

March 21, 2024

Armelle Chabot
MAST-LAMES
Univ Eiffel

Illinois Kent Seminar

Mechanical analysis of Debonding Phenomena in Pavements

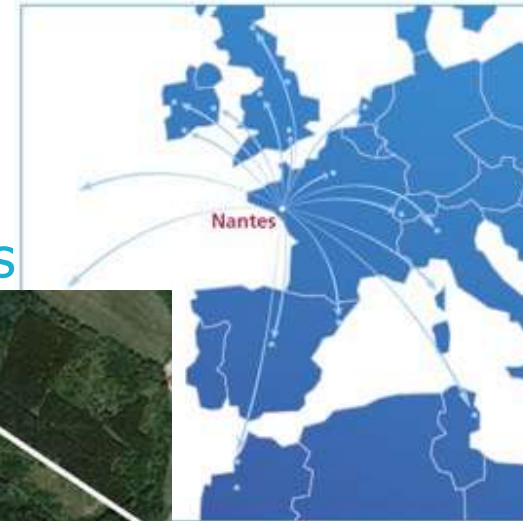


Université
Gustave Eiffel

Univ Eiffel Nantes Campus



280-320 staff in 12 research teams



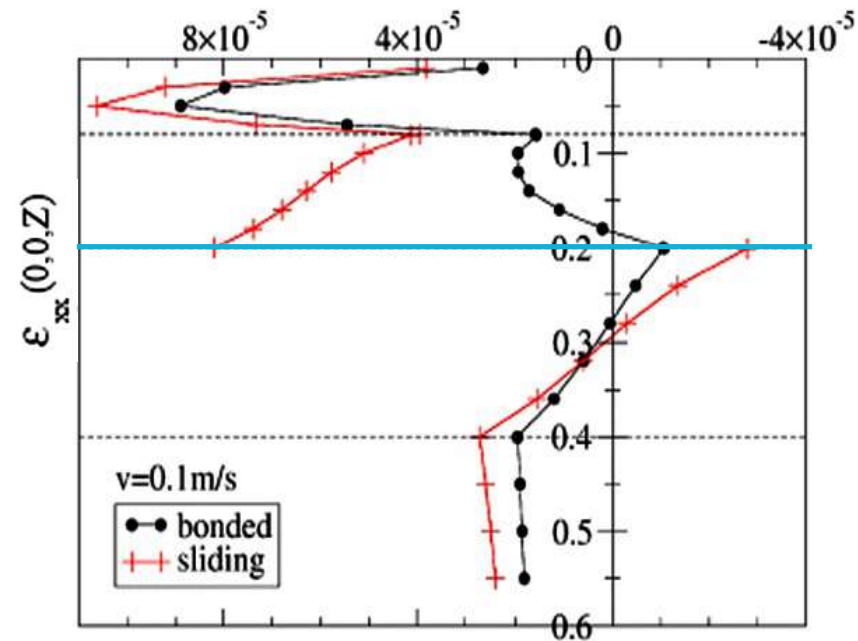
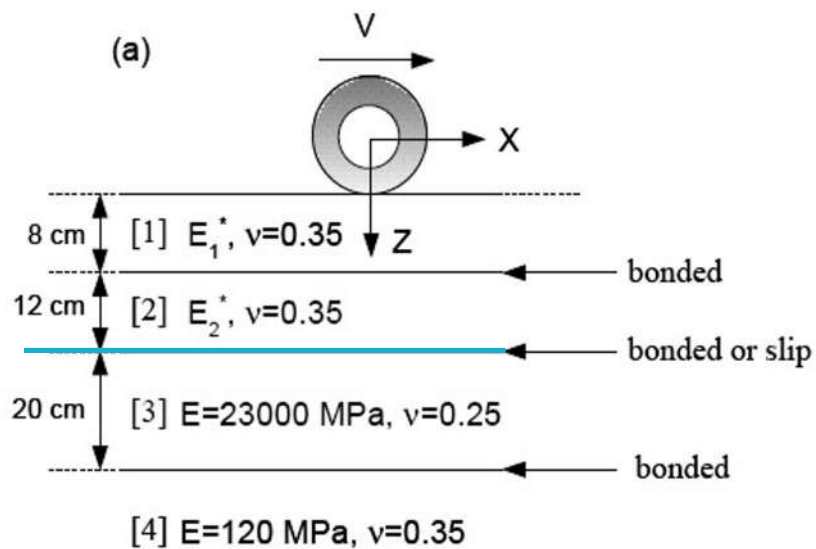
<https://www.youtube.com/watch?v=nGhMk1hEZw>



1/3: Interface Debonding & Pavements ?

Composite Pavement → Case of a Sliding Interface

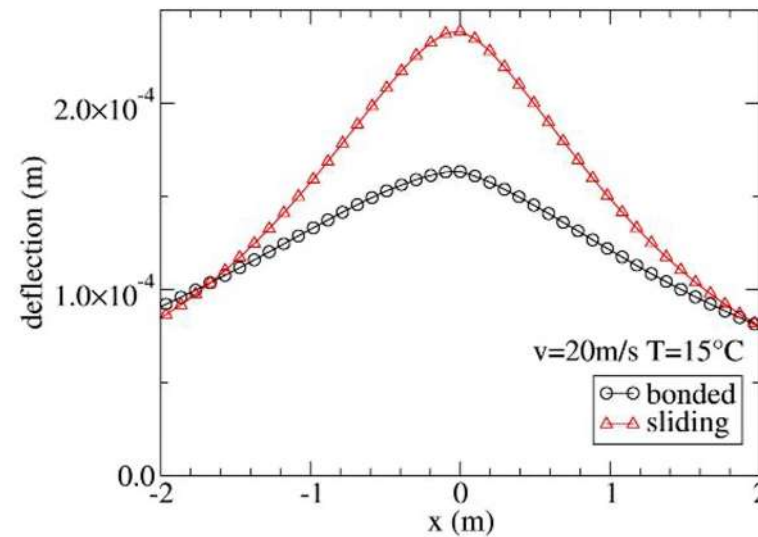
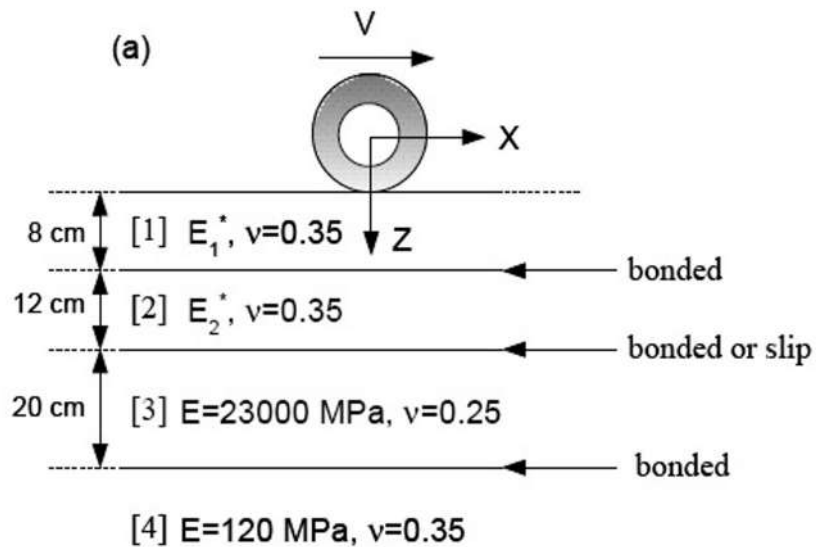
<https://lames.univ-gustave-eiffel.fr/materiels-et-logiciels/viscoroute>
 ViscoRoute2.0 © (LCPC,2009) All rights reserved



Chupin, Chabot, Piau & Duhamel, 2010. *IJSS*, 47 (25/26): 3435-3446, doi:10.1016/j.ijssolstr.2010.08.020

