Using TSD measurements to estimate the pavement strains under a moving load

By

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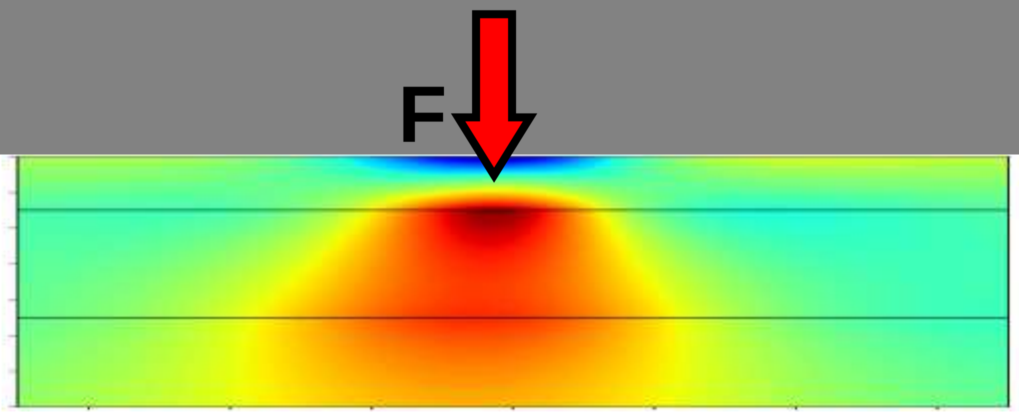
Pavement damage

Question: How large are the strains induced by a driving truck?

Estimate from surface response

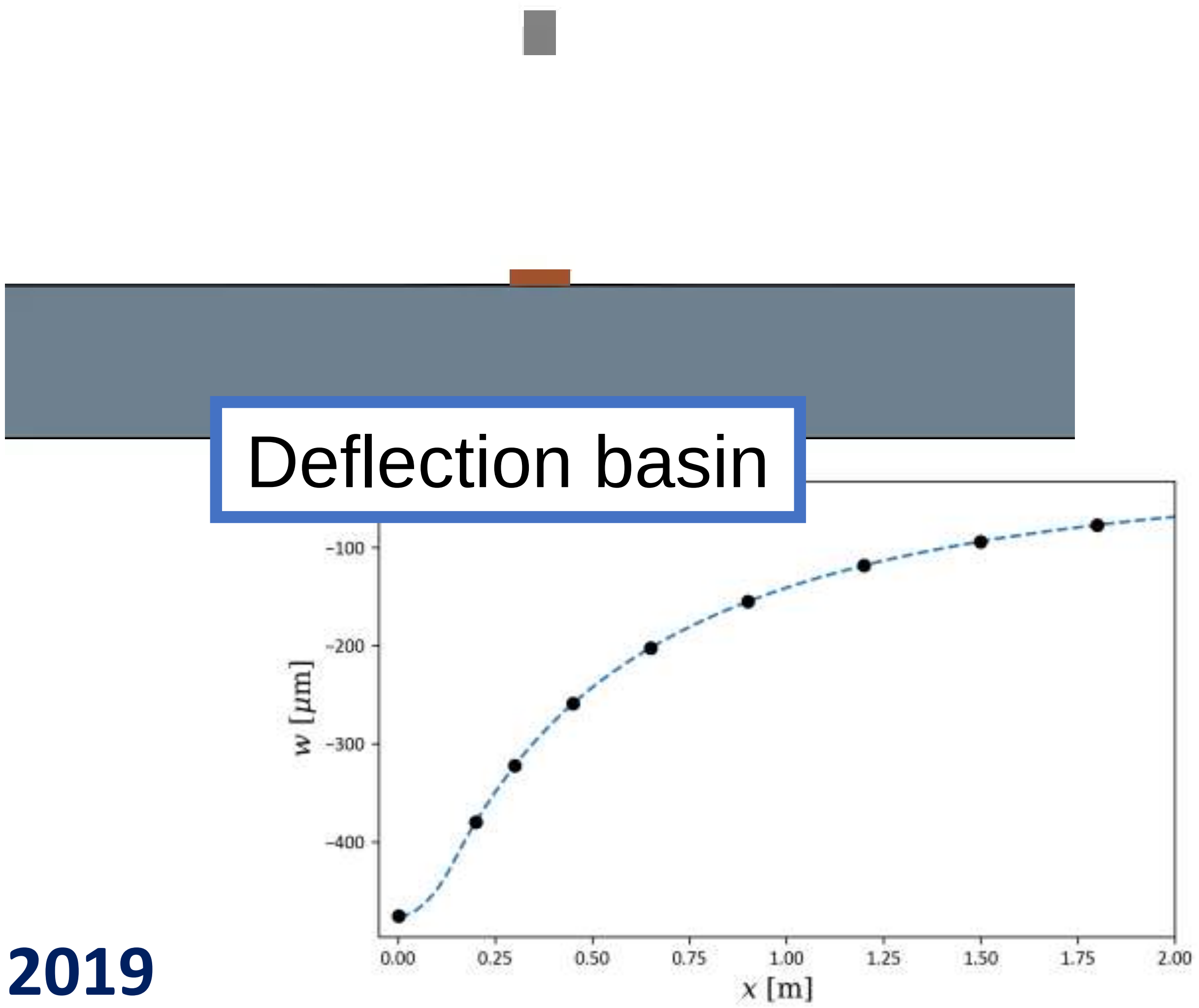


Horizontal strain

Strains cause damage in the pavement

- Horizontal strain in asphalt layer → fatigue cracking
- Vertical strain in subgrade → rutting
- Shear strain in asphalt → rutting

Traditional approach: FWD



A few issues

- FWD is slow
  - Costly
  - Disrupts traffic
  - Safety hazard
- Point measurements
  - May miss important features
- Impulsive load
  - How do the results relate to a moving load?

