Workshop: New approaches to address pavement failure more realistically in asphaltic pavement design methods

… to promote a discussion about different approaches to address pavement failure, primarily cracking, in design methods.

Jorge Soares & Michael Wistuba

Pavement design: past, present, future, where is the crack? by Dr. Laurent Porot (The Netherlands)

German design and management approaches addressing asphalt pavement cracking, by Dr. Michael Wistuba (Germany)

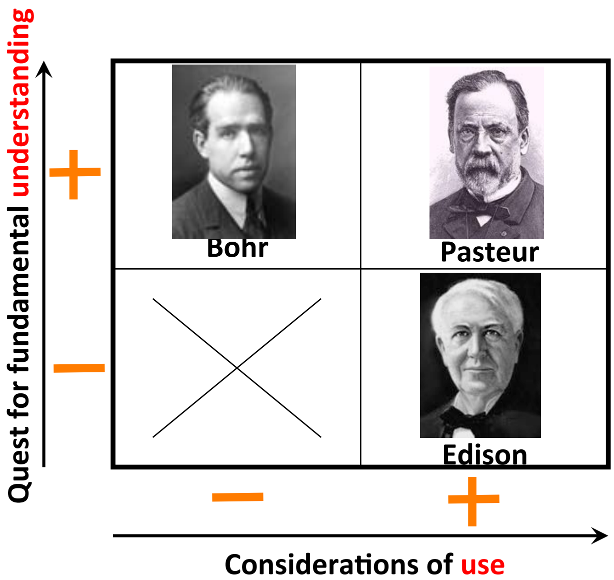
Fatigue cracking within the new mechanistic-empirical pavement design method in Brazil, by Dr. Jorge Soares (Brazil)

Recent Developments in Accelerated Pavement Testing (APT) as a Pavement Design Tool in Costa Rica, by Dr. Luis Loria-Salazar (Costa Rica)

June 8th, 2016

Pasteur's Quadrant

Good Science, Well Appplied



Fatigue cracking prediction within the new M-E pavement design guide in Brazil

Workshop: New approaches to address pavement failure more realistically in asphaltic pavement design methods

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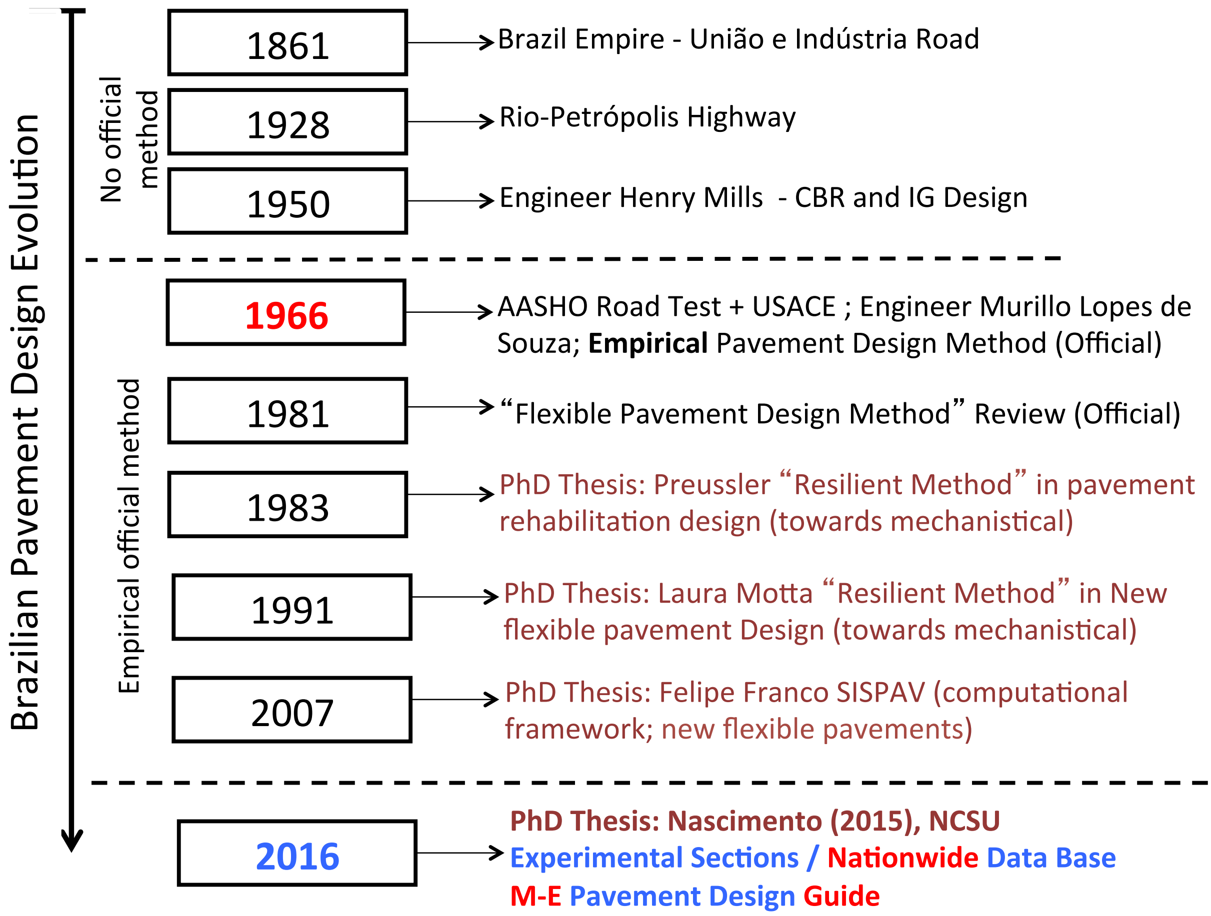
PETROBRAS