Composite Pavement → Case of a Sliding Interface

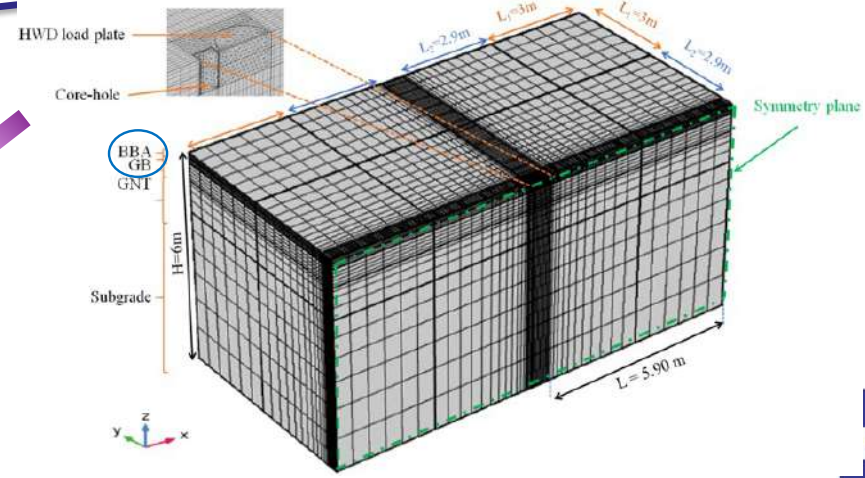
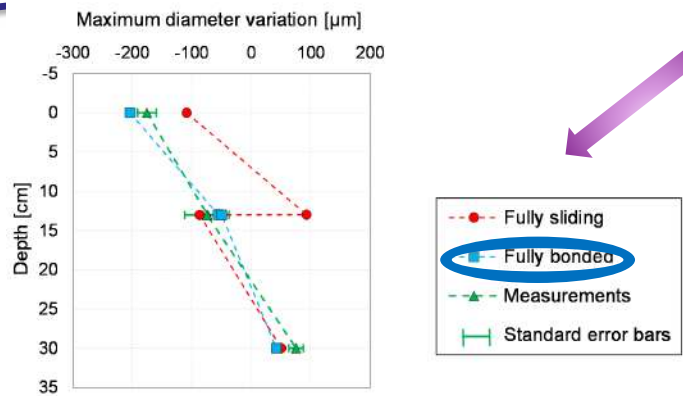
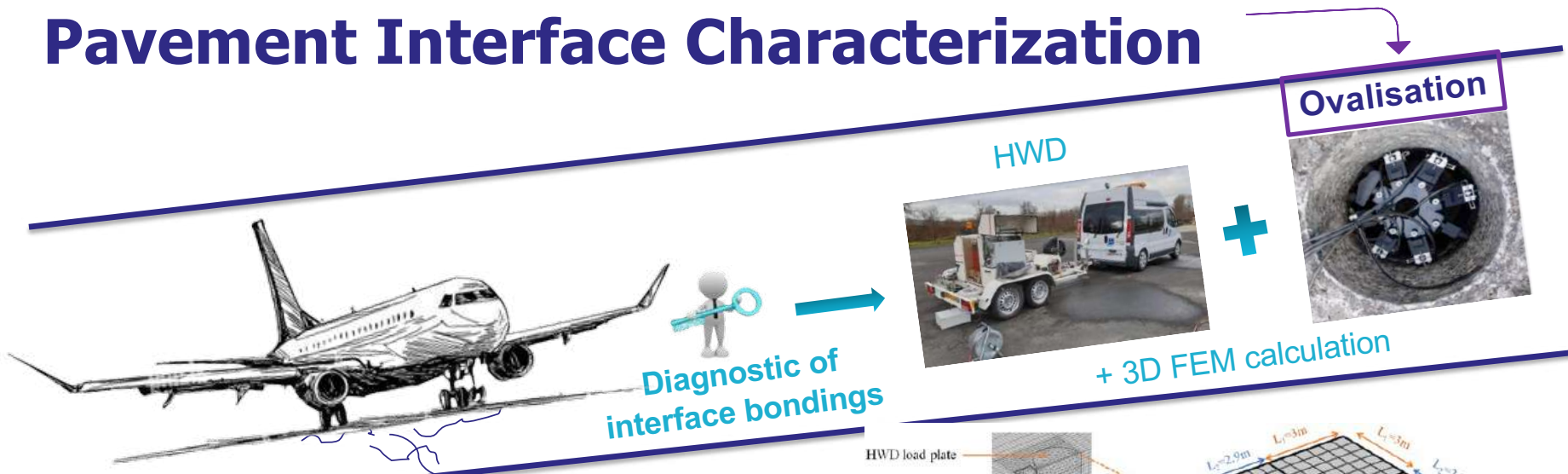
<https://lames.univ-gustave-eiffel.fr/materiels-et-logiciels/viscoroute>
 ViscoRoute2.0 © (LCPC,2009) All rights reserved



→ Pavement life ↘

Chupin, Chabot, Piau & Duhamel, 2010. *IJSS*, 47 (25/26): 3435-3446, doi:10.1016/j.ijssolstr.2010.08.020

In Situ Measurement Device for Airfield Pavement Interface Characterization



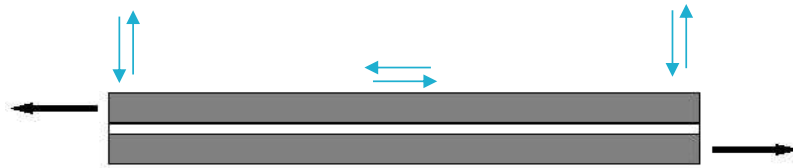


Debonding & Pavements?

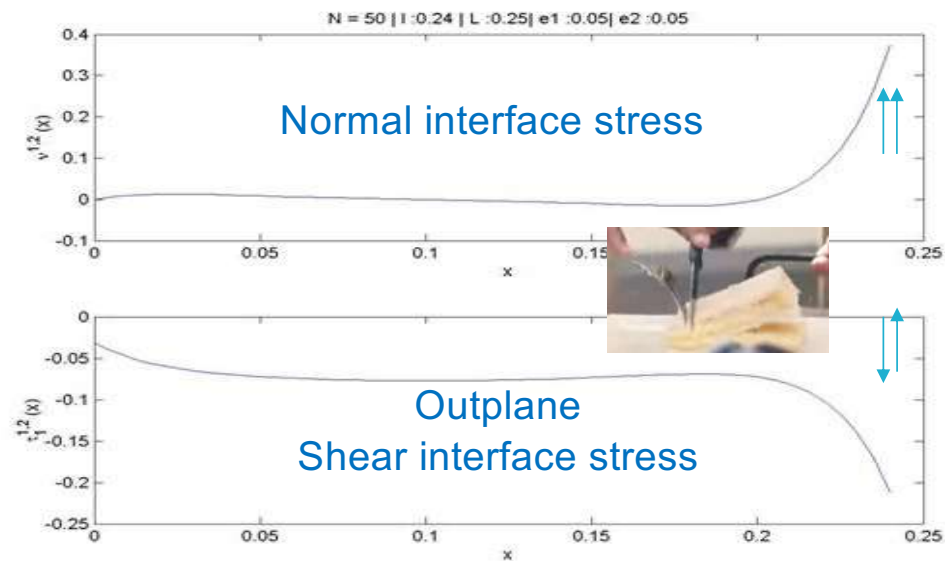


Edge effects → Outplane Interface Stresses

Tension exemple

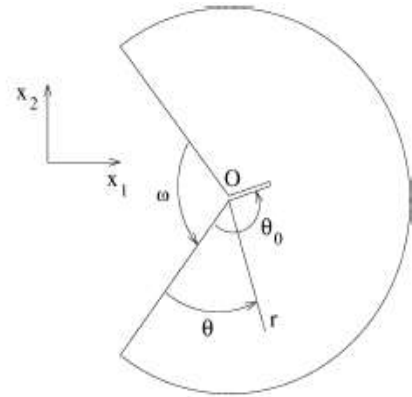


Bending exemple Pouteau PhD thesis (2004) <https://theses.hal.science/tel-03118831>



Bond Criteria ? $G < G_c$

Homogeneous elastic material: $\lambda = 1/2$



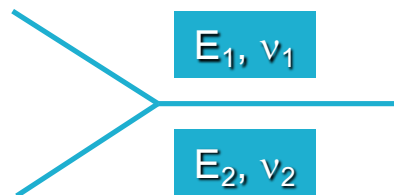
$$\bar{\sigma} = \frac{K_I}{\sqrt{r}} f_I(\theta) + \frac{K_{II}}{\sqrt{r}} f_{II}(\theta) + \dots$$

$$\underline{U}(x_1, x_2) = \underline{U}(O) + kr^\lambda \underline{u}(\theta) + \dots$$



The critical value k_c depends on the opening ω of the notch, it must be experimentally determined. The factors k and k_c are strongly dependent of the singularity and in particular of the exponent λ . Units for

For a bi-material, λ is a complex number!



Point stress?

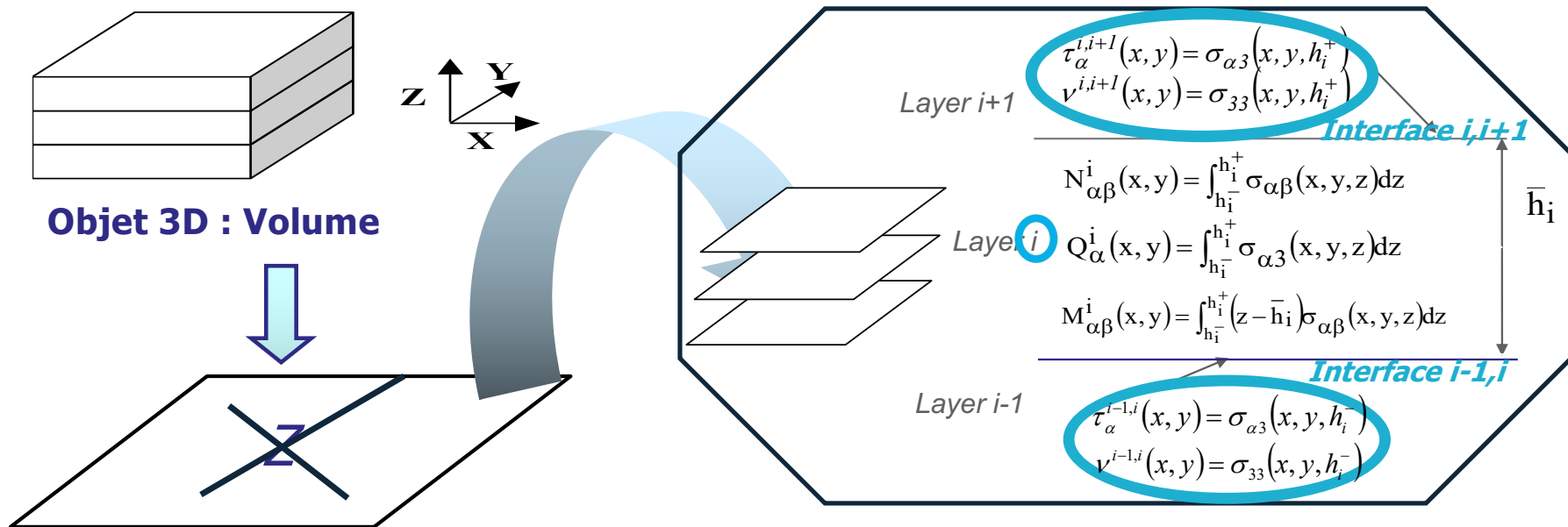
Average stress?

