

2022/08/18

Instrumented roadway characterized through an Optimized Indicators Method

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Introduction

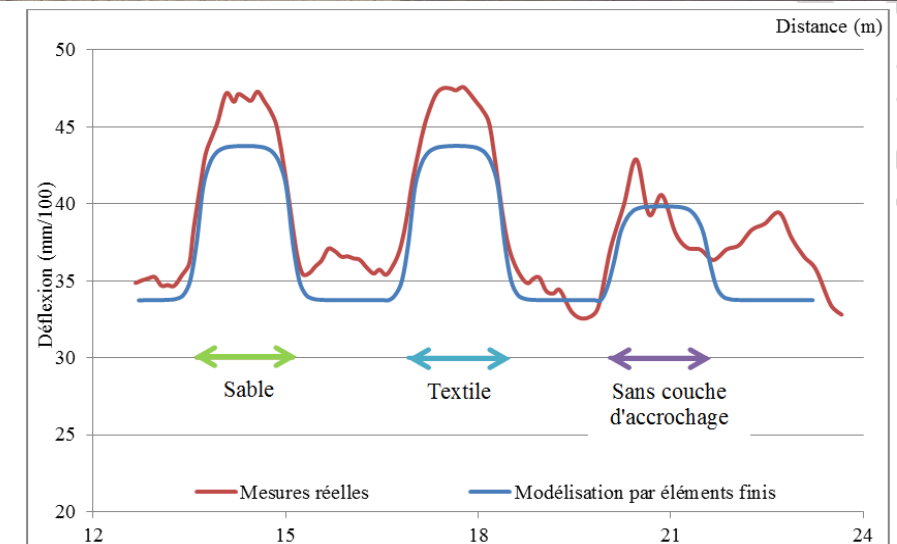
Structural Pavement Monitoring along a road

- A long practice
- NDT devices (Deflectometer, GPR, ...)
- Survey of simple indicators with location (ie maximum deflection)

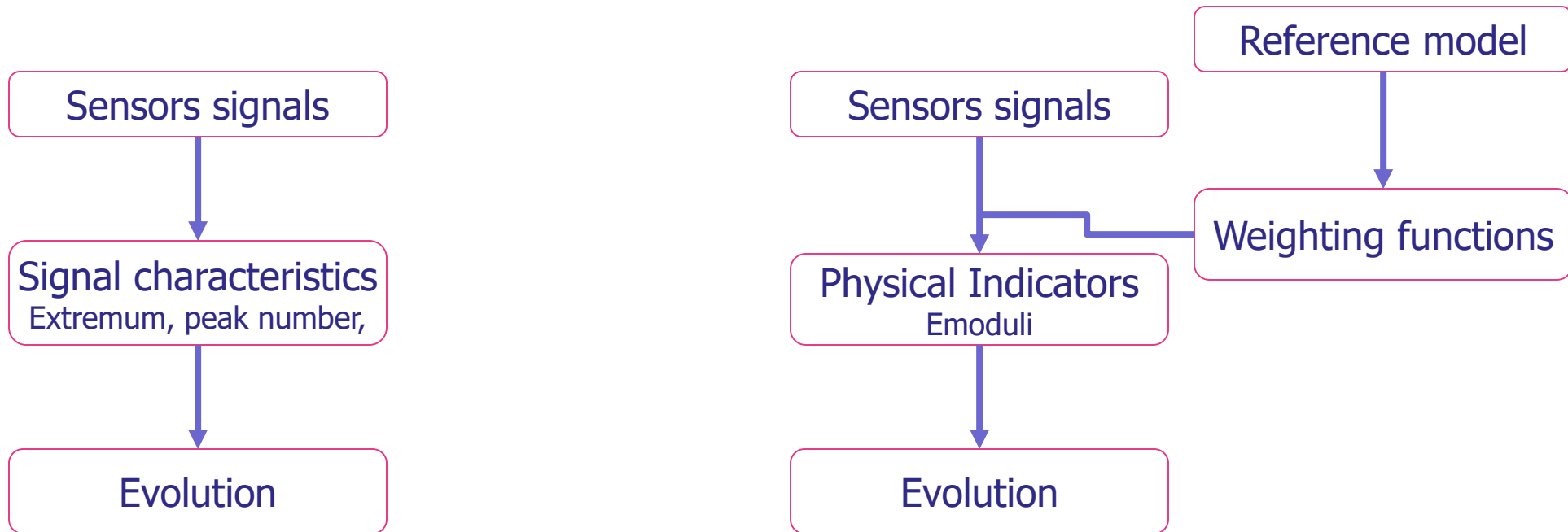
Pavement Monitoring with embedded sensors