The Traffic Speed Deflectometer

- Measures pavement response to a moving load
  - Continuous measurement
  - At traffic speed 1 km/h – 90 km/h
- Uses laser Doppler vibrometers to measure pavement response

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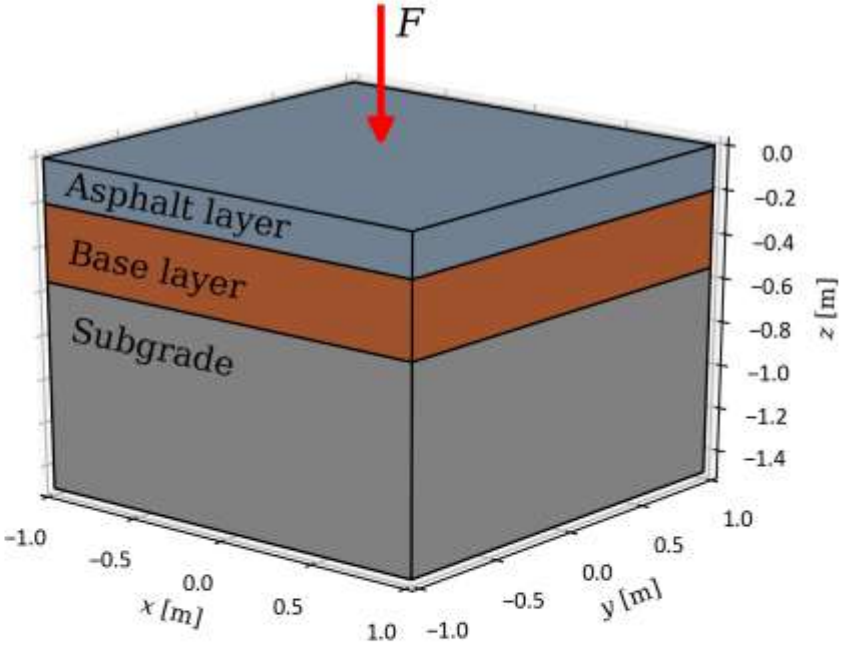
Estimating pavement strains from surface response