Energy release rate -> fatigue...: Paris law?

England AH, 1965. A crack between dissimilar media. Journal of Applied Mechanics: 32:400-402.
Williams ML., 1959. The stress around a fault or crack in dissimilar media. Bull ScismolSoc Am, 49:199-204.

Family of (5+2) Multi-particle Model of Multi-layer Materials (M4) - Chabot PhD thesis (1997) <https://pastel.hal.science/tel-00197853>

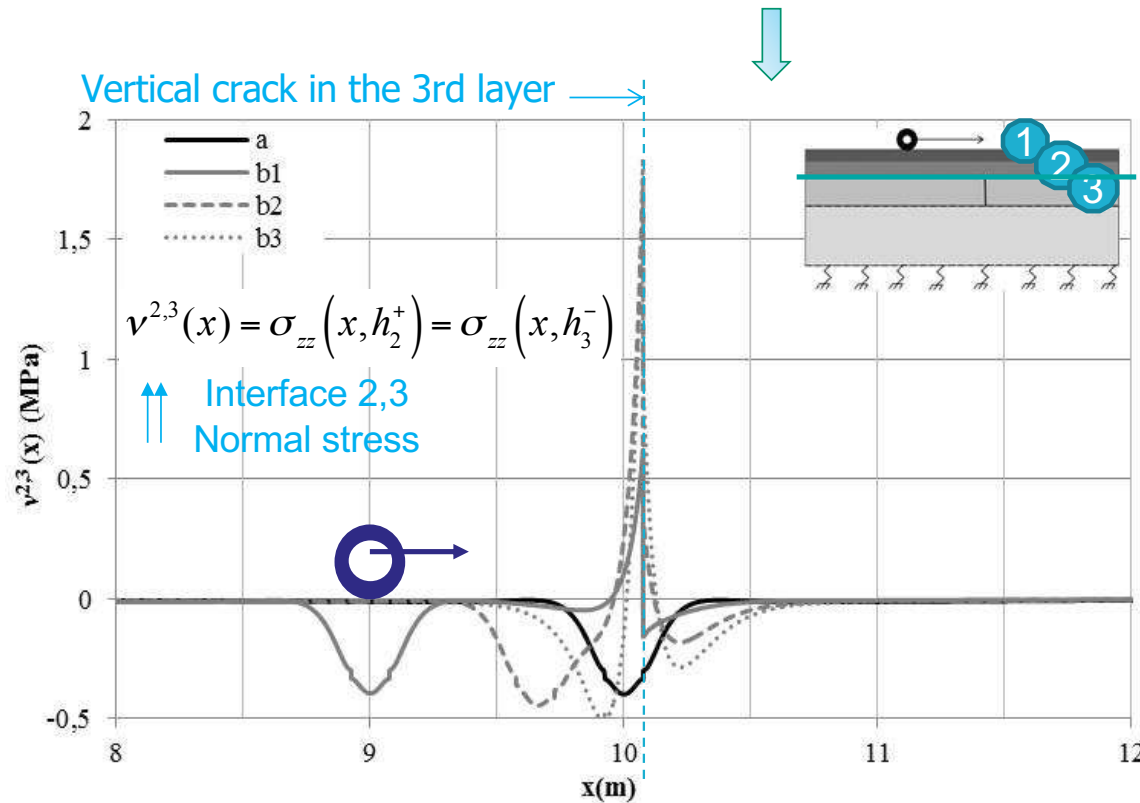
- ✓ Polynomial approximation per layer i in z for $\sigma_{ij}(x,y,z)$
- ✓ Hellinger-Reissner formulation (Reissner, 1950)



Composite pavement → Vertically Cracked Layer

Nasser PhD thesis (2016)

2D Half-analytical Elastic Solution & *3D Mixed FEM Developments



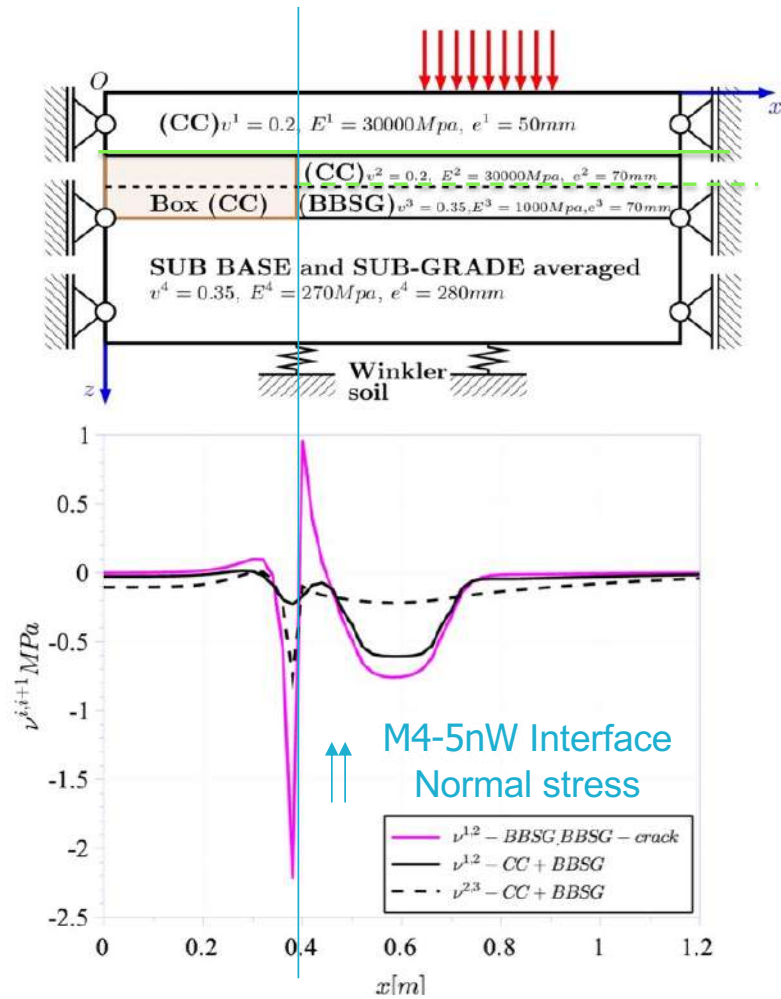
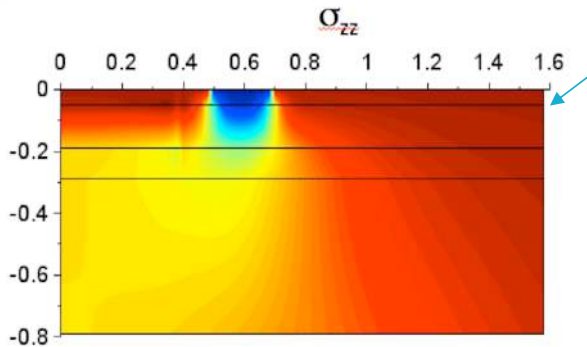
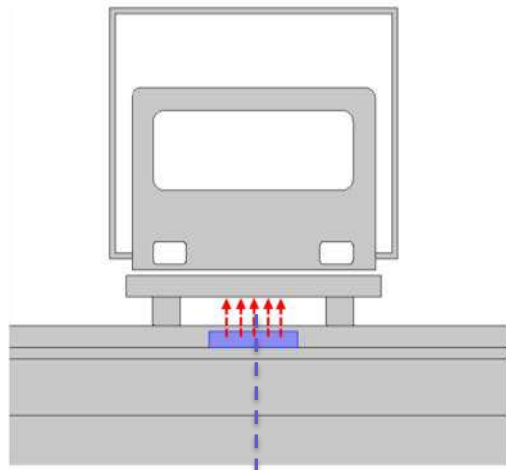
| Material | Thickness (m) | Young's modulus (MPa) | Poisson's ratio |
|----------|---------------|-----------------------|-----------------|
| BBSG | $e^1=0.08$ | $E^1=5400$ | $\nu^1=0.35$ |
| GB3 | $e^2=0.15$ | $E^2=9300$ | $\nu^2=0.35$ |
| GC3 | $e^3=0.23$ | $E^3=23000$ | $\nu^3=0.25$ |
| Soil | - | $E^s=120$ | $\nu^4=0.35$ |

M4-5nW :

- 5 kinematic fields per layer $i, i \in \{1, n\}$
- Winkler's springs for the soil

eRoad composite system

After Chen KTH PhD thesis (2016), Sweden



Chabot A., Deep P., 2019. *RMPD*, 20 (sup2): s590-s603, doi: 10.1080/14680629.2019.1621445

2/3: Lab. Characterization?