- More recent practice
- Strain gages; Geophone; Accelerometer
- Survey of "new" indicators with time (or loading number)

Signal indicators \neq physical indicators



Optimized Indicators Method



Needs of an physical interpretation

No interpretation needed

Optimized Indicators Method

Consider **Signal** $\varepsilon(x, Y_l)$: acquisition parameter x (time or distance) and structural characteristics Y_l (elastic modulus).

Find indicators I_j **depend**

- Strongly (only) of a structural characteristic Y_j
- Weakly (not) of the other structural characteristics $Y_{k \neq j}$

Indicators can be define as an **integral form** (whole signal)

$$I_j = \int_{-x}^{+x} p_j(x) \varepsilon(x, Y_l) dx \quad \text{where} \quad I_j(x): \text{weighting function essentially sensitive to } Y_l$$

Functions $p_j(x)$ define **at the vicinity of a reference structure** as a **linear form** of the first derivatives

$$p_j(x) = a_{jk} \frac{\partial \varepsilon}{\partial Y_k}(x, Y_l)$$

Then calculating $\delta I_j = b_{ik} a_{jk} \delta Y_i$

(see detailed in Simonin, J.-M.; Piau, J.-M.; Le-Boursicault, V.; Freitas, M. Orthogonal Set of Indicators for the Assessment of Flexible Pavement Stiffness from Deflection Monitoring: Theoretical Formalism and Numerical Study. Remote Sens. 2022, 14, 500. <https://doi.org/10.3390/rs14030500>)

Orthogonality condition of a_{jk} and b_{ik} calibration matrix $\blacktriangleright a_{jk} b_{ik} = 1$ for $j = k$ $a_{jk} b_{ik} = 0$ for $j \neq k$
Coefficients a, b **deduce from** δY_i of the reference numerical model

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Optimized Indicators Method

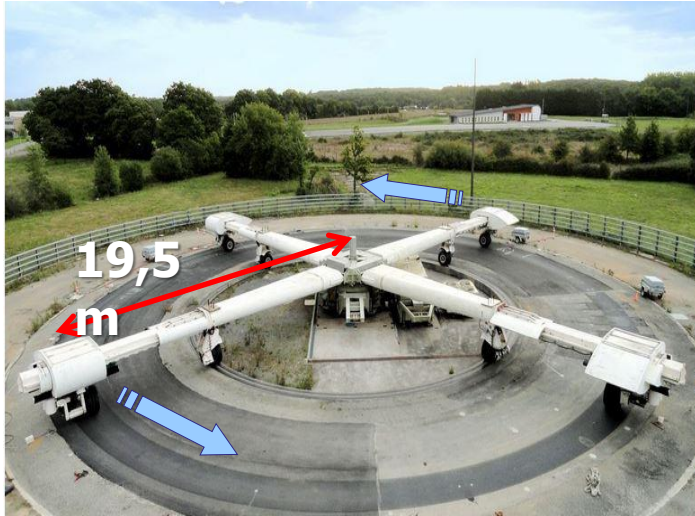
Application to an instrumented roadways

- Description of the test site
- Monitoring with indicators
- Monitoring with optimized indicators

Conclusion and prospects

Application to an instrumented roadways: Description of the test site

Fatigue carousel (Univ. Eiffel Nantes)



APT

4 arms with dual-wheeled loads 65kN

Test track around 100m length

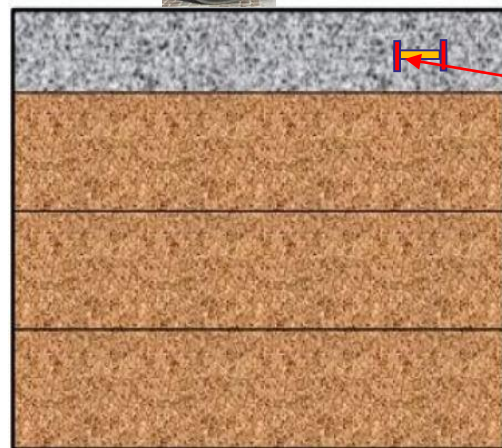
Speed : up to 100km/h

11 positions on transverse profile

More details in the following link :

<https://lames.univ-gustave-eiffel.fr/en/equipments/the-pavement-fatigue-carousel>.