Layered elastic structure

(✓) Layer thicknesses
- Elastic moduli

✓ Applied force



Pavement model

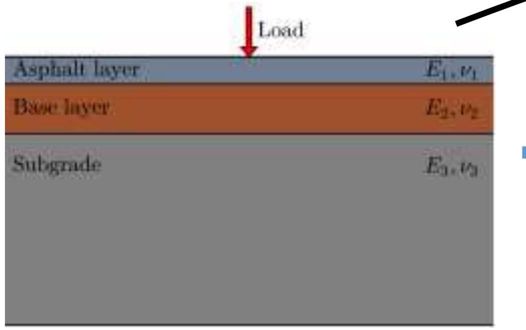
Strains

Can be found from the surface response by making a back-calculation

Back-calculation

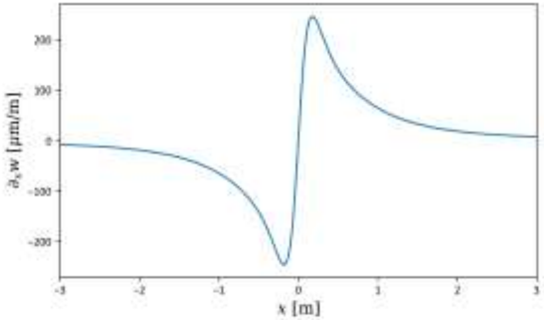
Modify

Pavement model



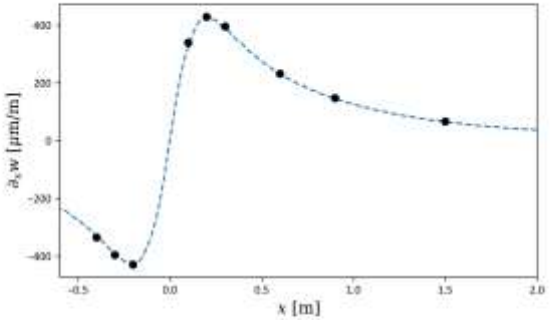
Dynamic analysis

Simulated slopes



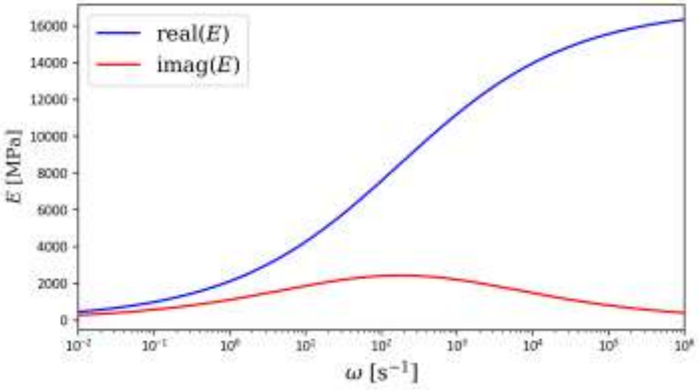
Compare

TSD slopes



TSD: moving load

Asphalt complex modulus



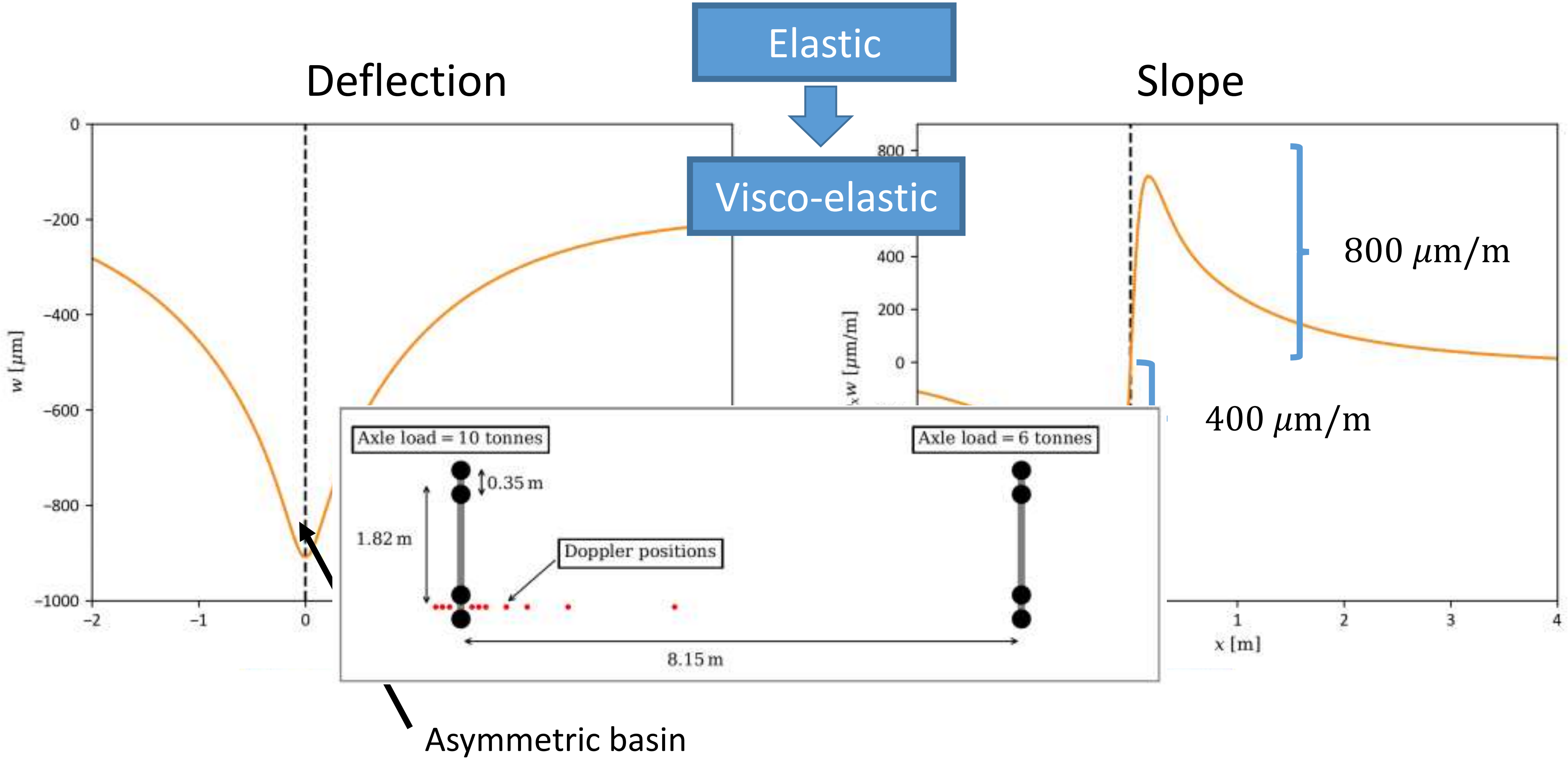
$$E(\omega) = E_0 + \frac{E_\infty - E_0}{1 + \delta(i\omega\tau)^{-k} + (i\omega\tau)^{-h}}$$