Cracking in Pavement Group (2001-2004)

→ 5th RILEM CP Int. Conf. (CP2004) Limoges, France

*Pavement Cracking Study Group
1st Meeting BRRC Brussels, November 2001*

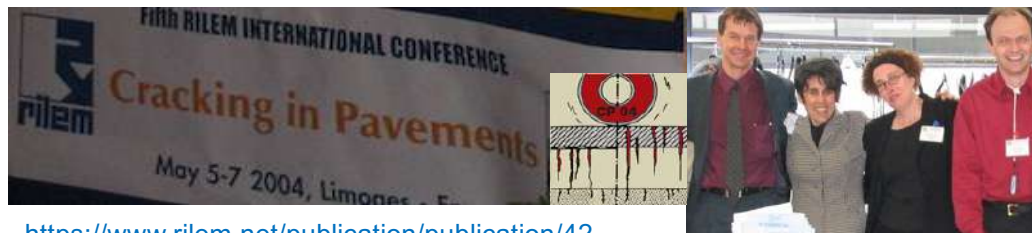
Document TC157-PRC N21

1st Meeting of the Cracking in pavement study group

Belgian Road Technical University of KRAKOW (Poland)
April 19-20 1999

Presents :

Mrs Wanda GRZYBOWSKA, Leslie MYERS, Prof. Imad Al Qadi, Louis FRANCKEN (Chairman), Ann VANELSTRAETE, Arlette CHABOT, Louise WENDLING, Anne MILLIEN, Prof. Christophe PETIT, Prof. André MOLENAAR, Arian DE BONDT, John POTTER, Didier LEONARD.



<https://www.rilem.net/publication/publication/42>



...TG2 of TC241-MCD (2011-2017) → Interface Debonding Behavior

2 MODE I – OPENING MODE

2.1 Tensile Bond Test (TBT)

2.2 **Tensile Notch Bond Test (TNBT)**

3 MODE II – IN PLANE SHEAR MODE

3.1 Shear Bond Test SBT (without normal stress)

3.2 Shear Bond Test SBT (with normal stress)

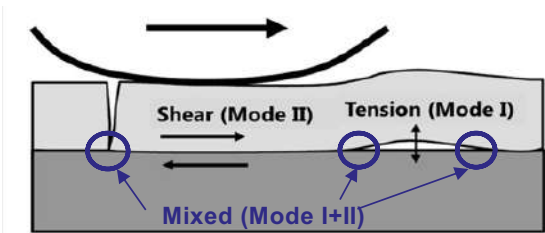
4 MODE III – OUT PLANE SHEAR MODE

5 MIXED MODE (I + II)

5.1 **Three point bending test**

5.2 Four point bending test

5.3 Composite specimen interface test (CSIC)

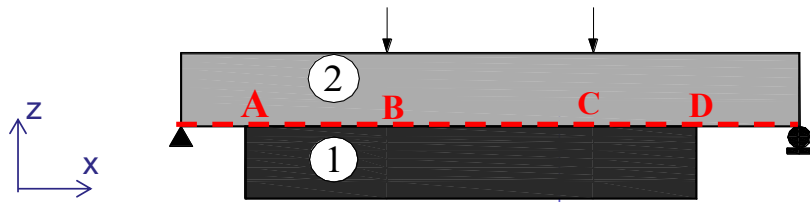


After Raab & Partl (2004)

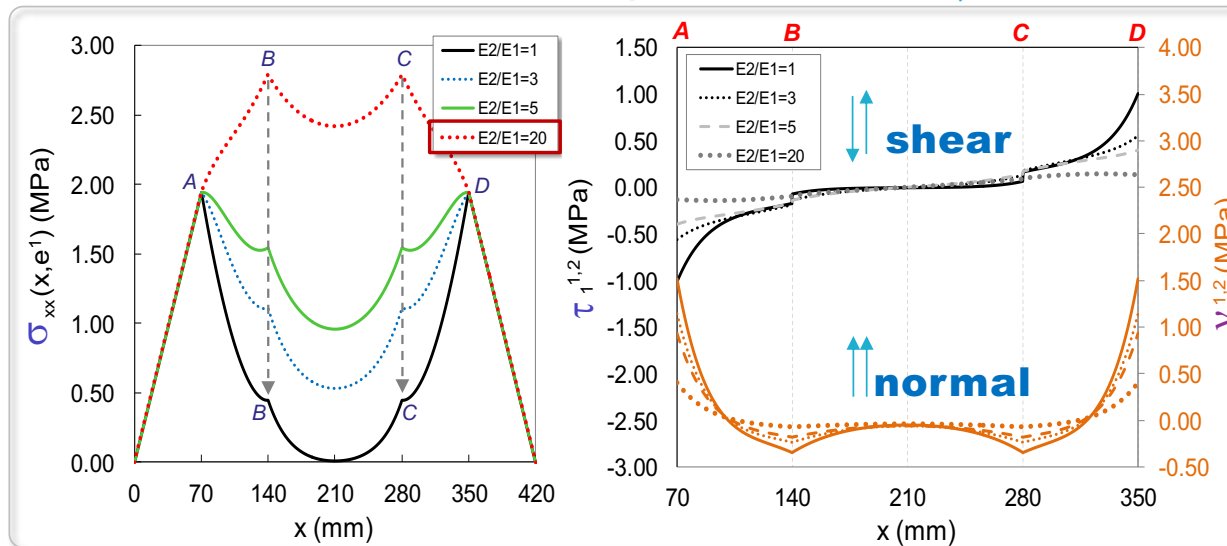


4pt Bending tests (Mixed Mode): geometry & E_2/E_1

Hun PhD thesis (2012) <https://www.theses.fr/2012ECDN0042>



Tension stress at the Bottom of layer2 Interface 1,2 stresses



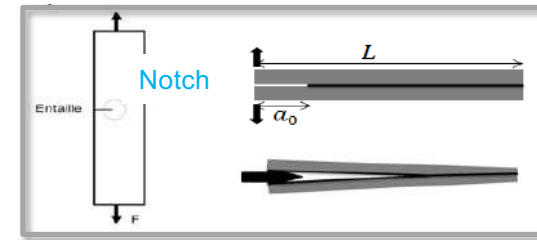
M4-5n Energy Release Rate using VCCT, G_{VCCT}

$$G_{VCCT}(a) = G_I(a) + G_{II}(a)$$

- G_I function of $(v^{1,2}(x_a))^2$
- G_{II} function of : $(\tau_1^{1,2}(x_a))^2$ and! $Q_1^1(x_a) \cdot \tau_1^{1,2}(x_a)$

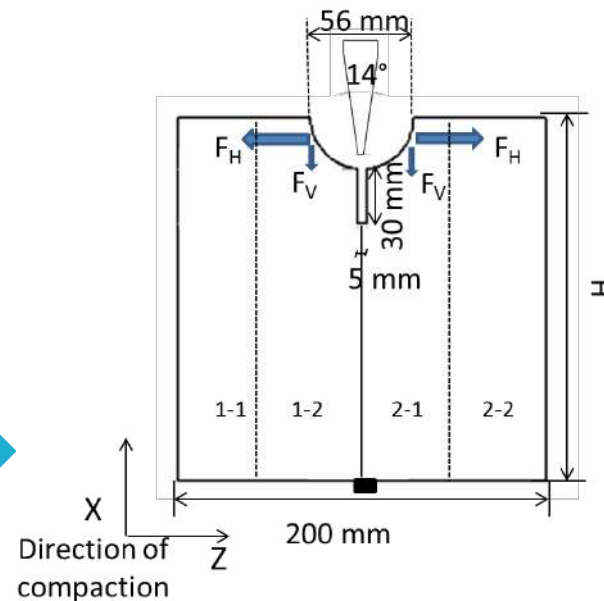
Wedge Splitting Test (WST)

Gharbi PhD thesis (2018) <https://www.theses.fr/2018ECDN0037>



Tschegg, 1986. Equipment and appropriate specimen shapes for tests to measure fracture values, AT No. 390328, Austrian Patent Office, Vienna, Austria.

