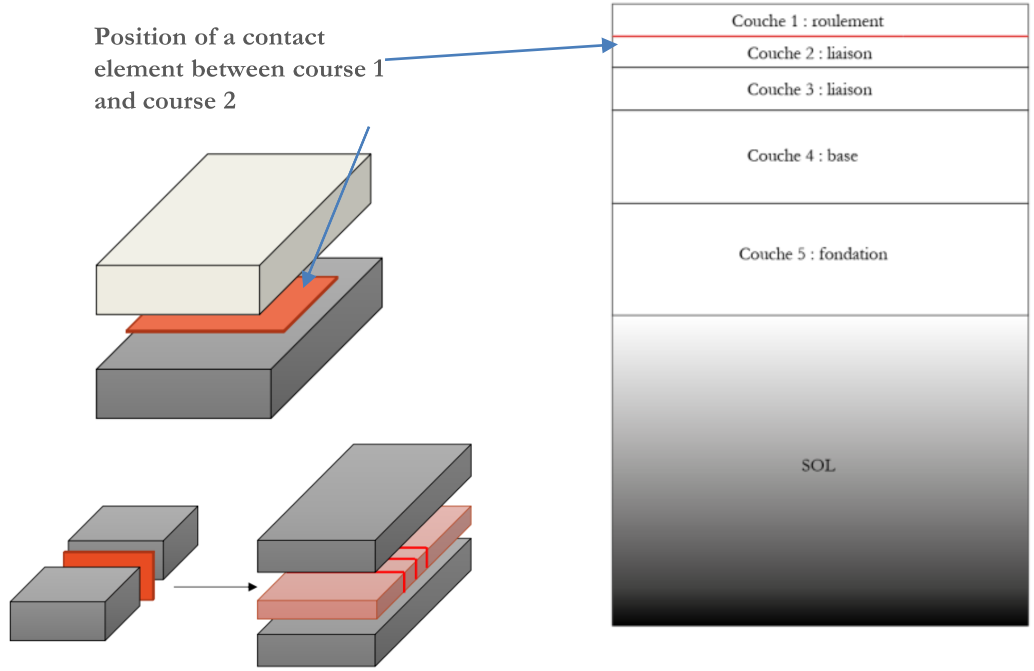


► Main deteriorations considered

- **Delamination between** 2 courses and opening of the interface. The surfaces considered can be large **(15 m²)** or small **(~ 1 m²)**
- Short (**1 m**) or long (**9 m**) **transverse** or **longitudinal** cracks with a spacing interval of 0.2 m
- Course thickness variation +/-1 cm

➢ Calculated deflections

- **Absolute deflection**
- **Simulation** of deflection measurement using a **curvometer**



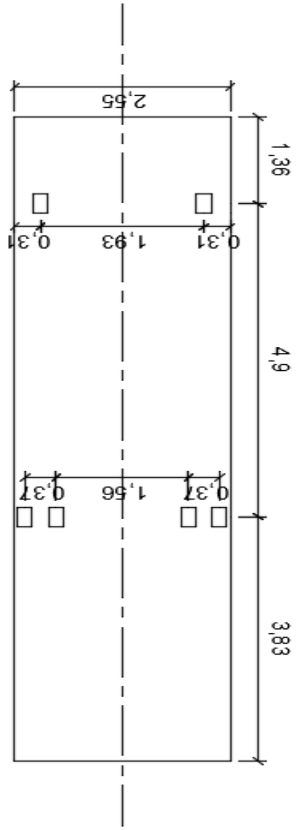
Transverse cracks in a course

Road pavement layers	Wearing CoR (TAS)	Link 1 CL1 (BBG)	Link 2 CL2 (BBG)	Base CdB (BBG)	Foundation CdF (BBG)	Soil (PF3)
Thickness [m]	0.04	0.04	0.05	0.10	0.11	3.00
Behaviour	Elastic	Elastic	Elastic	Elastic	Elastic	Elastic
E [MPa]	4581	4581	4581	5174	13680	120
ν	0.35	0.35	0.35	0.35	0.35	0.25