Visco-elastic back-calculation of TSD measurements, Nielsen 2019, TRR

PE 2019

RPUG Road Profile Users' Group

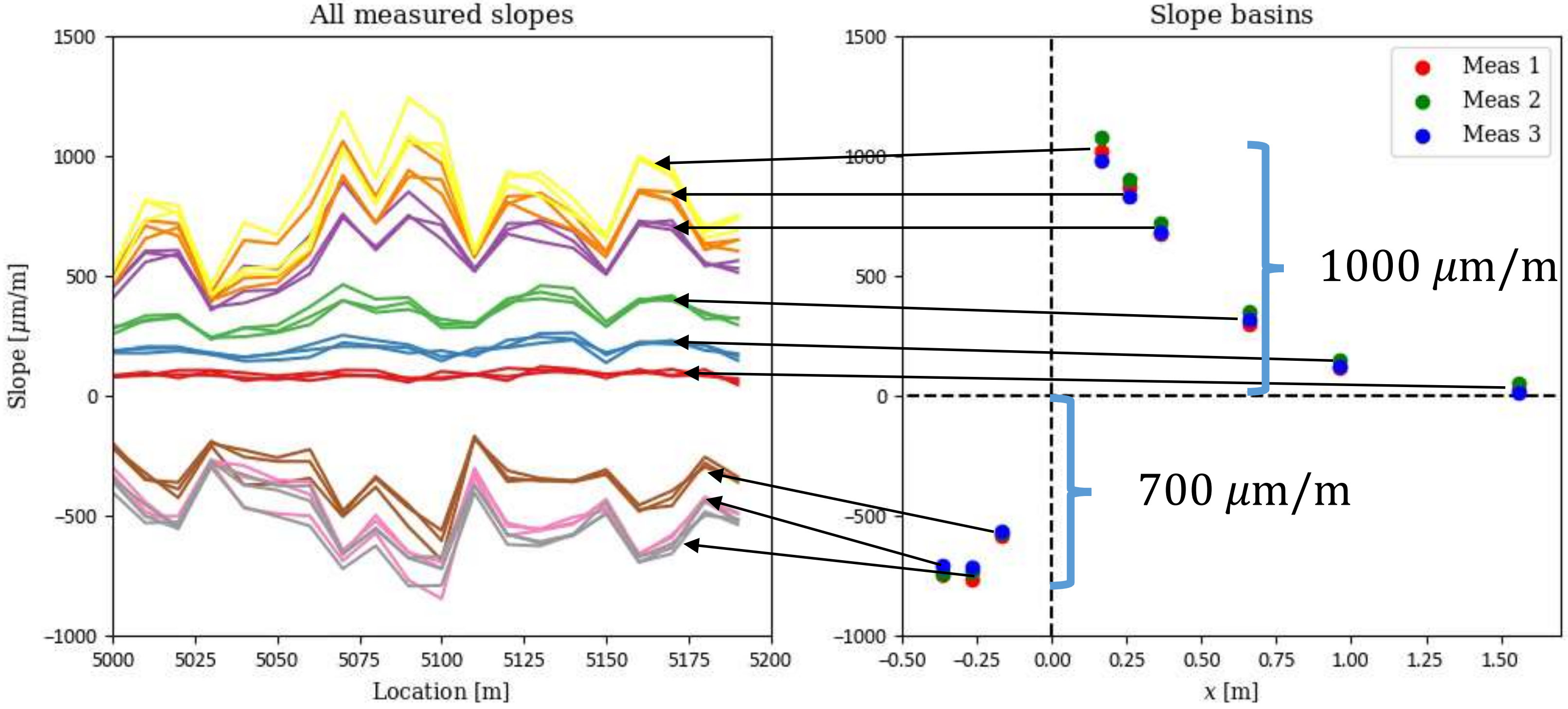
Visco-elastic deflection basin



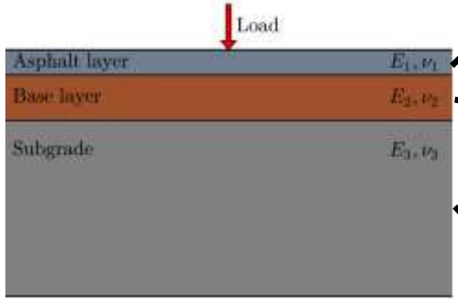
Measurement examples

Pavement condition varies rapidly with distance ⇒ Important to have continuous measurements

Road near Copenhagen.
Three runs.