Adaptation of the WST for extracted specimen coming from a test track

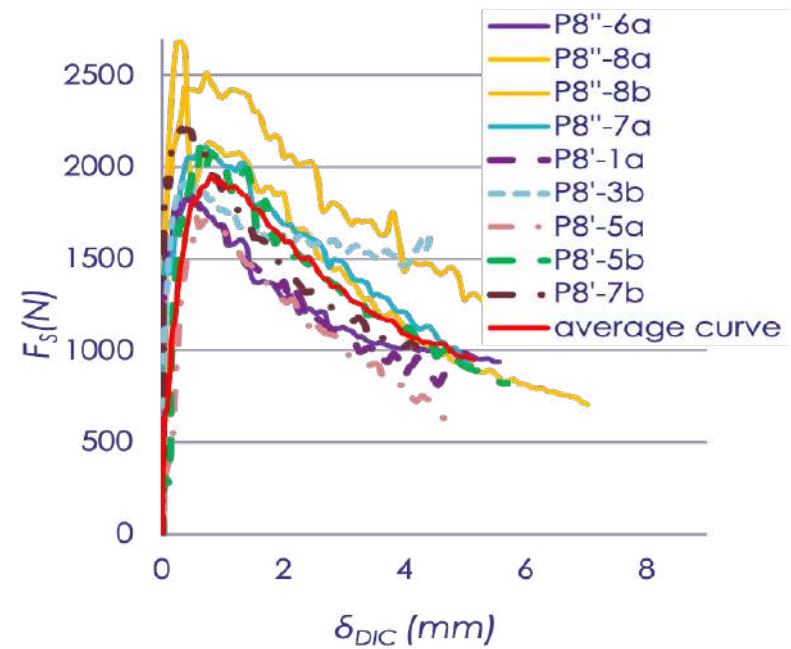
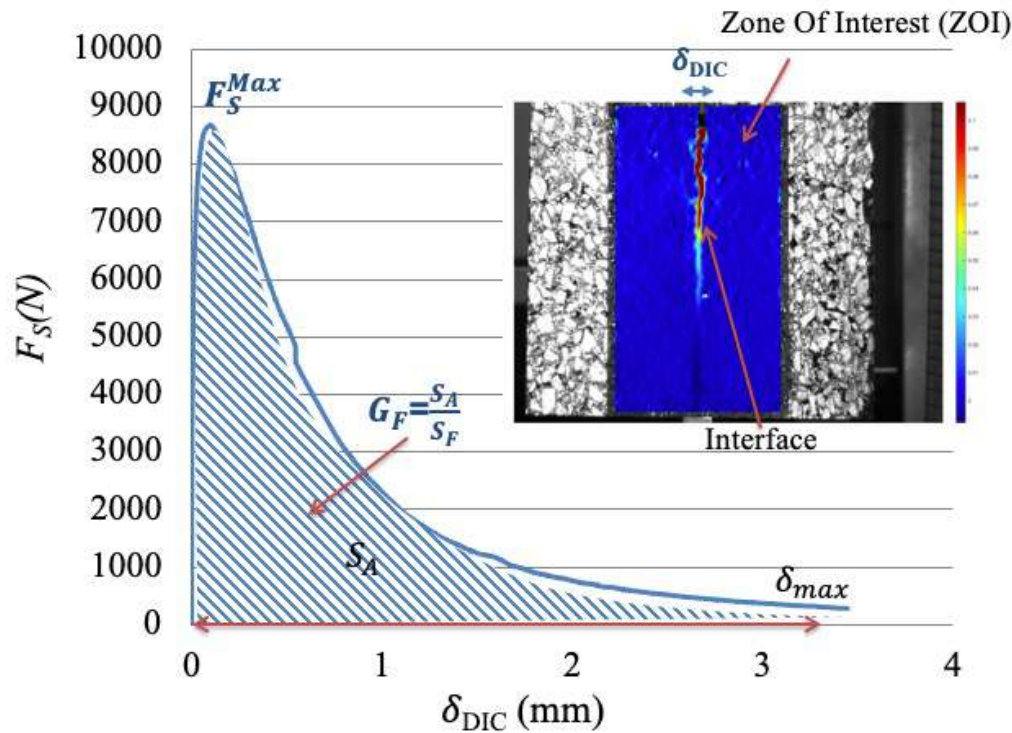


Gharbi, Nguyen, Trichet, Chabot, 2017. *BCRRA2017*, CRC Press (Verlag), doi: 10.1201/9781315100333-201



Mode I WST case

Gharbi PhD thesis (2018) <https://www.theses.fr/2018ECDN0037>

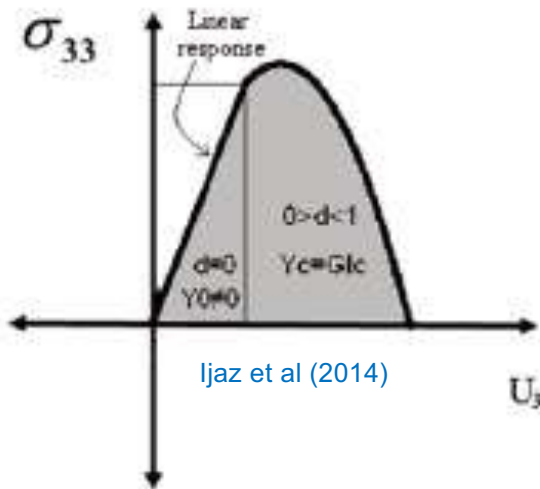


WST Modeling using Viscohinite in Cast3M FEM

Damage modeling tacking into account a delay and \neq opening modes

(Mode I or Mixed Mode I+II)

$$\text{Damage speed: } \dot{d} = k(\omega(\underline{Y}) - d)^m$$



$$\underline{Y}(t) = \sup_{\tau \leq t} \left[\left((Y_{d_n})^\alpha + (\gamma Y_{d_s})^\alpha \right)^{1/\alpha} \right]$$

$$\omega(\underline{Y}) = \left[\frac{n}{n+1} \frac{Y - Y_0}{Y_c - Y_0} \right]^n$$

Parameters

Interface stiffnesses: k_n, k_s

Energy : Y_0, Y_c

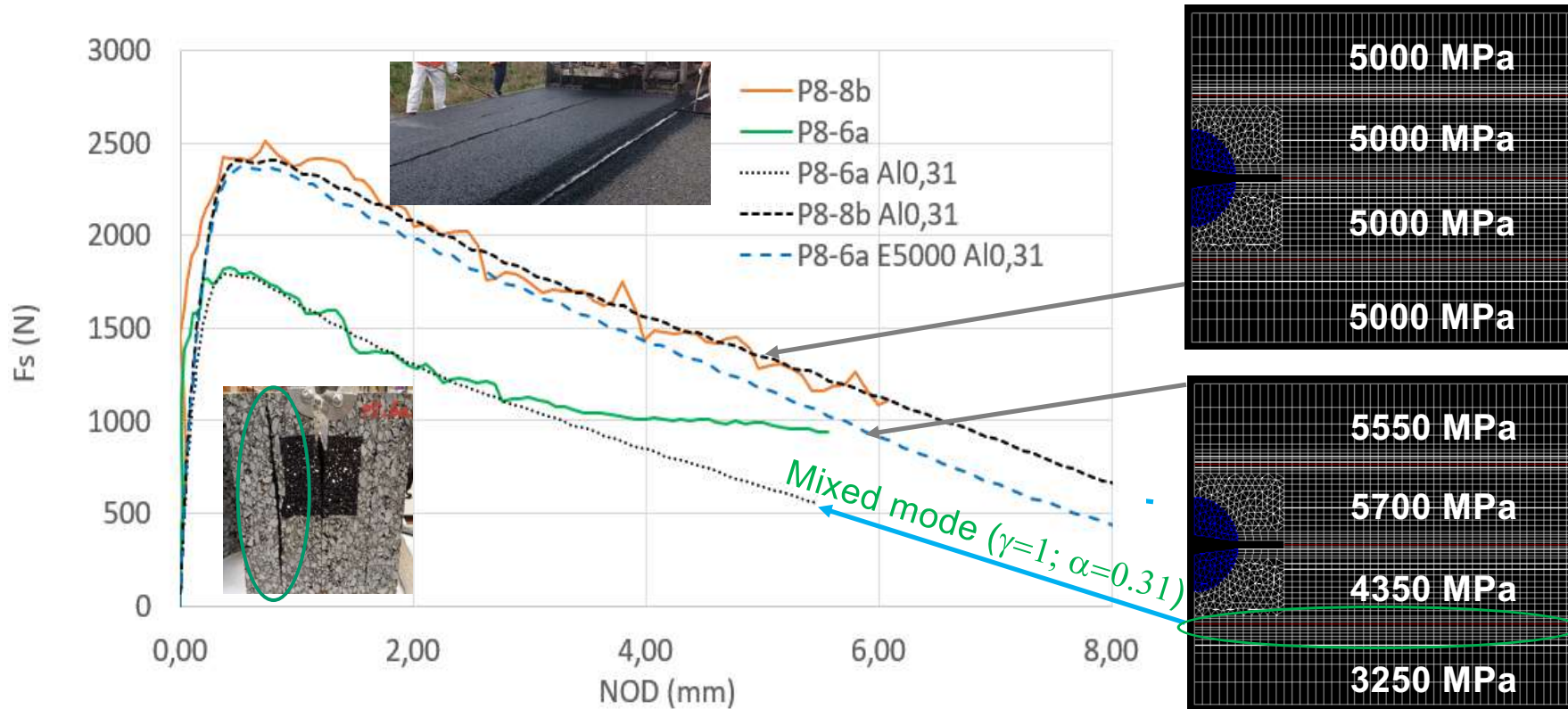
Delay : k, m

Mode I et II Contribution : γ, α

Interface fragility: n



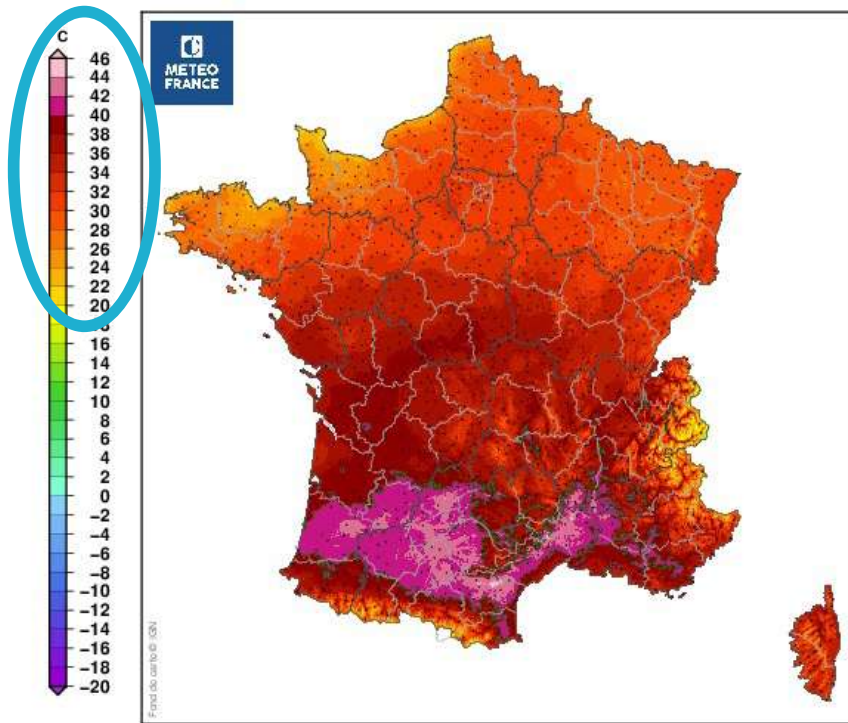
Fitting two exp. curves using the Viscohinte model