Pavement



10cm Bituminous layer

76 cm Base layers made of Unbound Granular Materials (UGM)



H-shaped strain sensor embedded at 9 cm depth.

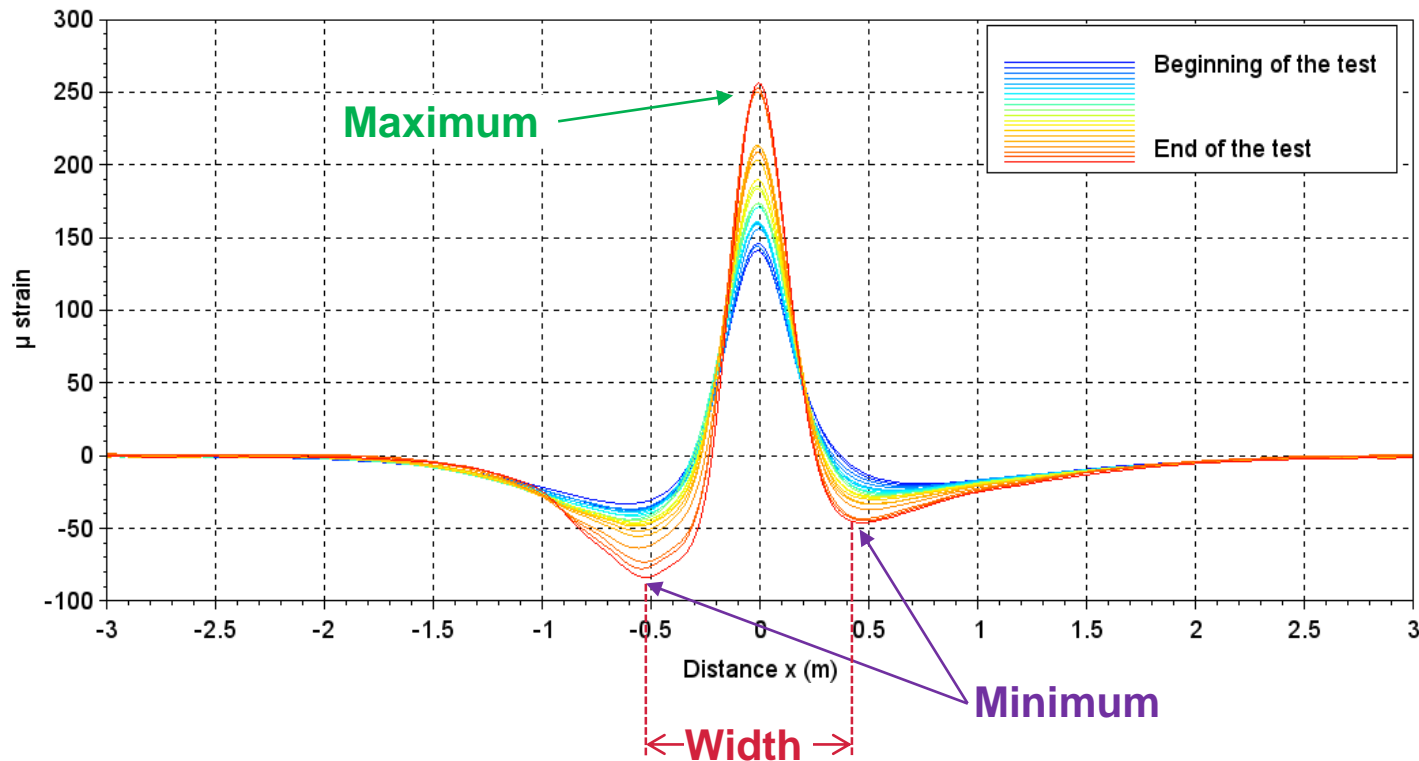
Measurements range up to 1500 μ strains.

Application to an instrumented roadways: Monitoring

Charging loads (65kN) ; 70km/h; lateral wandering (Gaussian).