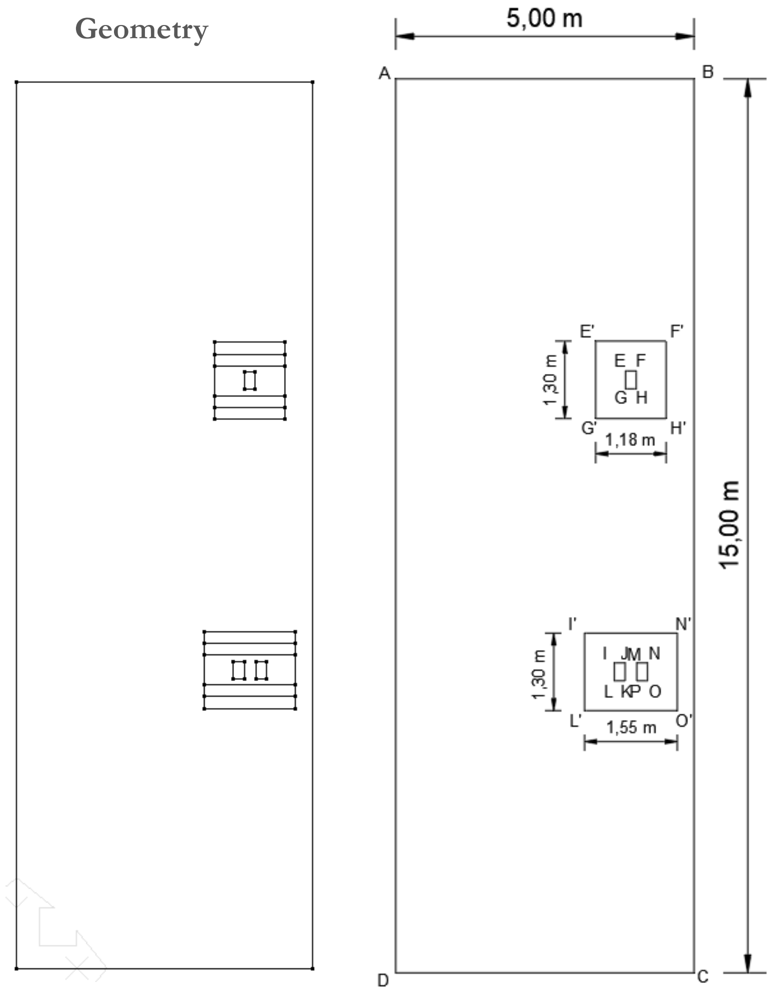
TABLE 1: CHARACTERISTICS OF THICK ASPHALT ROAD PAVEMENTS. CoR to Bond: data taken from the standard,
Base - Foundation: values deduced from complex modulus tests. Temperature and frequency measured under loading: 17°C and 8.1 Hz

▶ Curvometer type loading

Loading diagram (top view)