Laboratório de Mecânica dos Pavimentos

June 8th, 2016



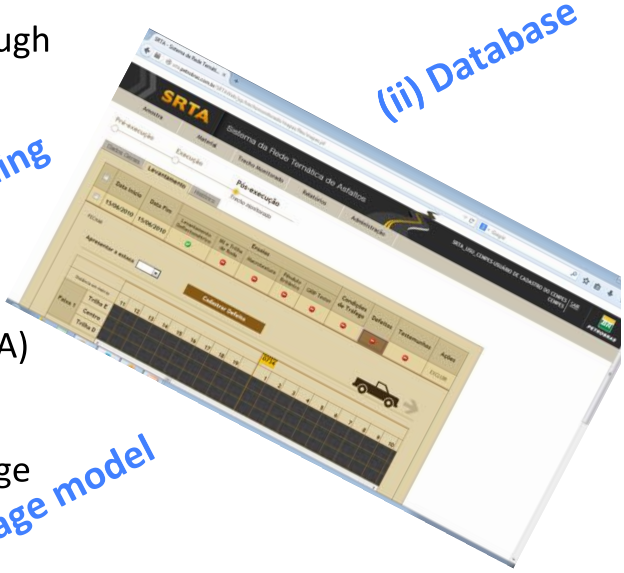
Pavement Analysis Background in Brazil

- Empirical approaches without thorough validation

- M-E pavement design guide under development by the **Asphalt Research Network** (**Petrobras** since 2005) ➔ **16 universities + DNIT** (Brazilian FHWA)

- **VECD model** for asphalt mixture characterization and pavement damage analysis

(i) Funding



(ii) Database

(iii) Damage model

OBJECTIVES:

- To build and to evaluate the **field performance** of asphalt pavement sections throughout the country, subjected to real traffic loading

- To develop and/or to validate pavement **materials performance models**; To develop an analysis **framework tool**

Brazilian Database

TS	Location	Traffic, number of ESALs (first year)	Cracked area at last survey, %	Construction technique	Designed asphalt thickness, mm	Asphalt mixture
UFSM 1	Santa Maria, RS	4.49E+05	32.9	Overlay, no milling	50	UFSM 50/70 2
UFSM 3	Santa Maria, RS	8.72E+05	0.0	New pavement	70	UFSM 50/70 1
UFRGS 2	Porto Alegre, RS	7.60E+06	0.0	New pavement	50	UFRGS 60/85
USP 4	Ribeirão Preto, SP	1.40E+05	0.0	New pavement	40	USP 50/70
USP 5	Ribeirão Preto, SP	1.40E+05	0.0	New pavement	40	USP 30/45
ND 1	Aparecida do Norte, SP	2.56E+06	9.0	Overlay, partial milling	140	ND 15/25
ND 2	Aparecida do Norte, SP	2.56E+06	3.0	Overlay, partial milling	200	ND 15/25
ND 3	Aparecida do Norte, SP	2.56E+06	4.8	Overlay, partial milling	140	ND 15/25
ND 4	Aparecida do Norte, SP	2.56E+06	12.5	Overlay, partial milling	200	ND 15/25
ND 5	Aparecida do Norte, SP	2.56E+06	19.0	Overlay, partial milling	200	ND HM 1
ND 6	Aparecida do Norte, SP	2.56E+06	5.9	Overlay, partial milling	200	ND HM 1
ND 7	Aparecida do Norte, SP	2.56E+06	10.0	Overlay, partial milling	140	ND HM 1
ND 8	Aparecida do Norte, SP	2.56E+06	0.0	Overlay, partial milling	140	ND HM 2
ND 9	Aparecida do Norte, SP	2.56E+06	0.0	Overlay, partial milling	200	ND HM 2
ND 10	Aparecida do Norte, SP	2.56E+06	0.0	Overlay, partial milling	140	ND HM 2
UFSC 2	Araranguá, SC	1.33E+07	20.0	New pavement	150	UFSC 50/70
UFSC 3	Araranguá, SC	1.33E+07	0.0	New pavement	114 (top) 56 (bottom)	UFSC 50/70 (top) UFSC RA (bottom)

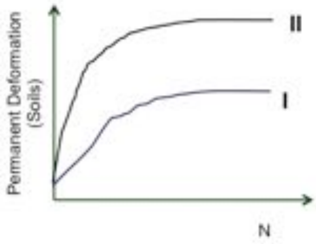
Pavement Analysis Background in Brazil

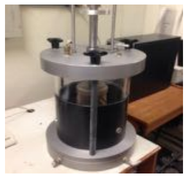
Basic Level

Advanced Level

Permanent Deformation

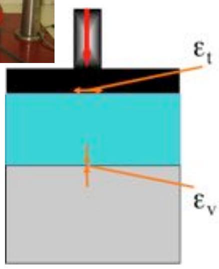
Flow Number (traffic)

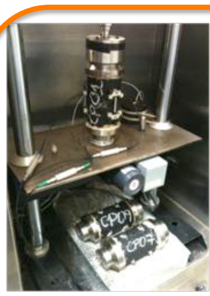


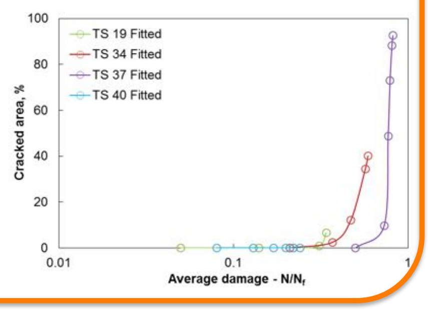


Flow Number (traffic) (confinement?)