Phase 0: Consolidation step of the structure (post-compaction of layers) -> 151200 charges
Reference state of pavements for calibrations of the OIM.

Phase 1: Gauge's signals recorded ; load at pos 6; 2020 Nov. -> 2021 Feb. (from 151200 to 881600 charges).

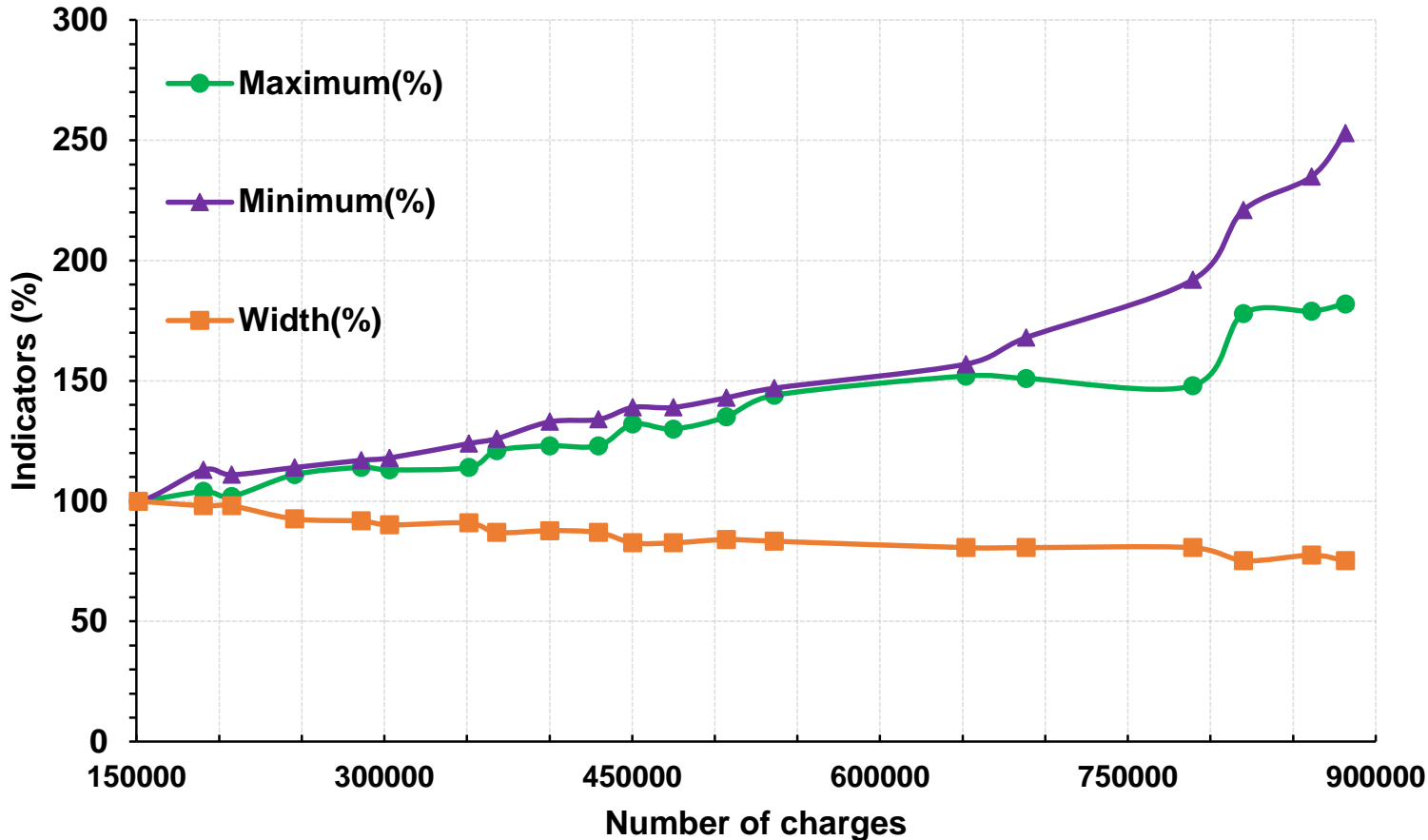


Mean pavement's temperature : 7 to 12°C.