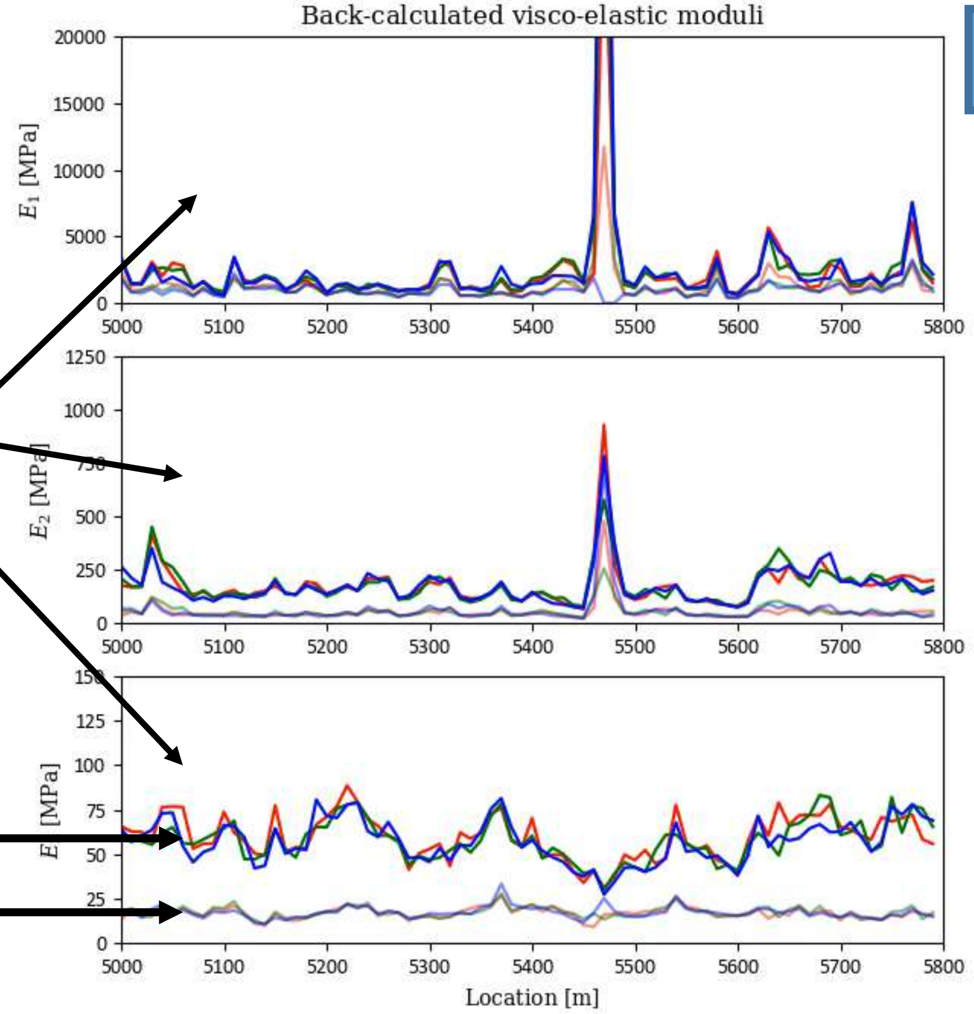
Back-calculation of TSD measurements



$h_1 = 15$ cm
$h_2 = 30$ cm
$h_3 = \infty$

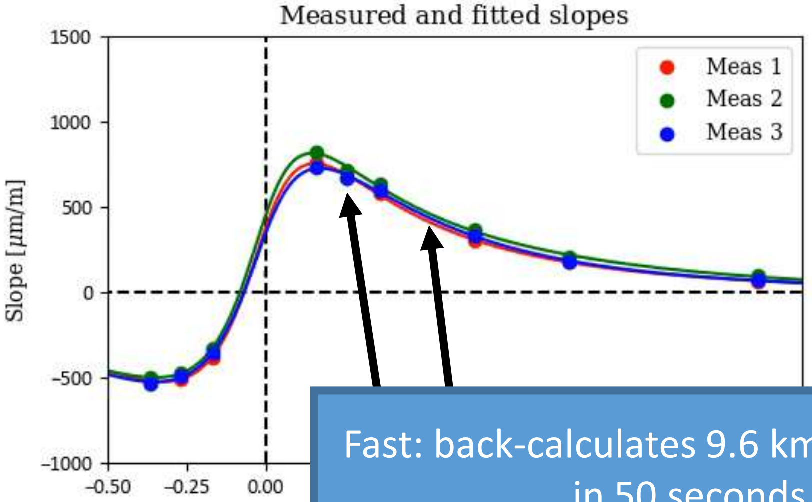
Real part

Imaginary part



Reasonable values of elastic moduli

Excellent fit to measured slopes