Fatigue

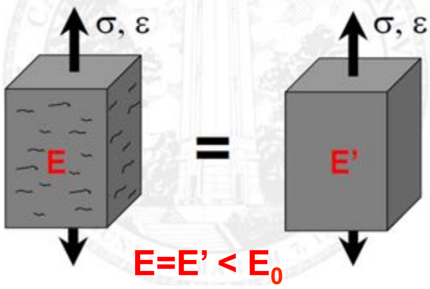


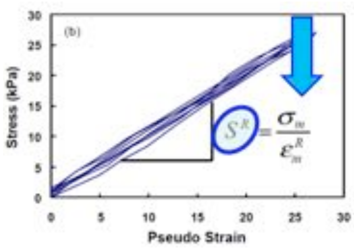




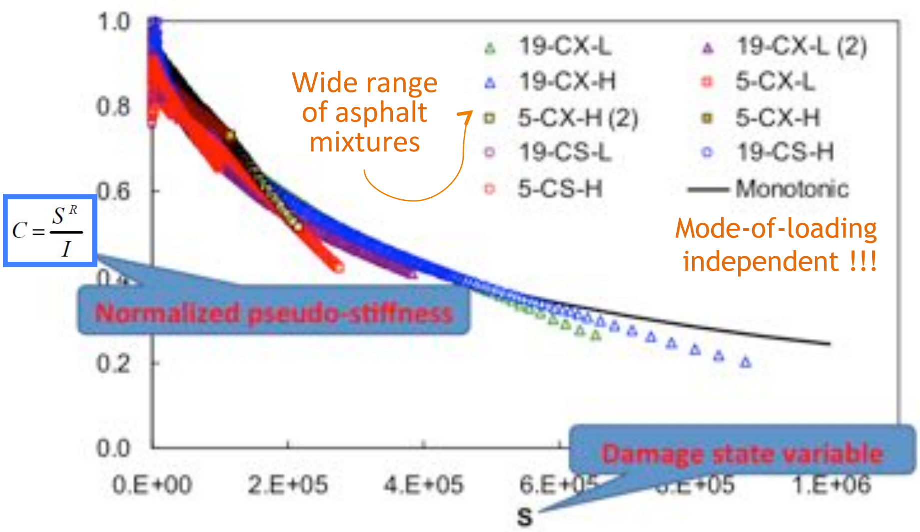
LABORATORY

Viscoelastic Continuum Damage Theory
VECD Model





Typical evolution of a damage test



$$C = e^{aS^b}$$

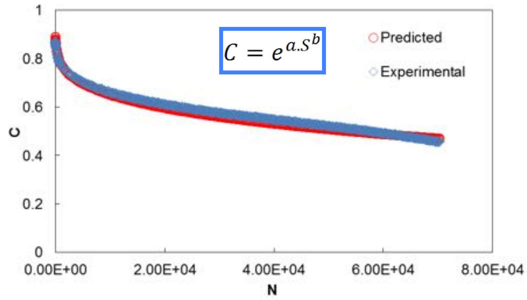
Microcracking described by state variable *S*

LABORATORY

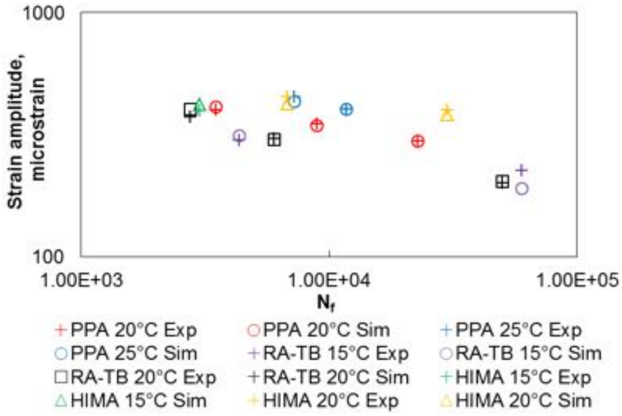
Controlled-strain Fatigue Testing Simulation