Conventional indicators as a function of the numbers of charges :

- maximum
- minimum
- distance between the two minimum peaks (depth).

Application to an instrumented roadways: Monitoring



Global behavior of the whole structure.

Difficulty to extract the characteristics of structure's layers separately :
- physical meaning ?

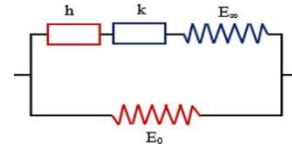
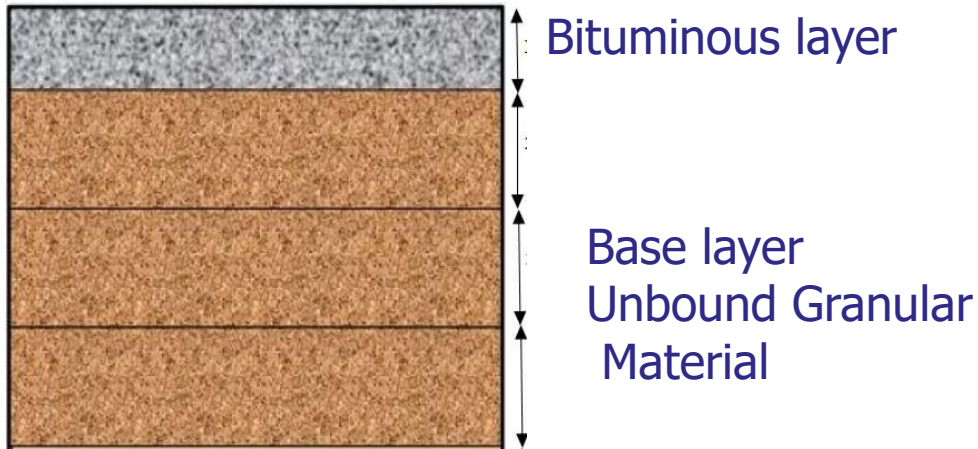
- which layer is affected ?



Numerical simulation of signal considering pavement's layers characteristics and experimental measurements conditions.

Application to an instrumented roadways: Monitoring with OIM

Define a numerical reference model



Visco-Elastic (Huet Sayegh model)
2 parabolic dampers;
 E_∞ Instantaneous elastic modulus

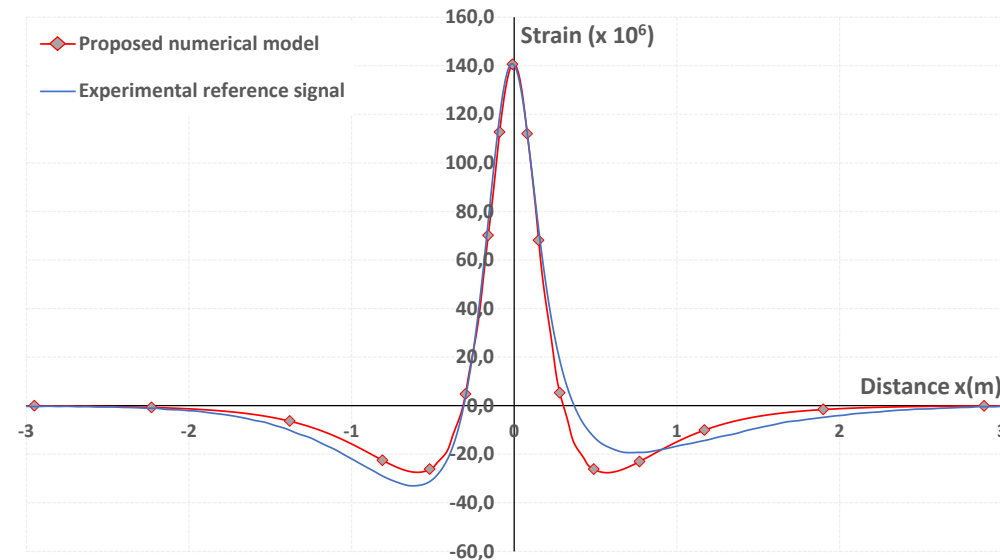


Elastic E_{UGM}

Adjust parameters to reference
signal (151 000 loads)