Lemartinel, Chabot, Dave, Gornet, 2022. 25ème Congrès Français de Mécanique. <https://hal.science/hal-03713539>

3/3: Actual Direction
→ Cities & Urban Heat Island Pb

Climate Evolution (T°C)



Températures maximales du 23 août 2023. © Météo-France

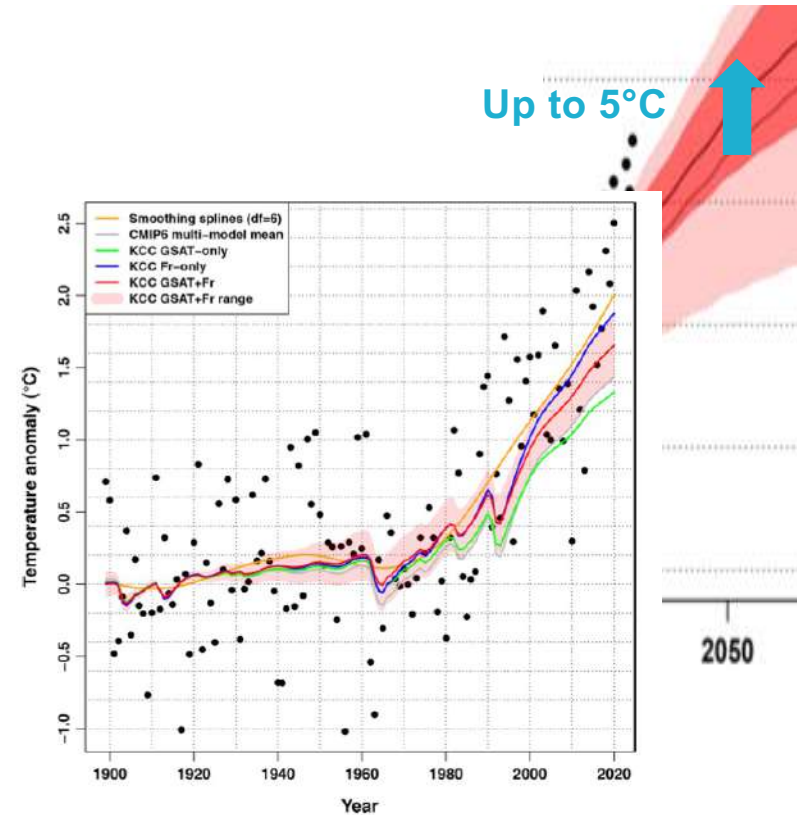
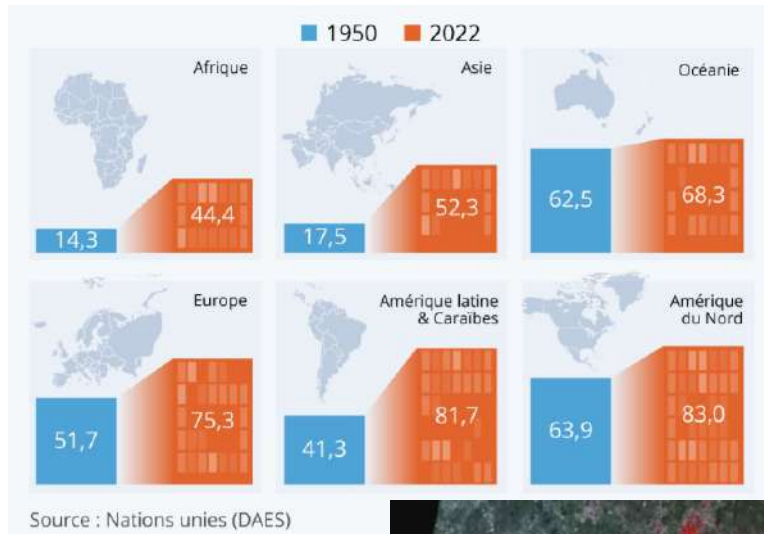


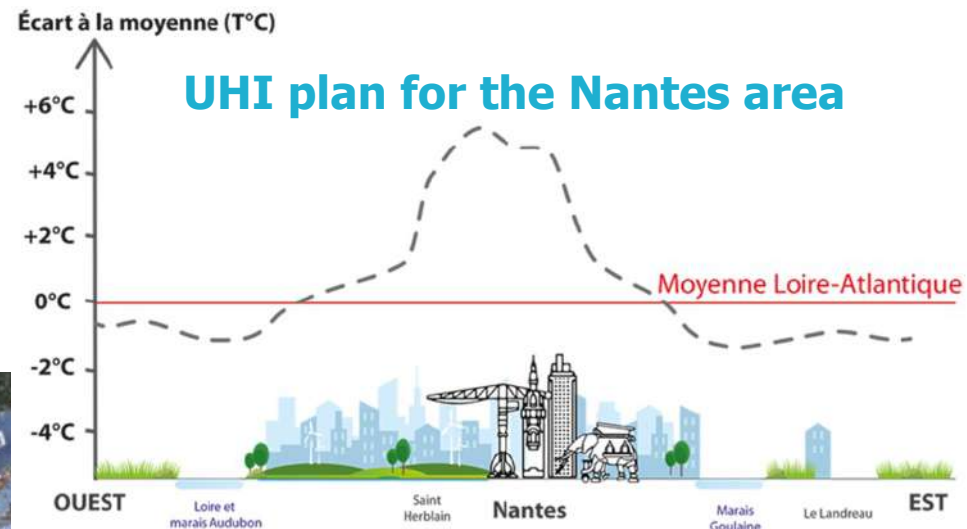
Figure 1. Observations vs. forced response estimates. Observed annual mean temperatures over France (1899–2020, black points) are compared to various estimates of the forced response over the same period. Orange: simple smoothing spline estimate using $df = 6$ (degrees of freedom). Gray: CMIP6 multi-model mean estimate (best estimate only). Green: result of the KCC constraint using only GSAT observations (best estimate only). Blue: result of the KCC constraint using only regional observations (i.e., over France). Red: result of the KCC constraint using both GSAT and regional observations to build the constraint. The 5%–95% uncertainty range is assessed in the latter case.

Urban Heat Island (UHI)

2020: 80% of French people live in cities



N°81 - Juin 2022 BNews



From <https://auran.org/content/quest-ce-quun-ilot-de-chaueur>



From http://klimat.czn.uj.edu.pl/enid/2__Climat_urbain/-_llots_de_chaleur_2uk.html



Some UHI Solutions...

From Colombert (2008) after www.espere.net



Paris



Lyon ... Los Angeles ...



Nantes, Durham, ... , Urbana-Champaign (2010)...



Upcoming literature review presentation:

→ Tormos, Chabot, Dave, 2024. Int. ISAP2024 conf., 2/6 June, Montreal, Canada. <https://isap2024.ca>