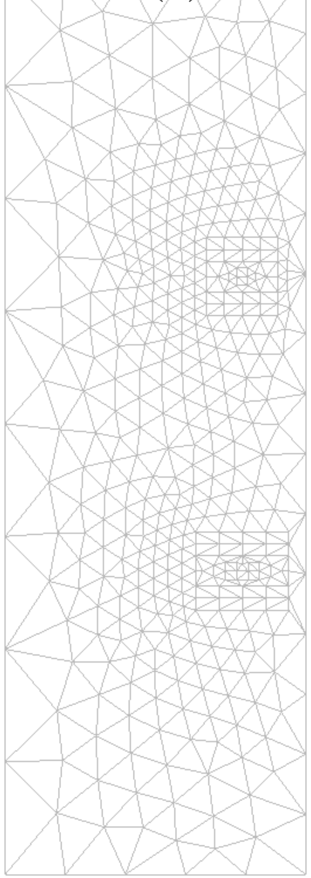


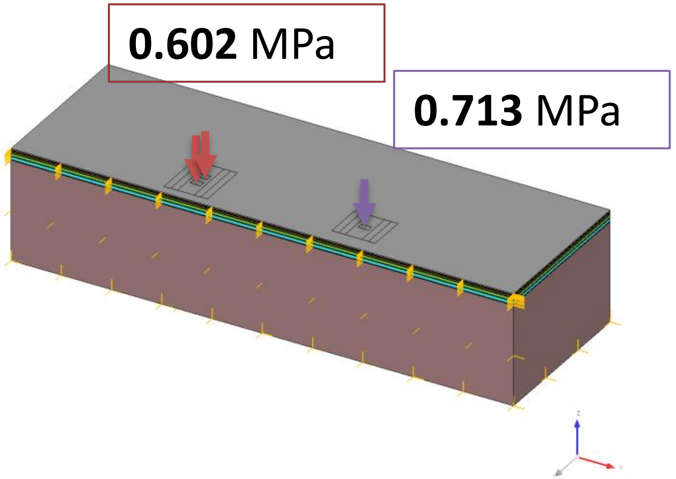
Geometry



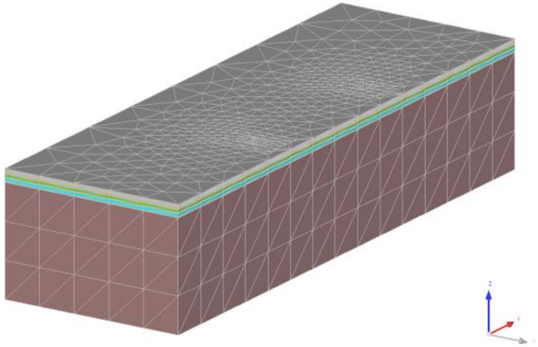
Load distribution

40.10³ EF (Q)





Surface area of each tyre ($0.18*0.3m^2$)





Comparison Alizé - César (EF) Thick asphalt road pavement

Maximum deflection (mm)	Alizé [transversal]	CESAR [transversal]	Alizé [longitudinal]	CESAR [longitudinal]	Alizé-César spread [transversal]	Alizé– César spread [longitudinal]
Without delamination	-0.2277	-0.2230	-0.2115	-0.2061	2%	3%
CoR_L1(*)	-0.2530	-0.2452	-0.2337	-0.2260	3%	3%
L1_L2(*)	-0.2800	-0.2687	-0.2622	-0.2506	4%	4%
L2_Base(*)	-0.3135	-0.2973	-0.2997	-0.2818	5%	6%
Foundation_Base(*)	-0.3263	-0.3083	-0.3145	-0.2944	6%	6%

*** With complete delamination of the interface (5*15 m^2)**

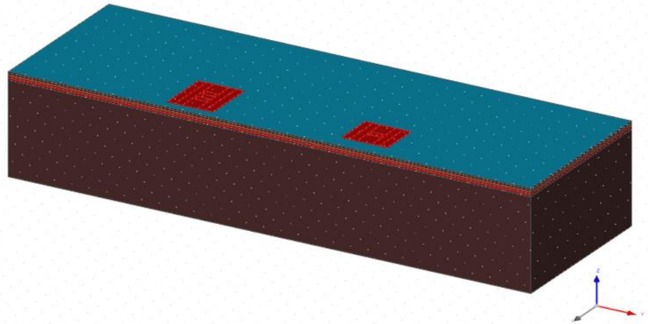
Characteristics of the interface with perfect sliding (César (EF))

Sliding interface	RT	E
CoR – Link 1	1 MPa	4581 MPa
Link 1 – Link 2	1 MPa	4581 MPa
Link 2 – Base	1 MPa	4581 MPa
Base - Foundation	1 MPa	5174 MPa

- **We note that the ALIZE model corresponds to our modelling using the CESAR (EF) software.**
- **The perfect sliding of the ALIZE software corresponds to a sliding surface with a tensile strength coefficient RT= 1MPa (tensile opening limit) and a Young's modulus equal to the smallest modulus of two courses in contact.**