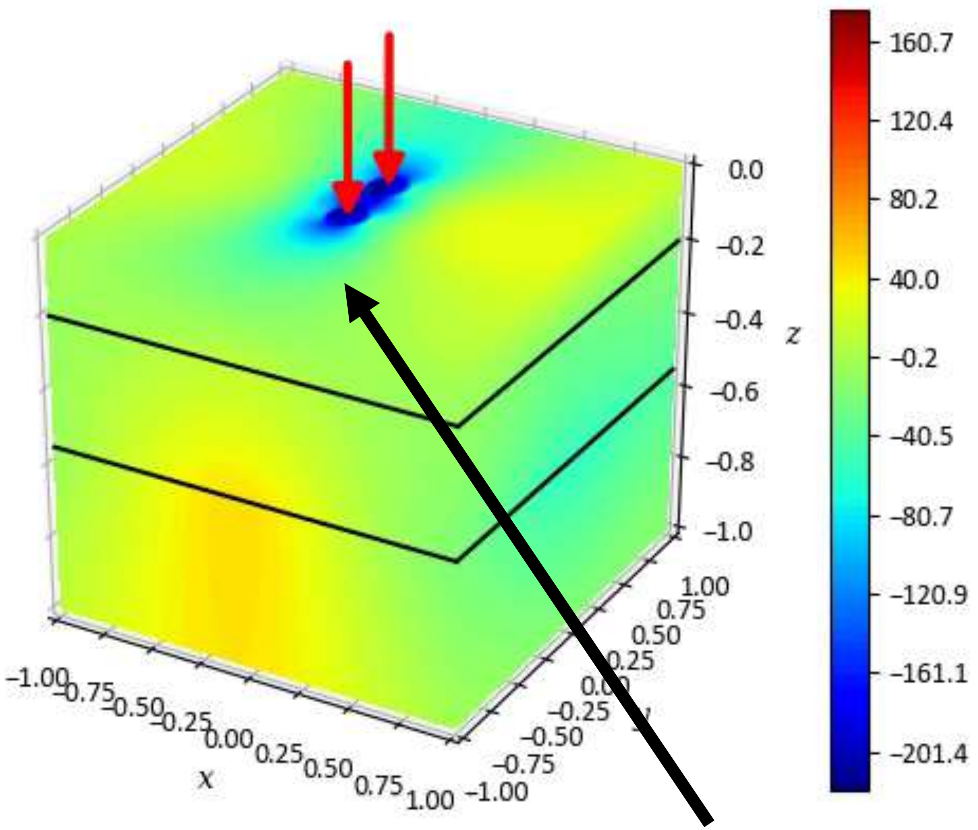


Fast: back-calculates 9.6 km (960 meas.) in 50 seconds

Good agreement between moduli from different measurements

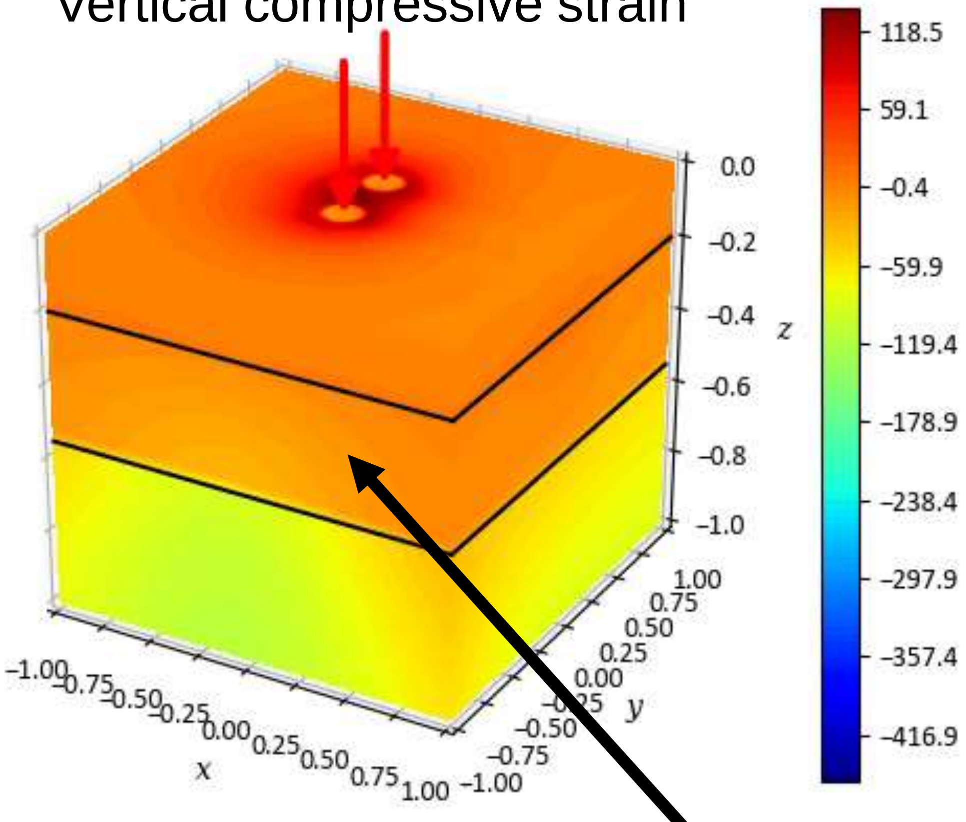
Strain estimates

Longitudinal tensile strain



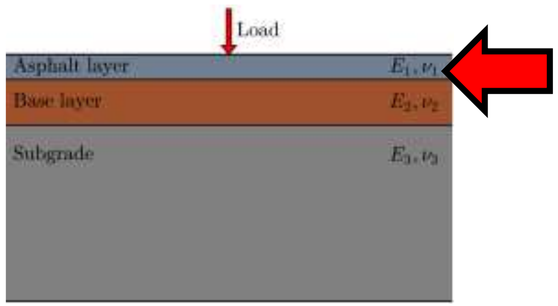