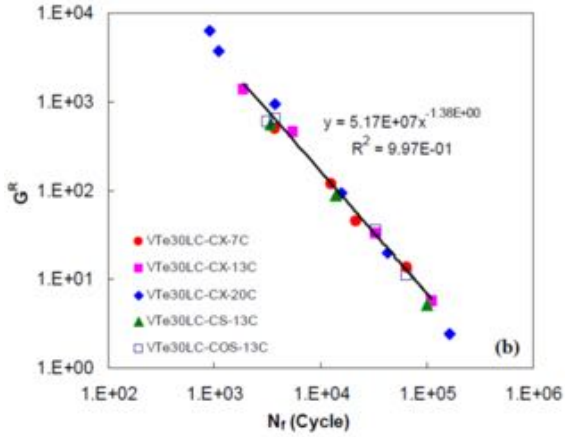
S-VECD + G^R - based failure criterion

$$G^R = \frac{\overline{W}_C^R}{N_f} = \frac{\int_0^{N_f} W_C^R}{N_f^2}$$



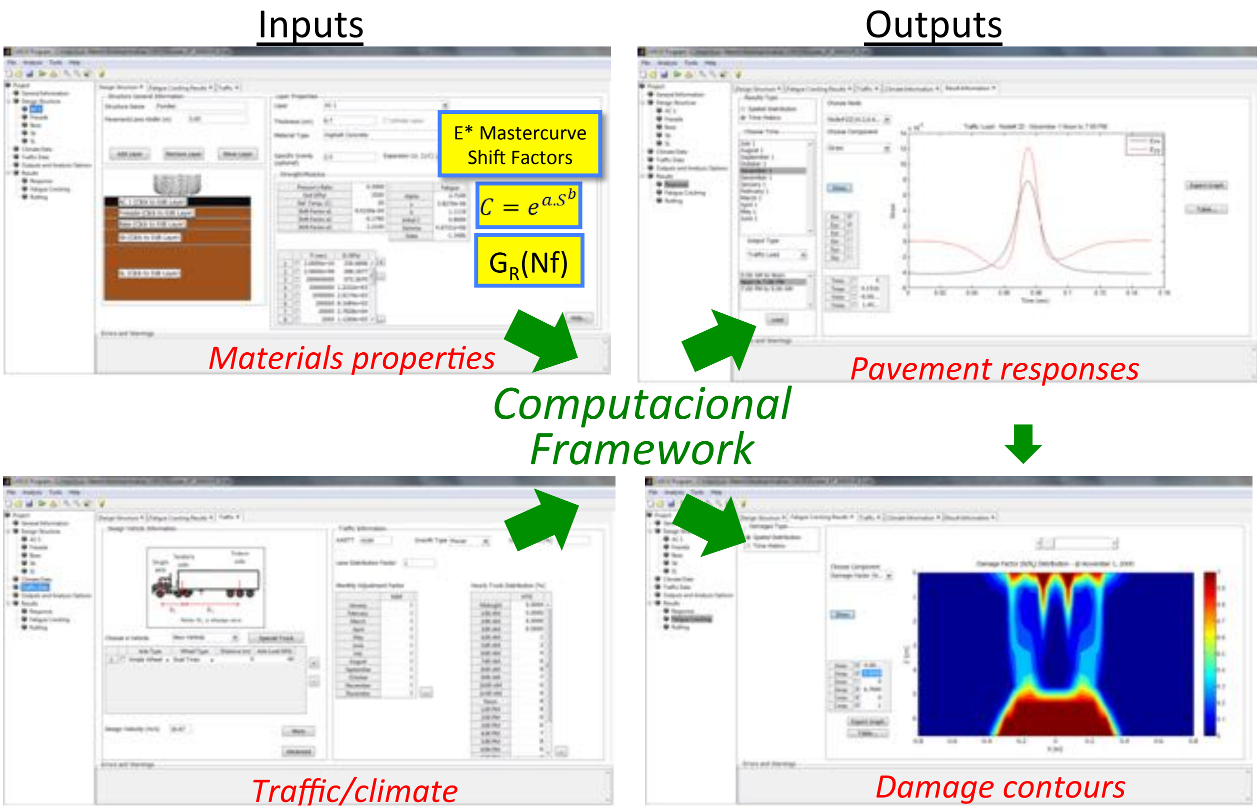
N_f → Predicted vs. Experimental





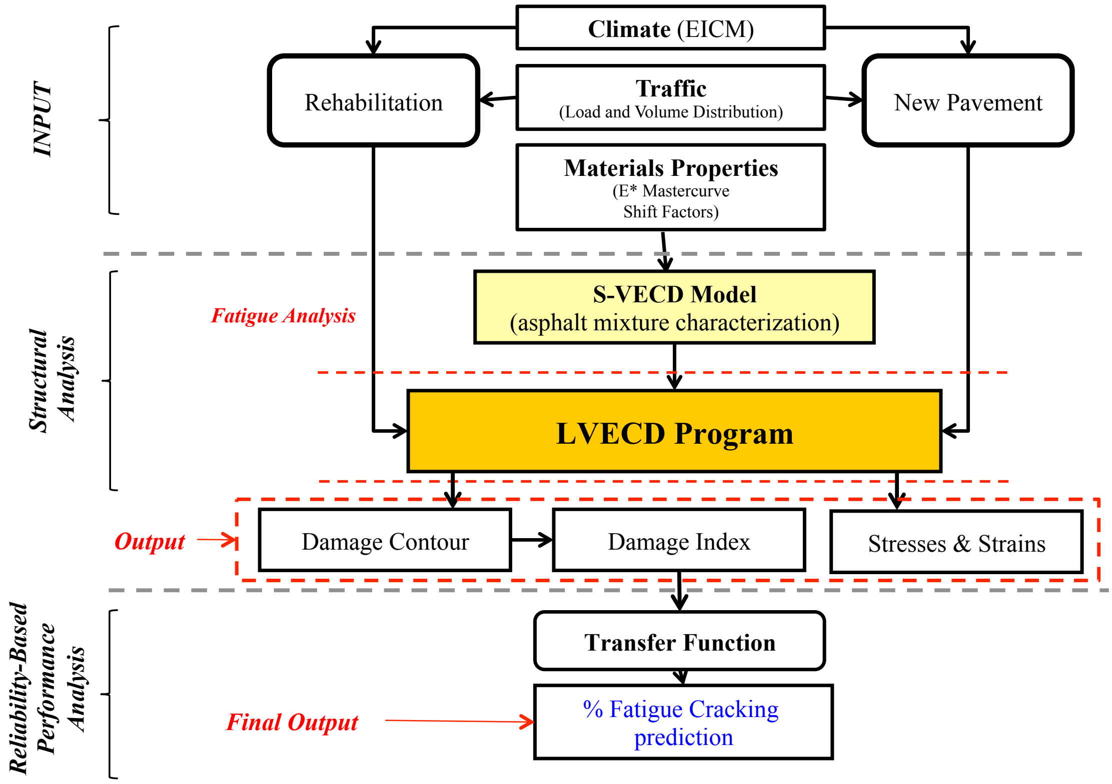
COMPUTATIONAL SIMULATION

Layered ViscoElastic Pavement Analysis for Critical Distresses (1.1Beta program)