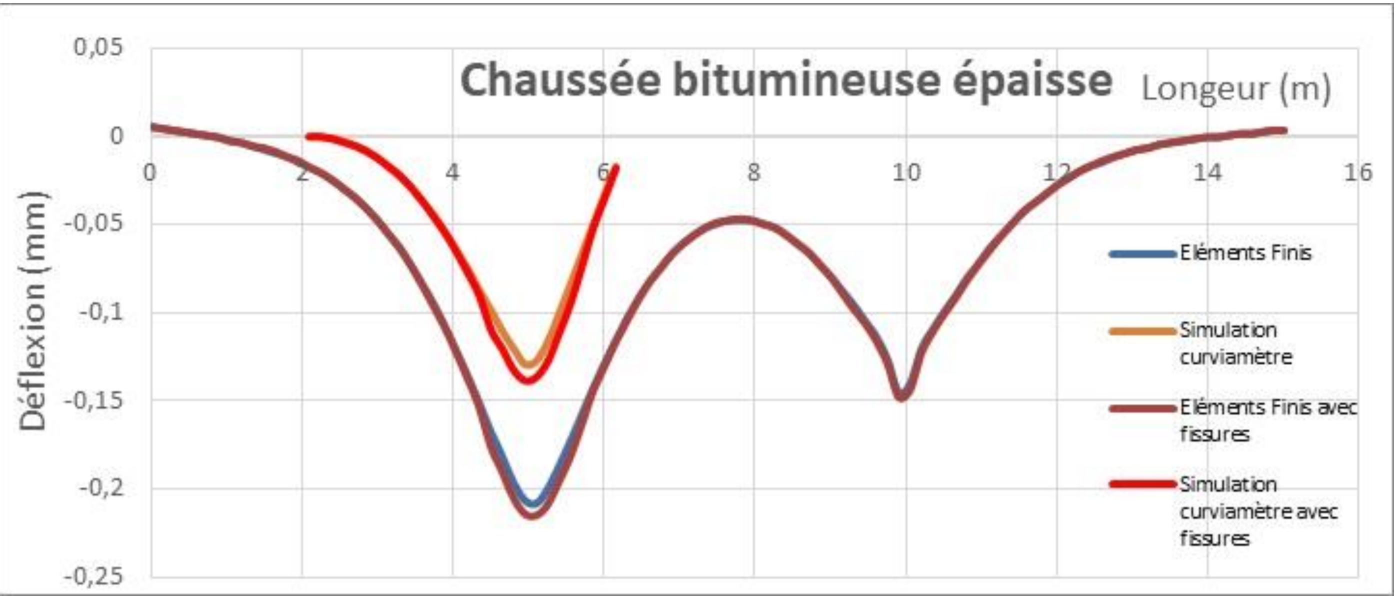
Reduced sliding surface (1.3*1.18 m^2) and interface without resistance

Sliding interface with opening	
RT	E
1 kPa	1 MPa



Interface	Maximum deflection (mm) César (EF) [transversal]	Increase/without delamination
Without delamination	-0.223	-
CoR – Link 1	-0.353	+56.88%
Link 1 – Link 2	-0.316	+40.44%
Link 2– Base course	-0.302	+34.22%
Base course – Foundation	-0.272	+20.88%

- Thick bituminous structure.
  Simulation of deflection basins using a curvometer calculation.



Deflection basins derived from the finite element calculation and simulation of the basin using a curvometer type calculation. (short longitudinal cracks)

Position of the 6 short longitudinal cracks	Transverse axis (EF)	Longitudinal axis (EF)	Curvometer (longitudinal calculation)
	w_{max} [mm]	w_{max} [mm] / relative deviation from non-cracked case	w_{max} [mm] / relative deviation from non-cracked case
No cracks	0.226	0.209	0.130
Wearing course	0.229	0.215 / 2.9%	0.139 / 6.9%
Link 1	0.231	0.213 / 1.9%	0.136 / 4.6%
Link 2	0.235	**0.232 / 11%**	**0.156 / 20%**
Base	0.245	**0.227 / 8.6%**	**0.149 / 14%**
Foundation	0.247	**0.232 / 11%**	**0.156 / 20%**