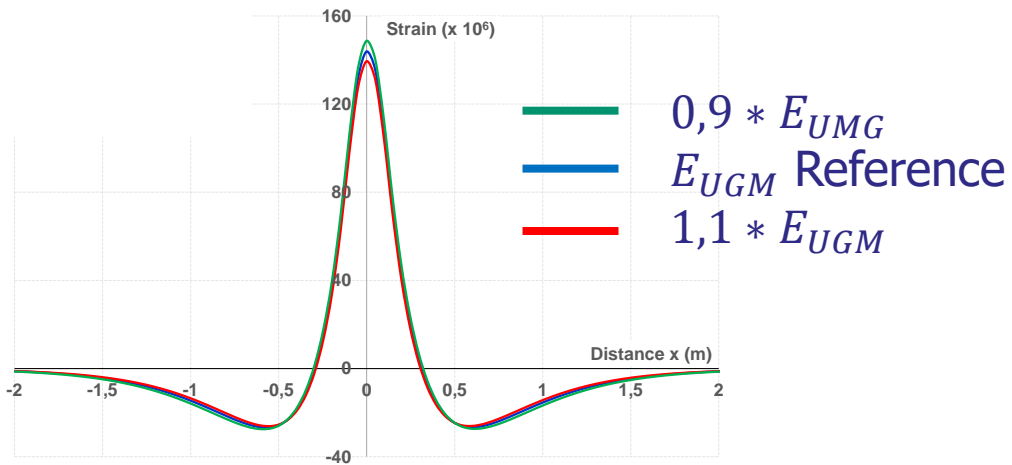
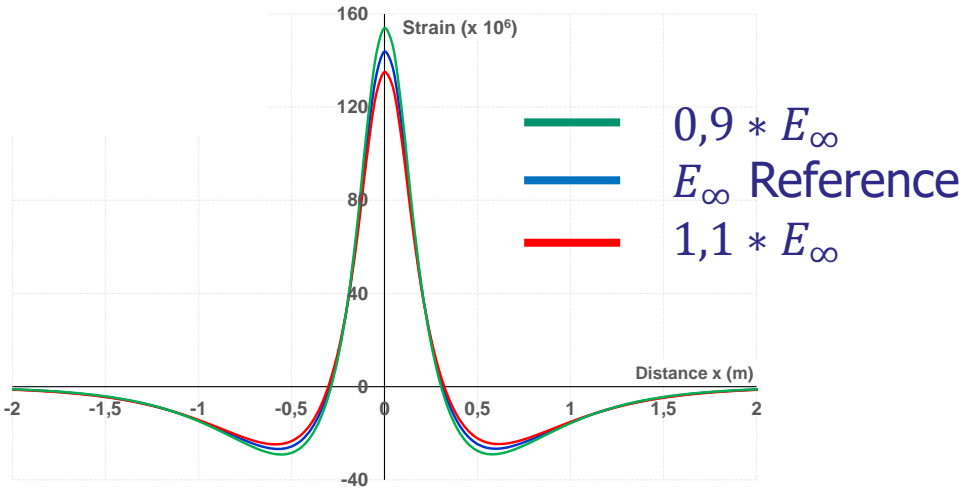
$$E_\infty = 19\,000 \text{ MPa}$$