Bending case with Discontinuities and climate change



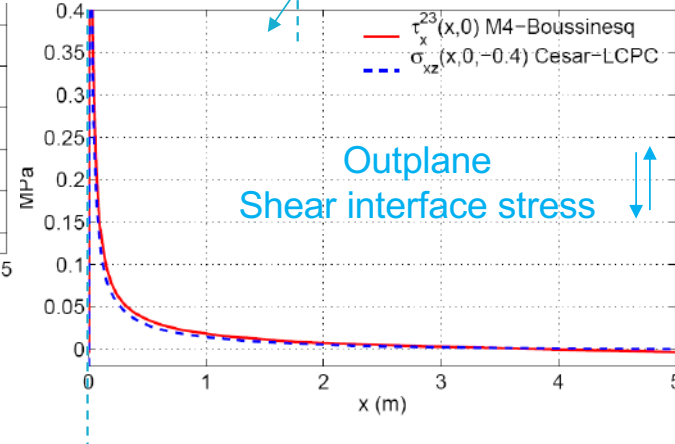
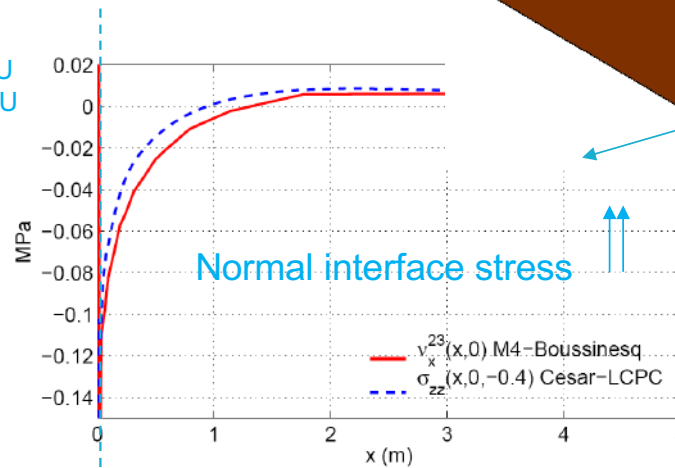
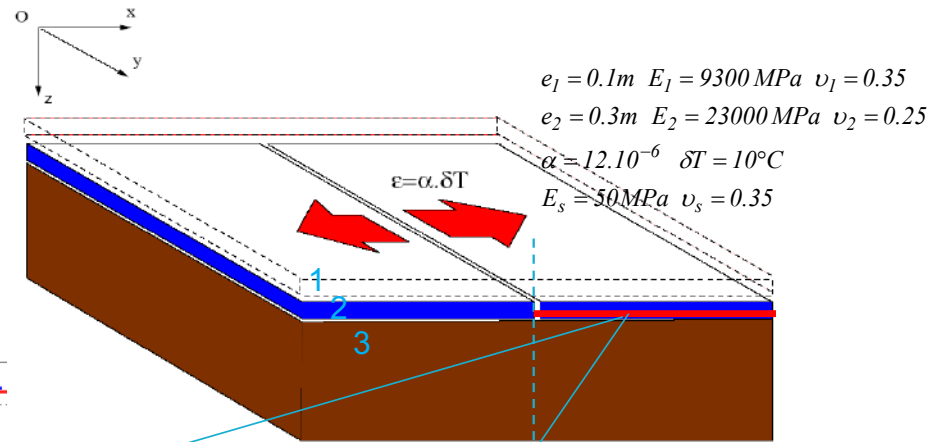
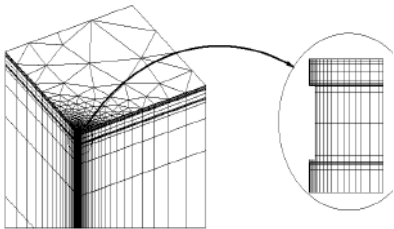
Comp. Pav. → Effect of the coef. of thermal expansion

Tran PhD Thesis (2004) <https://pastel.hal.science/pastel-00001026>

M4-5nB :

- 5 kinematic fields per layer $i, i \in \{1, n\}$
- Boussinesq model for the soil

M4-5nB (in Matlab) → 15min CPU
3D FEM(César-LCPC) → 2h CPU

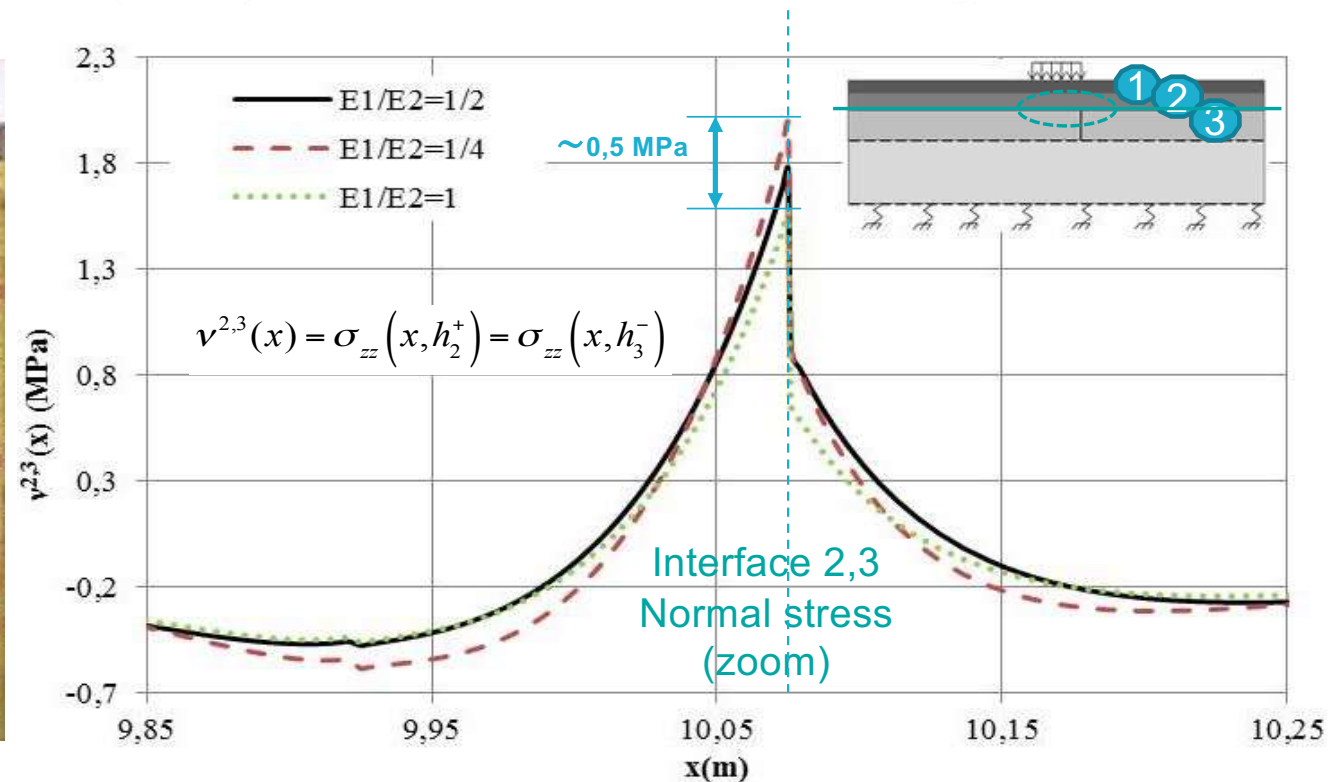


Chabot, Tran & Ehrlacher, 2007. CRC Press 1: 431-440. <https://pastel.hal.science/pastel-00001026>

Comp. Pav. → Effect of ≠ E Ratio due to ≠ T°C

2D M4-5nW analysis

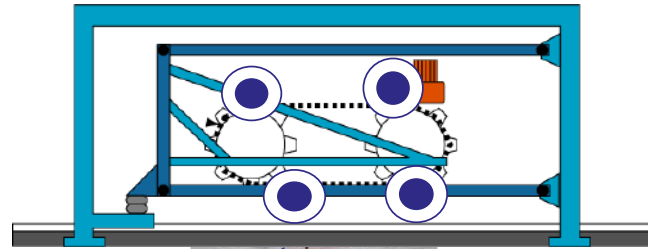
Composite pavement → Vertical crack reaching the interface 2,3



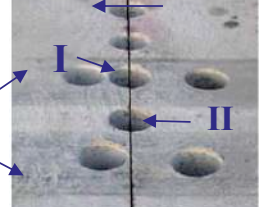
Nasser, Chabot, 2018. *Advances in Engineering Software*, 117: 107-122. <https://doi.org/10.1016/j.advengsoft.2017.06.008>

Bonding ALT analysis of UTW (French Urbain Roads)

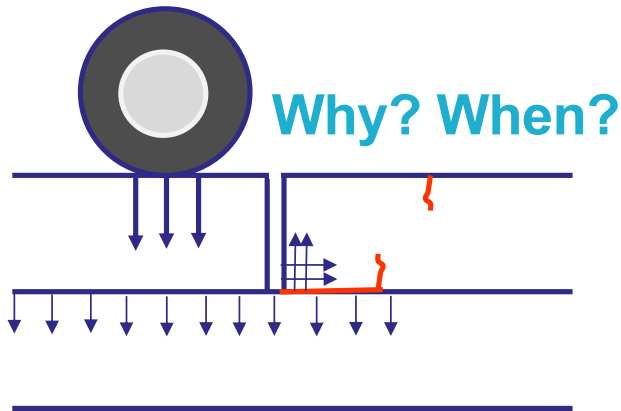
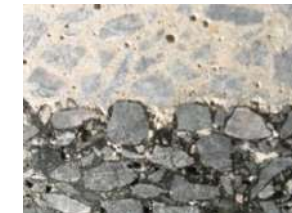
Pouteau PhD thesis (2004) - <https://hal.science/hal-04227042>



Rolling path



Interface or Interphase?



Cold T°C
→ 3 materials?