Analysis Framework

(Fatigue Cracking)



LVECD Validation and Calibration in Brazil

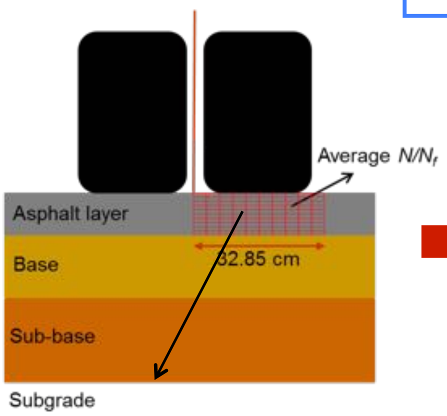
- **44 pavement sections** ➔ Rio de Janeiro, São Paulo, Santa Catarina, Rio Grande do Sul, and Ceará
- Wide range of pavement structures and traffic levels
- Different damage levels ➔ fatigue cracked areas
- Asphalt layers thicknesses: 40 mm to 200 mm
- Wide range of asphalt mixtures
- Materials and data availability

TS	ESALs (first year)	Cracked area, %	Overlay technique	Designed overlay thickness, mm	Asphalt mixture
19	7.28E+05	7.0	Full milling	50 60	30/45 19.1 mm (top) 65/90 19.1 mm (bottom)
34	1.11E+06	42	Partial milling	70	30/45 19.1 mm
37	1.18E+06	87	Partial milling	50	30/45 12.5 mm
40	1.39E+06	0	SAM / No milling	50	30/45 12.5 mm

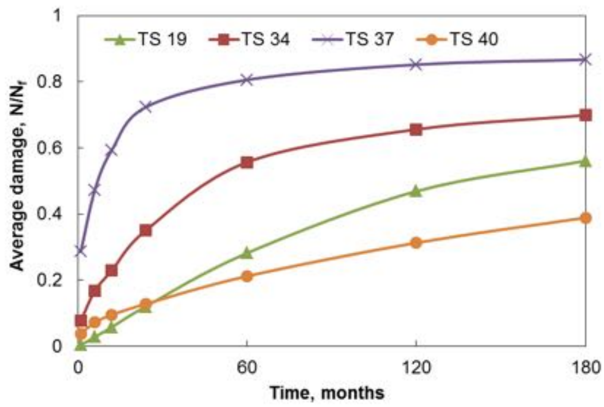
Damage Index Proposed N/Nf

- N/N_f ratio values underneath the loaded area are averaged
- N/Nf obtained from G_R failure criterion using Miner's law

$$G^R = \frac{\overline{W}_C^R}{N_f} = \frac{\int_0^{N_f} W_C^R}{N_f^2}$$



Grid of 110 points (10 x 11)



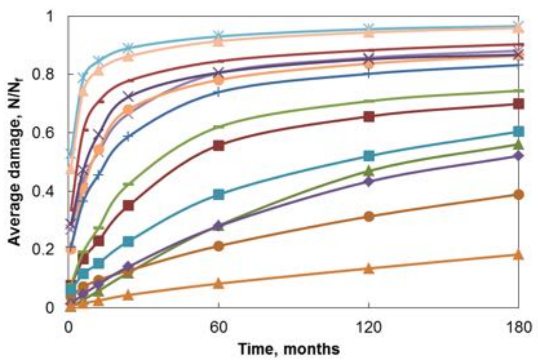
Averaged damage vs. Time

Crack Prediction:

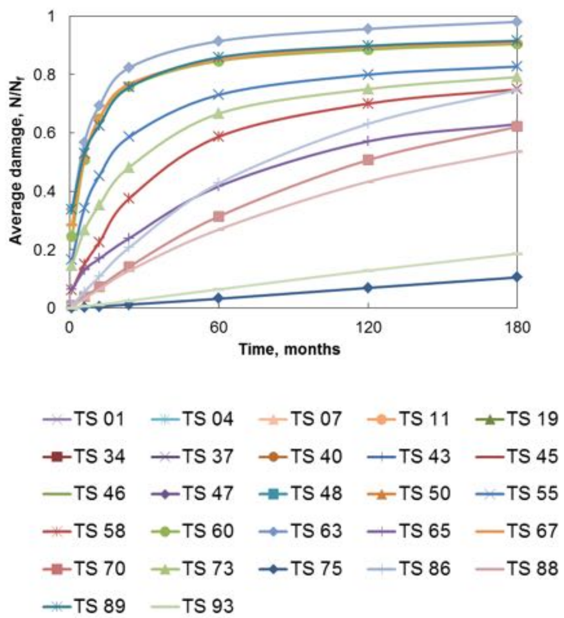
pavement structure; traffic; materials; climate

N/Nf Averaged Damage vs. Time

(a)