$$E_{UGM} = 120 \text{ MPa}$$

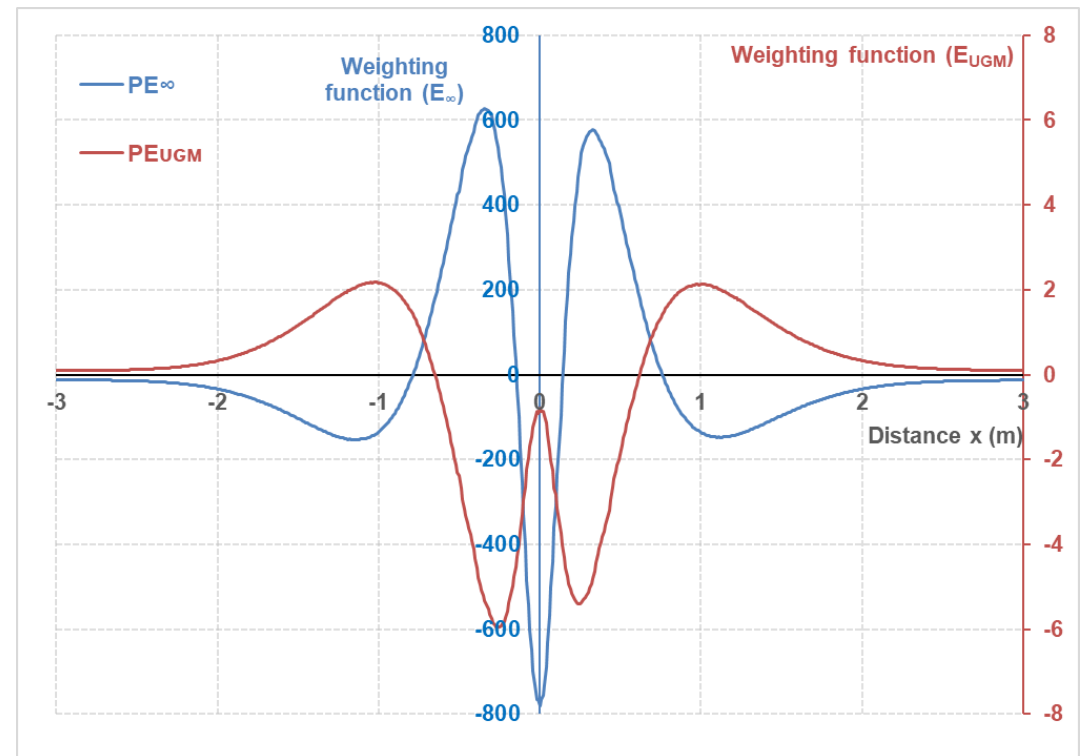


Application to an instrumented roadways: Monitoring with OIM

Calculate the signal derivative

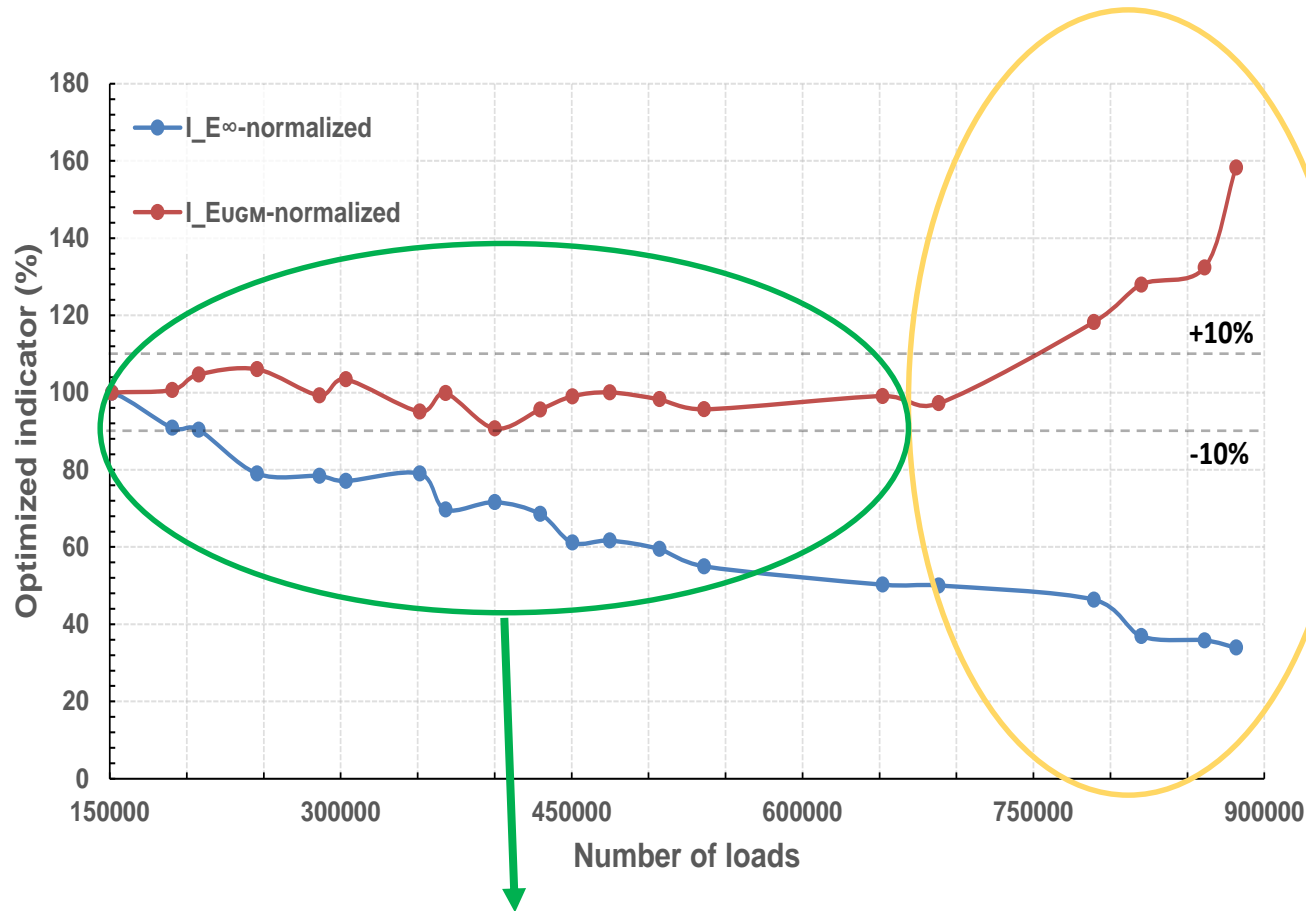


Deduce the weighting function



Application to an instrumented roadways: Monitoring with OIM

Evolution of the optimized indicators



Damage of the 2 layers
Or **limit of the method**
Linearisation processes

Recalibration of the
weighting function

Damage of the bituminous layer
Any damage of the base layer before
700.000 loading
This is physically consistent

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Conclusion and prospects