Summary of calculated maximum vertical displacements (w_{max}) (finite elements and curvometer) in absolute values for the thick bituminous pavement

Position of the 6 long longitudinal cracks	Transverse axis (EF)	Longitudinal axis (EF)	Curvometer (longitudinal calculation)
	w_{max} [mm]	w_{max} [mm] / relative deviation from non-cracked case	w_{max} [mm] / relative deviation from non-cracked case
No cracks	0.226	0.209	0.130
Wearing course	0.263	0.216 / 3.3%	0.140 / 7.7%
Link 1	0.262	0.247 / 18.2%	0.171 / 31.5%
Link 2	0.260	**0.244 / 16.8%**	**0.168 / 29%**
Base	0.259	**0.241 / 15.3%**	**0.165 / 26.9%**
Foundation	0.265	**0.250 / 19.6%**	**0.174 / 33.8%**



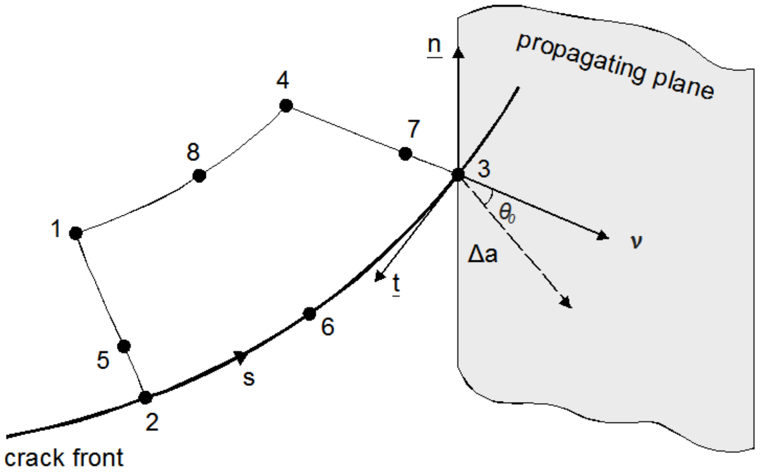
▶ 3D propagation of crack networks

- Developments are carried out using the Boundary Element Model
  - **Great flexibility in structuring 3D geometries**
  - Highly **accurate** determination of singular fields in **the vicinity of cracks**
  - Linking with the fast multipole method to set up a structural calculation code for **3D elasticity** and **3D fracture mechanics**.
- Paris law

$$\frac{da}{dN} = A.\Delta K^{m} \qquad \Delta K = K_{\max} - K_{\min}$$

- The stress intensity factors at node 2 are determined for **propagation modes I, II, III**

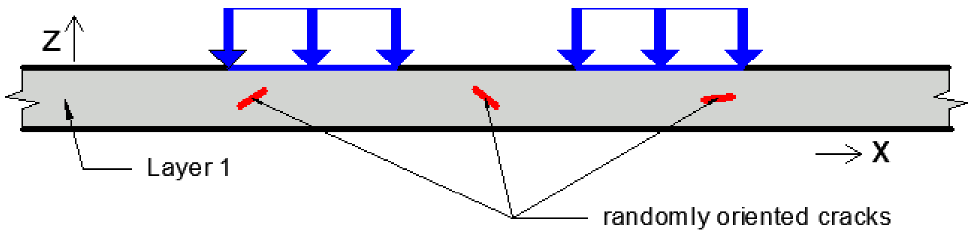
- **The angle of propagation** is given by the criterion of the maximum tangential stress