(b)



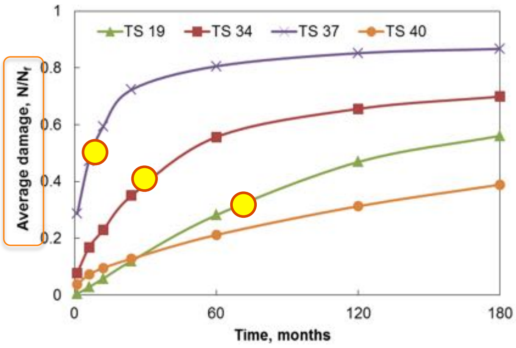
Different averaged damage growth patterns:

- Asphalt mixture properties and thicknesses
- Pavement structure
- Traffic level

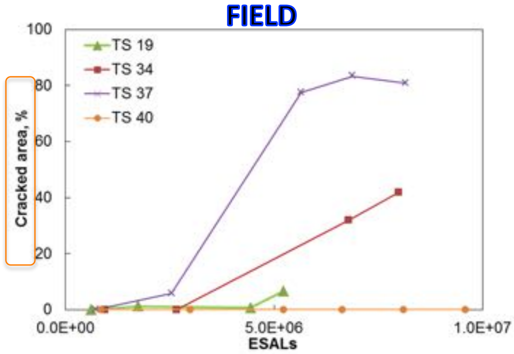
Averaged Damage vs. Time

🟡➔ Fatigue crack "start"

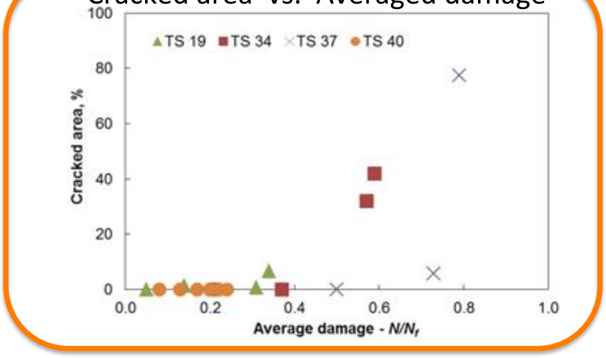
Averaged damage vs. time
SIMULATION



Cracked area vs. number of ESALs
FIELD



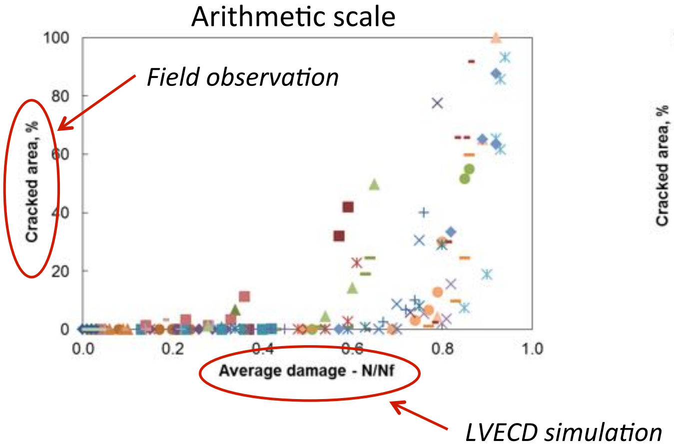
Cracked area vs. Averaged damage



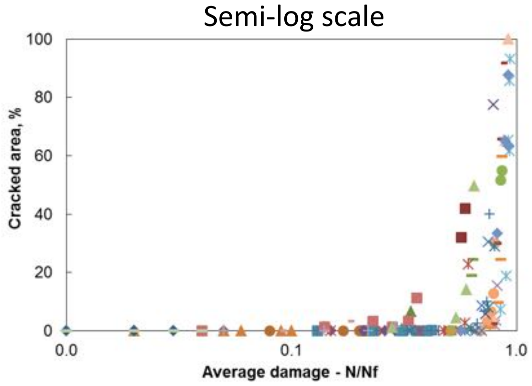
🟡 The higher the initial damage growth rate (faster cracking), the higher the damage level when the cracking begins

N/Nf Averaged Damage vs. Cracked Area

Arithmetic scale



Semi-log scale



Averaged damage vs. Cracked area:

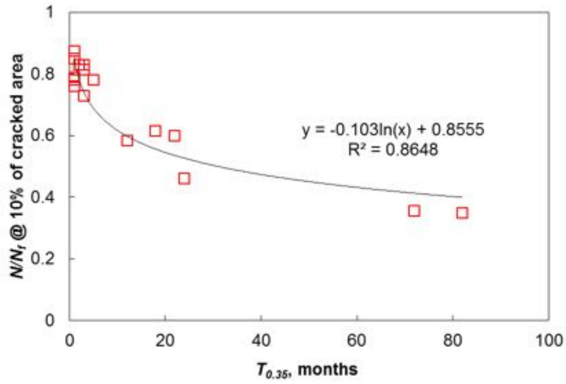
Can we collapse of all the curves at one single correlation?