Identify maximum strain

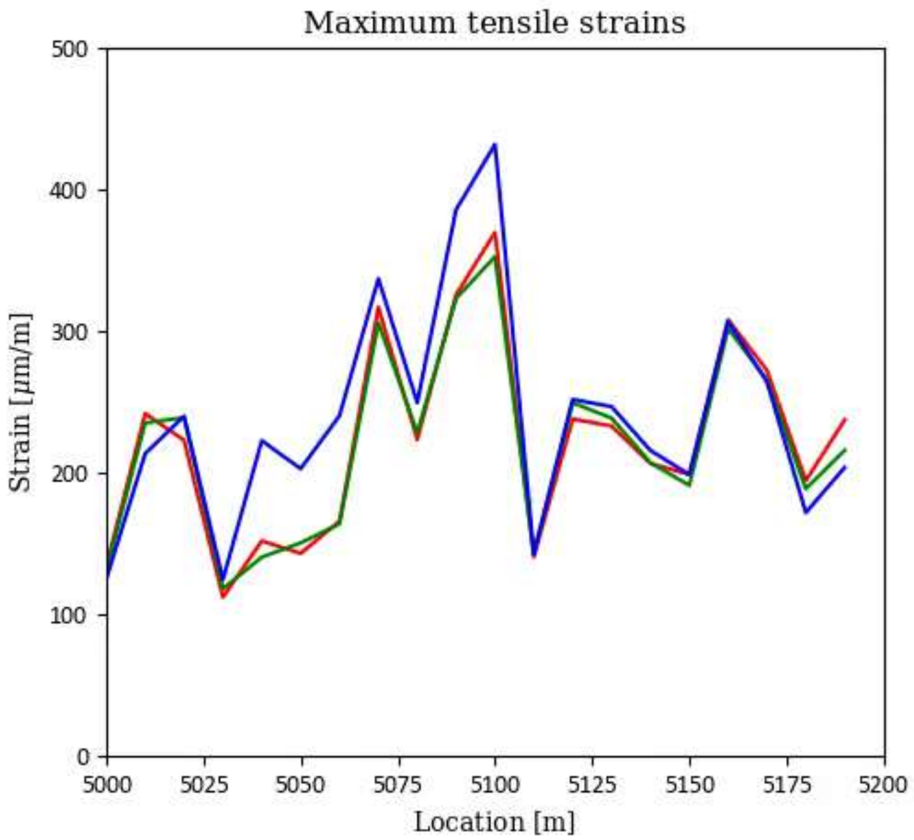
Vertical compressive strain

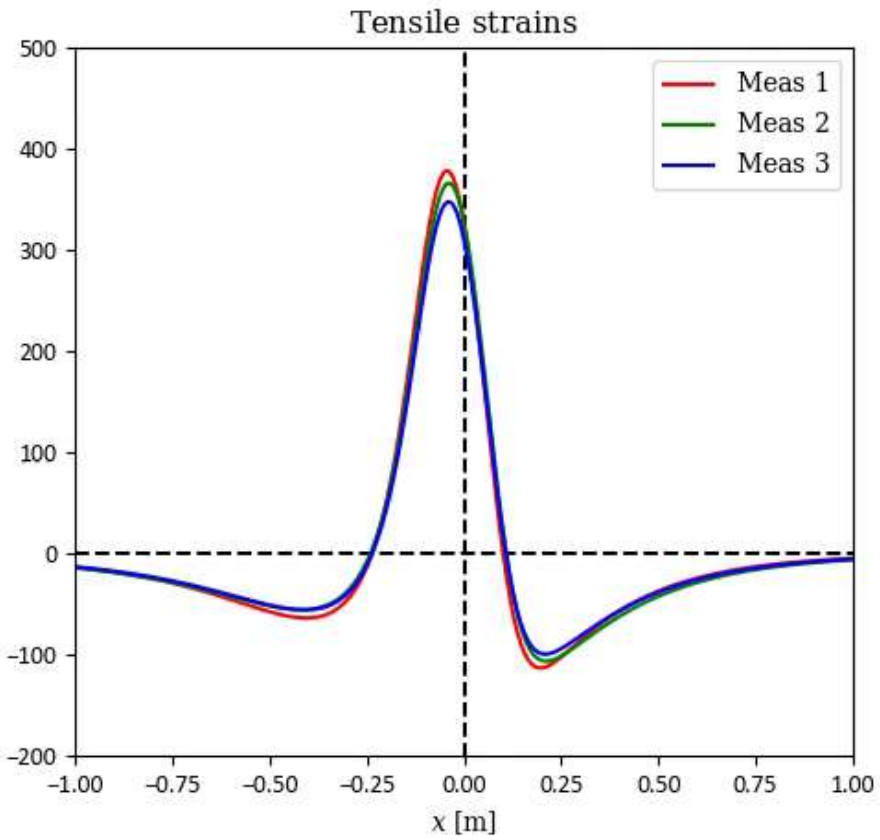


Identify maximum strain

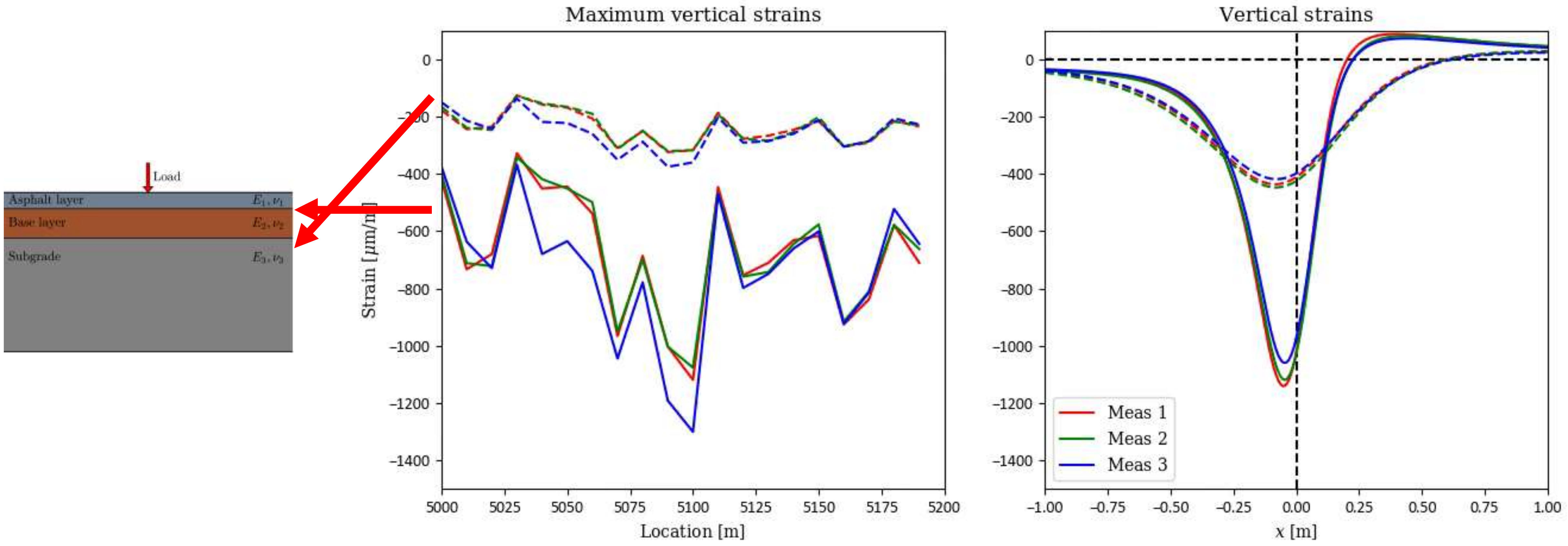
Tensile strain in bottom of asphalt layer