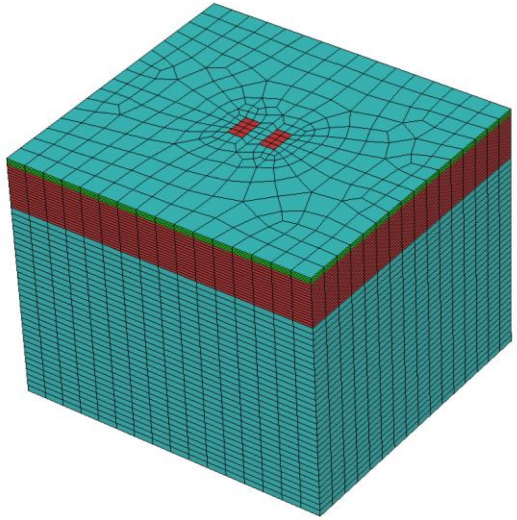




► Simulation of a road pavement with internal cracks

	Thickness (mm)	E (MPa)	ν
Wearing course	66	6610	0.35
Granular course	500	180	0.30
Soil	2220	80	0.25

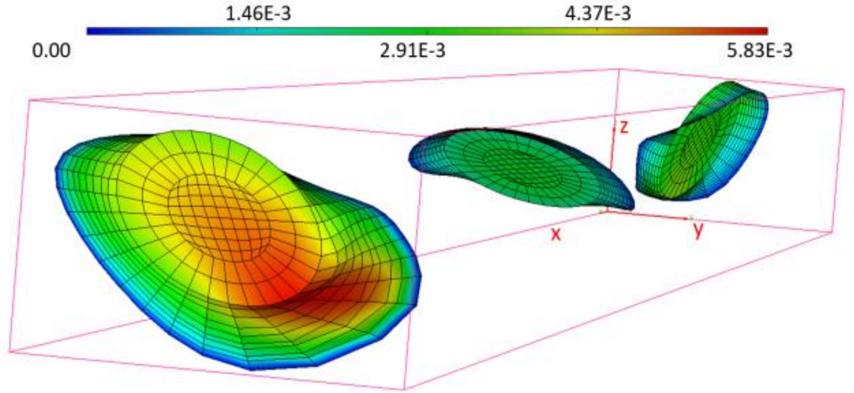




3D load distribution and pairing footprints: 2 *(0.18m * 0.3m)

#	N_c	N_{init}	N_{end}	$T_{\text{pre}}(s)$	$T_{sol}(s)$	$T_{\text{tot}}(s)$
1	1	15 441	18 033	201	667	883
2	3	17 559	25 335	345	1 382	1 749
3	5	19 677	32 637	1 241	3 166	4 434

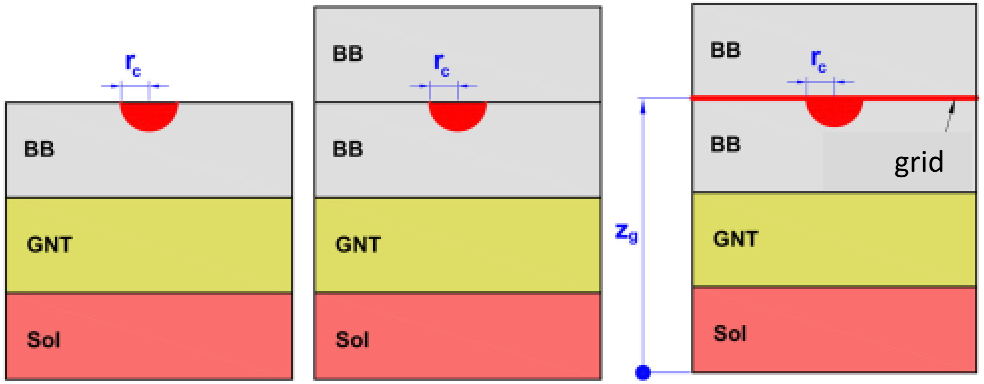
Calculation time for 1, 3 and 5 cracks



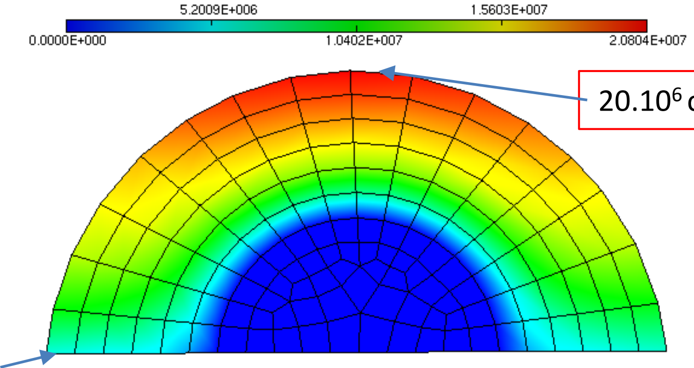
Shape of three cracks (**diameter 20 mm**) after propagation (crack opening in mm)