Fatigue Cracking Starting Point

Averaged Damage Growth Rate Dependency

$T_{0.35}$ ➔ simulated time for averaged damage (N/N_f) of 0.35

N/N_f @ 10% of observed cracked area (field) vs. $T_{0.35}$ (*simulation)*



- $T_{0.35}$ is strongly correlated to the averaged damage when cracking starts
- For $T_{0.35}$ > 80 months (slow damage growing) ➔ N/N_f @ 10% tends to stabilize

Fatigue Cracking Starting Point

Averaged Damage Shifting

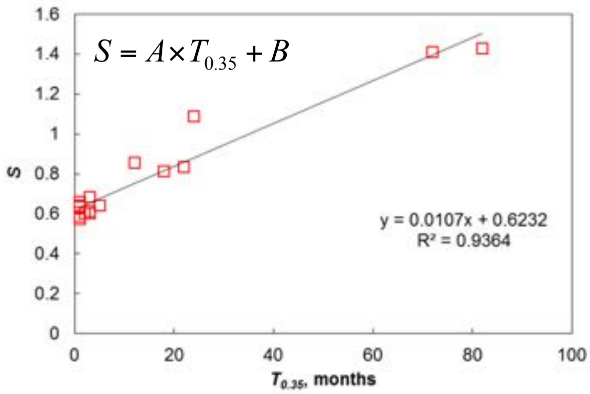
- Multiplicative shift factor ➔

$$ {N}/{N_f}\,red = {N}/{N_f} \times S $$

- Reference averaged damage for shifting ➔ 0.5

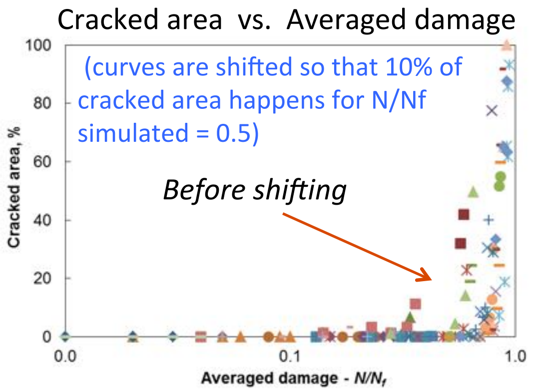
(all curves are shifted in such a way that their 10% of cracked area happens for N/Nf simulated = 0.5)

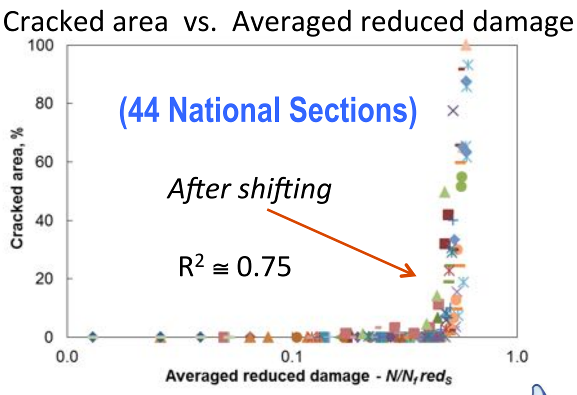
- The factors (S) for shifting the averaged reference condition were determined:



Defining the Damage-to-Cracked Area Transfer Function

Based on $T_{0.35}$





- **Cracked area** and **Averaged reduced damage** presented a unique and strong relationship (considering field variability)

$$CA = C_1 \times \left(N/N_f \; red \right)^{C_2}$$

Predicted vs. Observed cracked areas

Prediction capability:

TS	Cracked area on last survey, %	Predicted cracked area, %
UFSM 1	32.9	23.2
UFSM 3	0.0	0.0
UFRGS 2	0.0	0.0
USP 4	0.0	0.0
USP 5	0.0	0.0
ND 1	9.0	10.0
ND 2	3.0	0.4
ND 3	4.8	2.9
ND 4	12.5	0.5
ND 5	19.0	7.1
ND 6	5.9	7.1
ND 7	10.0	44.3
ND 8	0.0	0.4
[illegible]	[illegible]	0.0
[illegible]	[illegible]	0.2
UFSC 2	20.0	14.8
UFSC 3	0.0	0.5

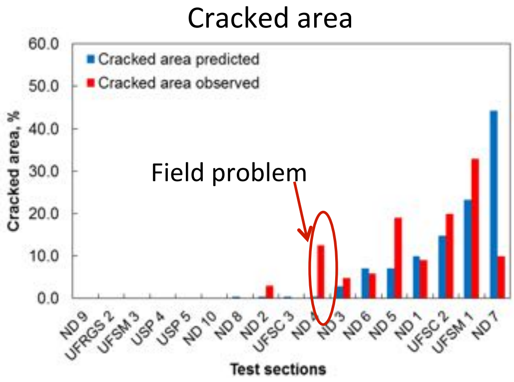
Binder content = 4.7%

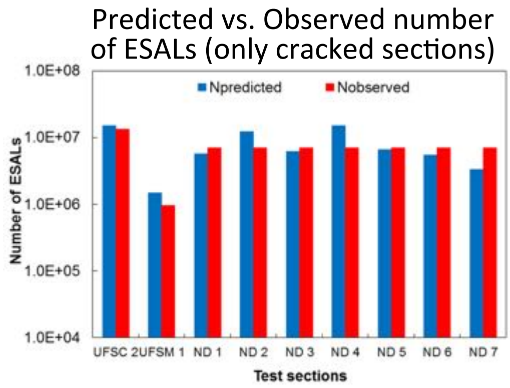
Same mixture

Binder content = 5.2%

Rubber asphalt at the bottom layer

Predicted vs. Observed cracked areas





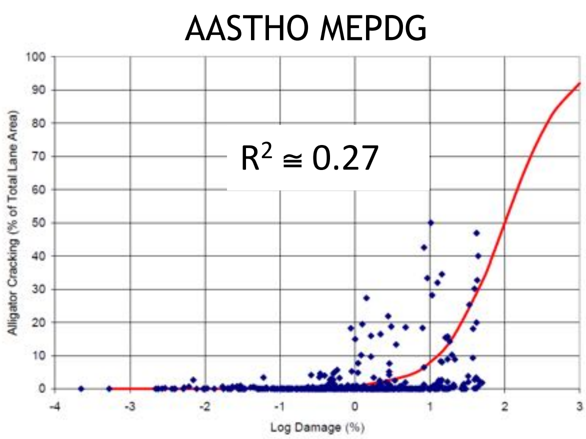
Large differences between the observed and predicted cracked areas are not necessarily associated with large differences regarding traffic level