Hot T°C: $E_{cc} \gg E_{ac}$

French Climate evolution (water)




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Égalité
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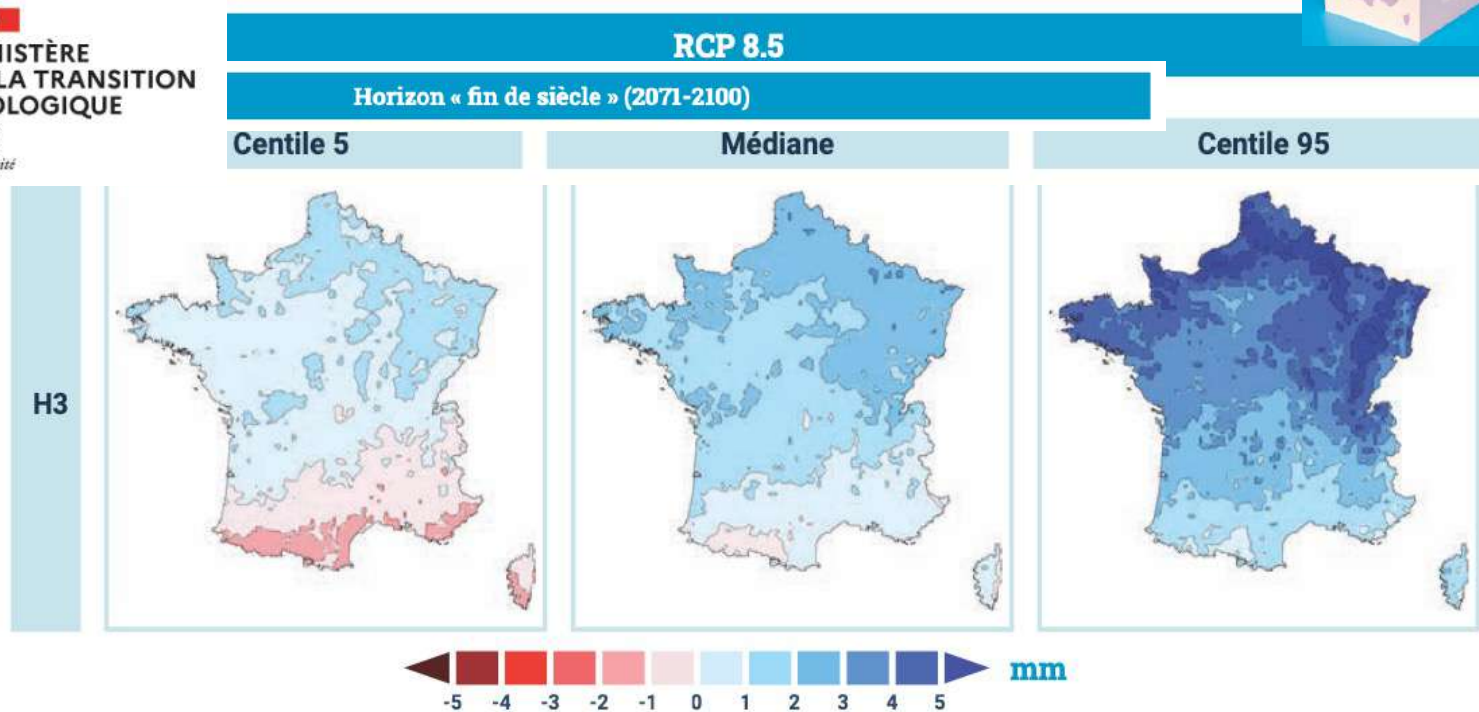


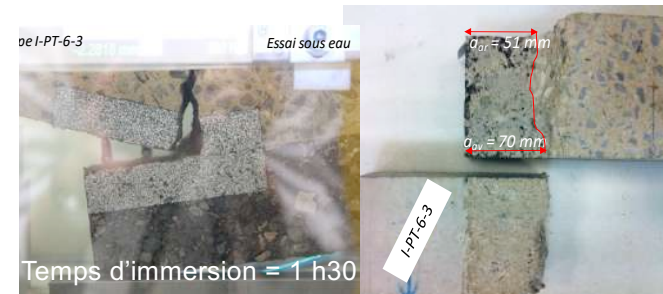
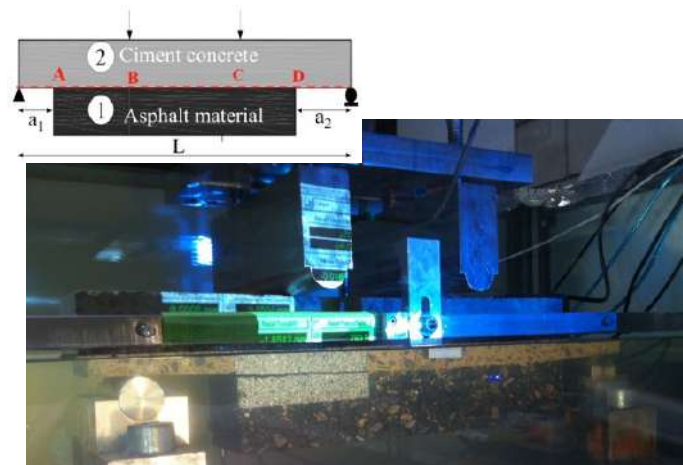
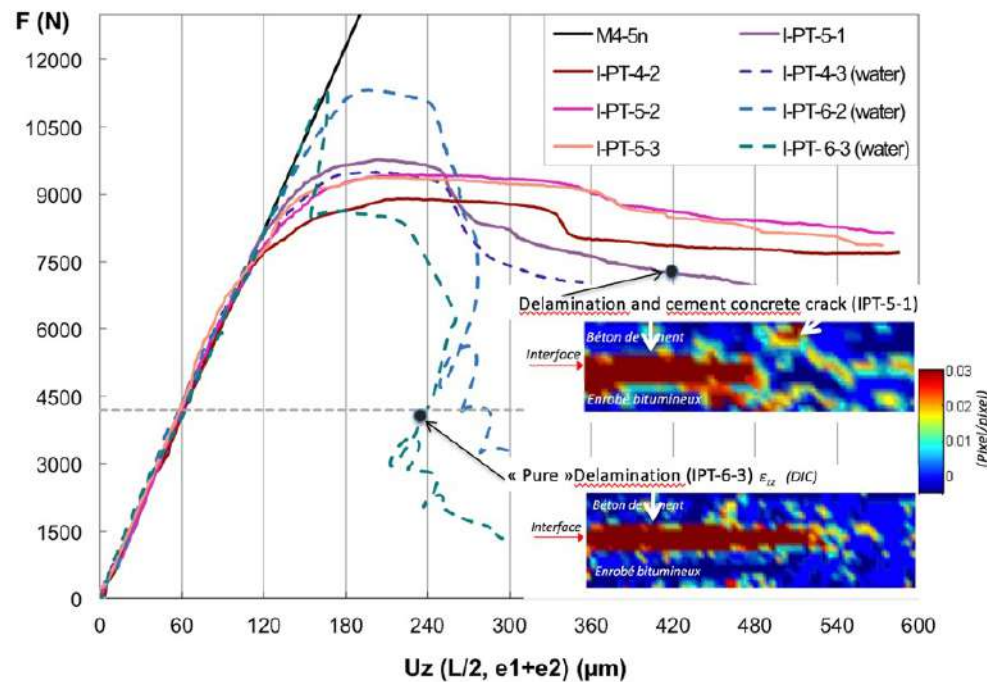
Figure 28 : Cartes des écarts de cumul de pluies extrêmes pour le RCP8.5 et les trois horizons et selon les paramètres de la distribution C5, C50 et C95.

<https://www.drias-climat.fr/document/rapport-DRIAS-2020-red3-2.pdf>

4pt Bending tests in Water & UTW Specimen

Hun PhD thesis (2012) <https://theses.hal.science/tel-00851093>

(0,7 mm/min) ~20°C

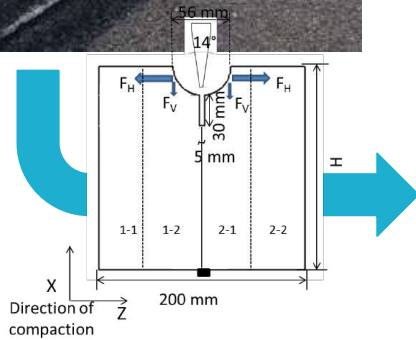


Chabot, Hammoum & Hun, 2017. *EJECE*, 21 (sup1): 54-69. doi: 10.1080/19648189.2017.1320237

WST in Water & AC specimens

Gharbi PhD thesis (2018) <https://www.theses.fr/2018ECDN0037>

WST (2 mm/min) in water



P8-15a, 20.6 °C



P8-2a, 19.9 °C



What about add. boundary condition effects?

Cities → Pavement inclusions (such as eRoads, vegetation, ...)



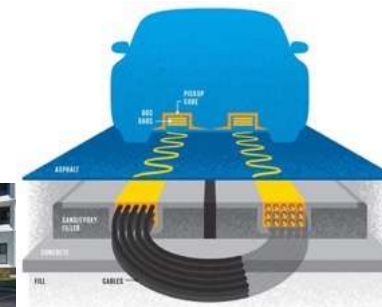
https://contrevues.paris/wp-content/uploads/2019/09/synthese-des-travaux-de-sun_compressed.pdf



Vincennes



Nantes





Conclusion / Prospects

Conclusion / Prospects

1/3: Interface Debonding & Pavements

Which Pavement model to use for which purpose?

Need of data coming from field (Loads & T°C & Water, Materials, Geometries)

Mixed-mode & "pure Mode" failure criteria required for debonding

2/3: Characterization of interface resistance up to failure

Repeated testing required for heterogeneous materials (sizes?)

Tests with \neq T°C with and without **water effect**

Tools: DIC; Damage/delay modeling (CZM)... but what about 3D?

3/3: Urban Heat Island Pb

Need to work with urban planning researchers

Multi-materials ; Multiple loadings... **Boundary conditions?**



PHOTOS. Chutes d'arbres, toits arrachés : les dégâts de la tempête Aurore à Paris | Actu Paris

2021

Thank you for your attention!



Armelle Chabot

MAST-LAMES (Campus de Nantes)
<https://www.univ-gustave-eiffel.fr/>

 **Université
Gustave Eiffel**