▶ Simulation of a road pavement with an open crack, grid reinforcement and overlay



(a) Non-reinforced (b) + Overlay (c) + Overlay + Grid

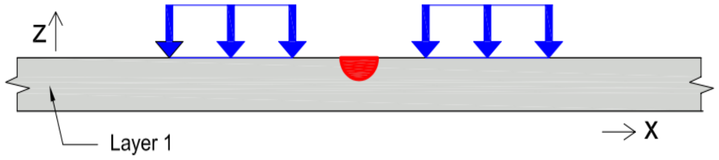


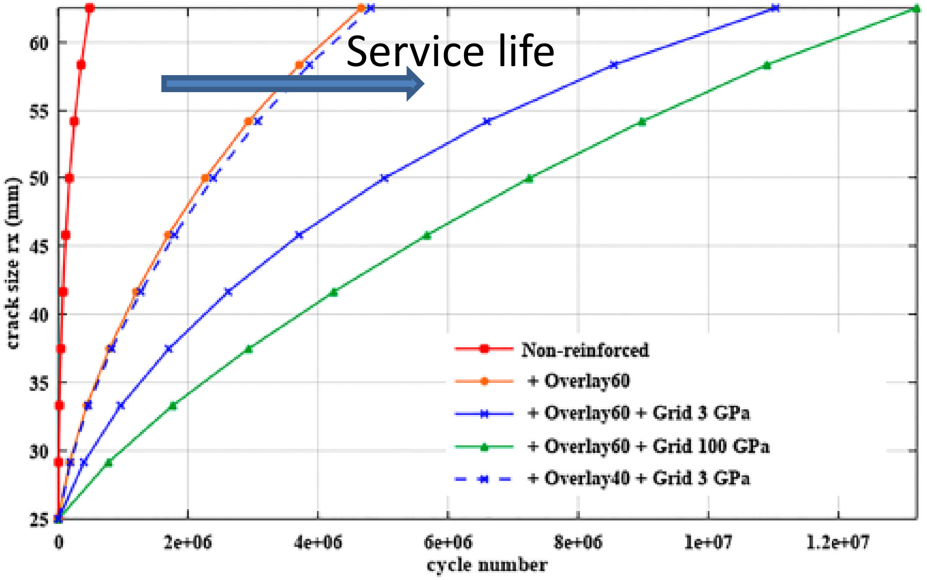
20.10^6 cycles

5.10^6 cycles

Mapping the number of cycles based on crack advance

p=0.6 MPa





Effects of reinforcements on crack propagation according to X of the crack (diameter 50 mm)

Conclusion and outlook

- Finite element calculations
  - For **delamination**: importance of interface, position and surface characteristics
  - For **vertical longitudinal (or transverse) cracks**: effect of the crack's position and length on the deflection basin.

    The longitudinal deflection measured by a **curvometer type calculation** follows this trend. This calculation is slightly more sensitive (20%/11% (short cracks) - 30%/17% (long cracks).
  - The **maximum relative deflection** (cracked/uncracked comparison) resulting from a theoretical longitudinal measurement (finite element calculation) is **4/100 mm** and that estimated by a curvometer type calculation is of the order of **5/100 mm**.

- Boundary element calculations
  - **3D crack path** strongly controlled by the direction of maximum tangential stress
  - The model shows **faster crack propagation at the surface** than in the material

- **Outlook**
  - Development of methods relating to the intersection of crack networks and propagation directions
  - Search for instrumented experiments or benchmarks