- Optimized indicator method is a promising data processing tool.
- Orthogonal indicators with physical interpretation
- Required 1 numerical model (from design or quality control)
- Application using strain gauge during an experiment on fatigue carousel was successful but shows limits.

Need for the re-calibration of weighting functions when one indicator reaches a $x\%$ variations.

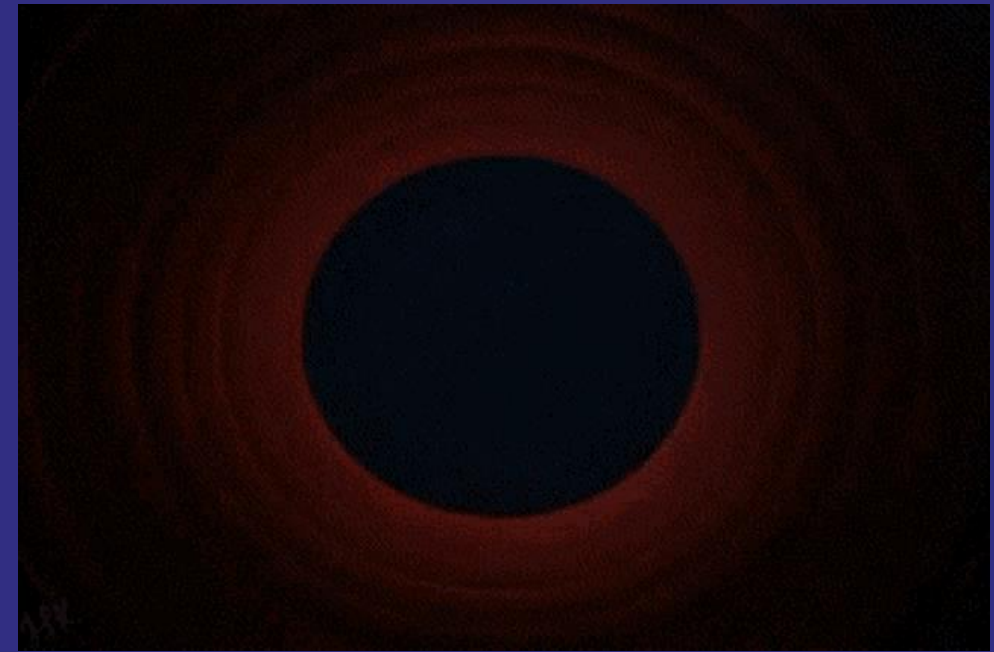
Transposition of the OIM to

- Others sensors (geophone, accelerometer, ...)
- Other survey (monitoring along an itinerary using deflection measurement)
- Other physics (electrical, electromagnetism, ...)

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Thanks