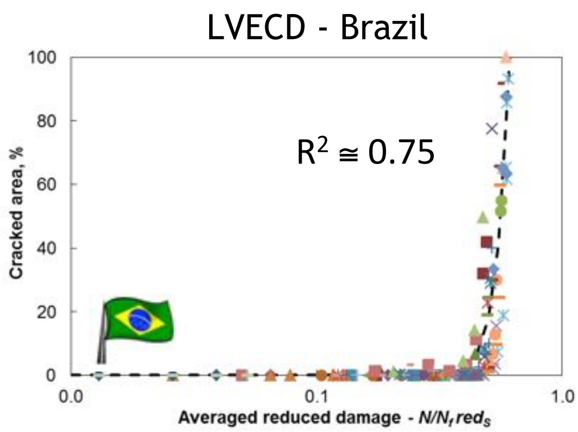
Fatigue cracking prediction standard error — **Final Performance Cracking Function**

$$Se_{\left(N/N_f\,red\right)} = a + \frac{b}{\left(1 + e^{c - d\times\log\left(100\times N/N_f\,red\right)}\right)}$$

$$\Rightarrow \quad CA_{Reliab.} = CA_{Predicted} + Se_{\left(N/N_f\,red\right)} \times Z_p$$

LVECD in Brazil





- NCHRP Report 457: prediction capability with $R^2 > 0.65$ ➔ very good

- The prediction error is about five times smaller than the error obtained through the AASHTO MEPDG

Next Steps

- **More national pavement sections** will be included in the calibration

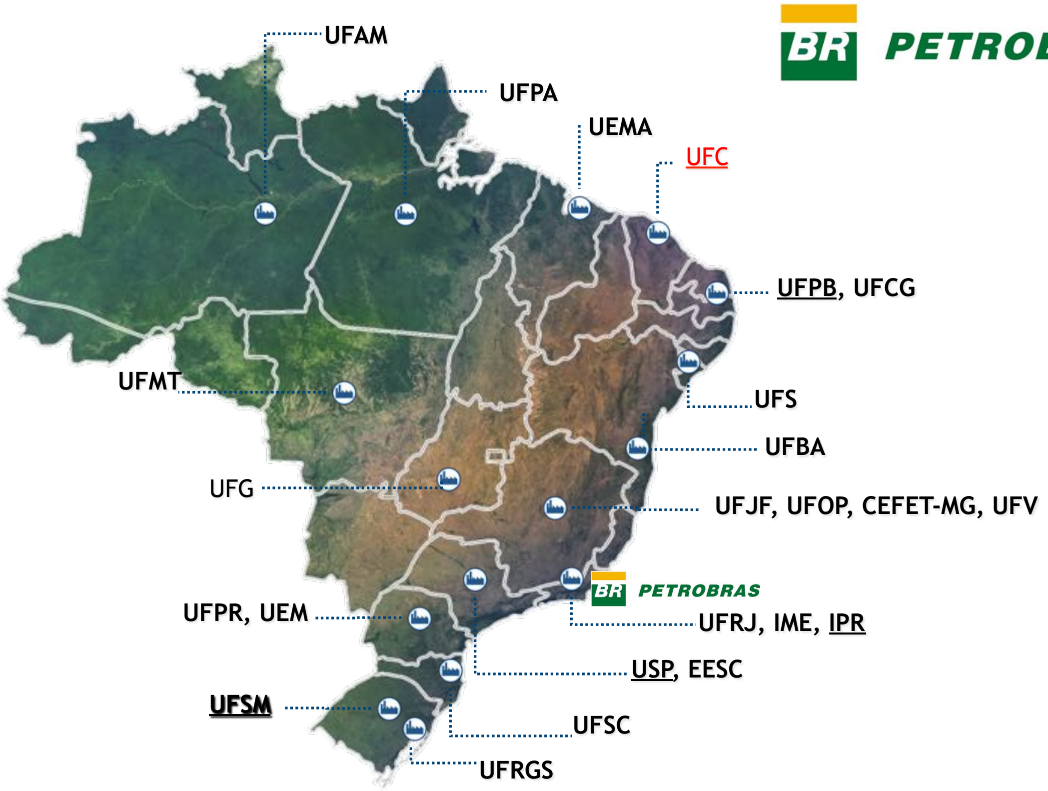
- Introducing asphalt mixture **self-healing** properties in the analysis

- **Permanent deformation** prediction models validation for asphalt mixture and structural layers

- Analysis of Portland **cement treated materials**.

ACKNOWLEDGEMENTS

PETROBRAS



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ISAP Workshop in 2012 (≈ 50 people)
ISAP Symposium in 2012 (≈ 150 people)
RMPD Workshop sponsored by ISAP in 2016 (≈ 50 people)
ISAP Conference in 2018 …

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