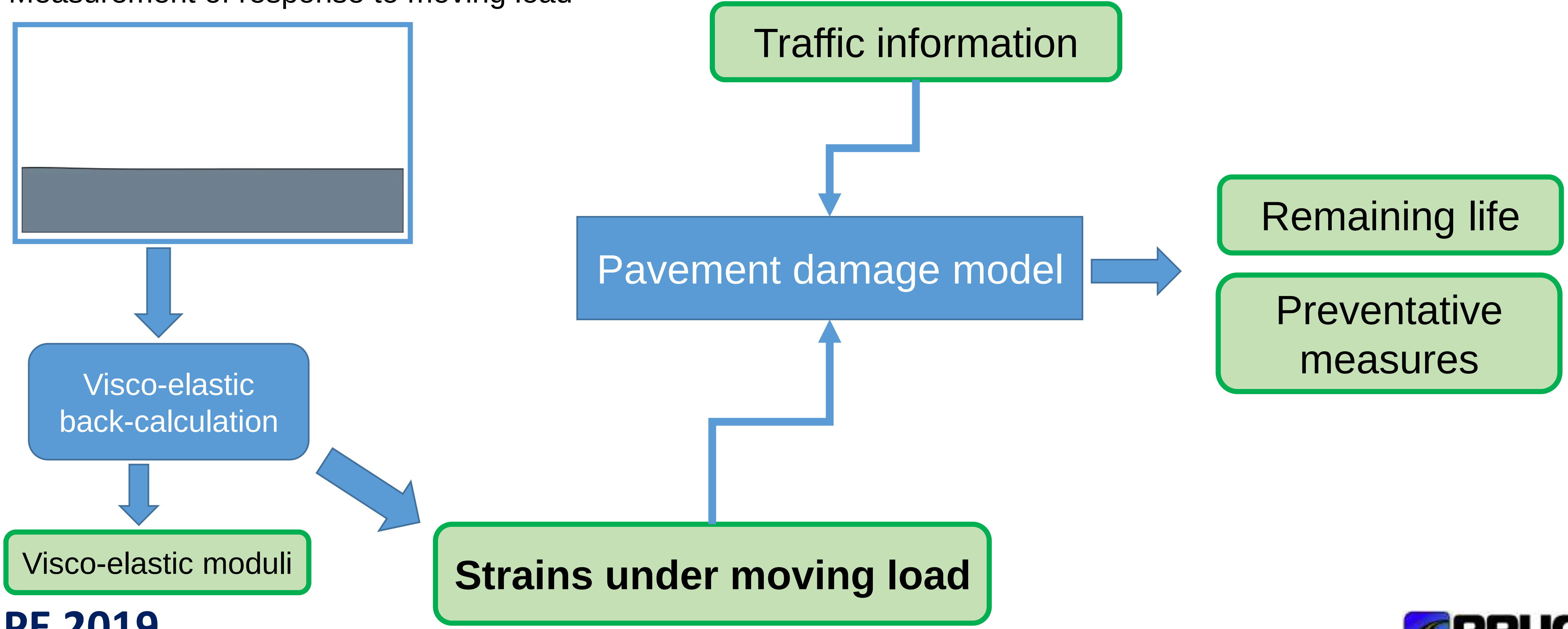


Vertical strains in top of base layer and subgrade



Strains under actual moving load

Measurement of response to moving load



Direct estimation of strains

Visco-elastic back-calculation

Strains under moving load

Can we cut out the middle man?

Fatigue strain

Plate theory

Strain in bottom of plate $\epsilon_{xx} = \frac{h}{2}\frac{d^2 w}{dx^2} \approx \frac{h}{\Delta x^2} SCI_{300}$

Rutting strain

Correlation analysis by Nahsimifar *et al.*:
$\epsilon_{zz} \propto DSI = w_{300} - w_{900}$

Nearly independent of the specific E moduli

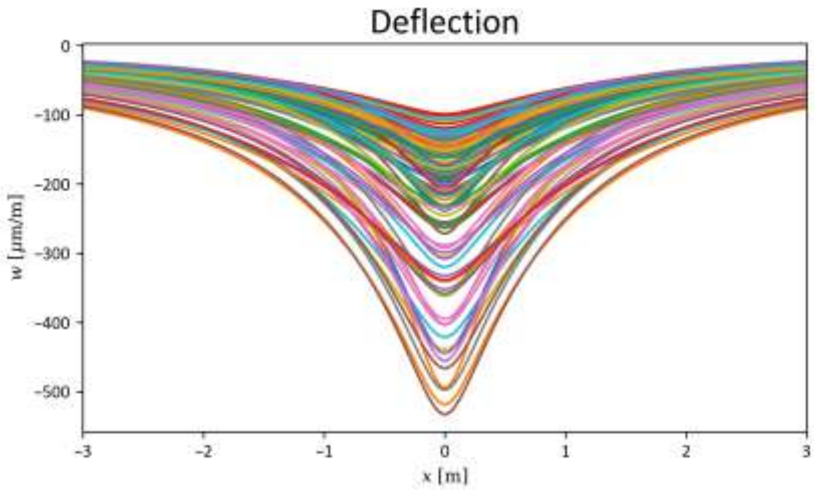
Rutting strain transfer function

Look at transfer function between w and ϵ_{zz} in Hankel domain

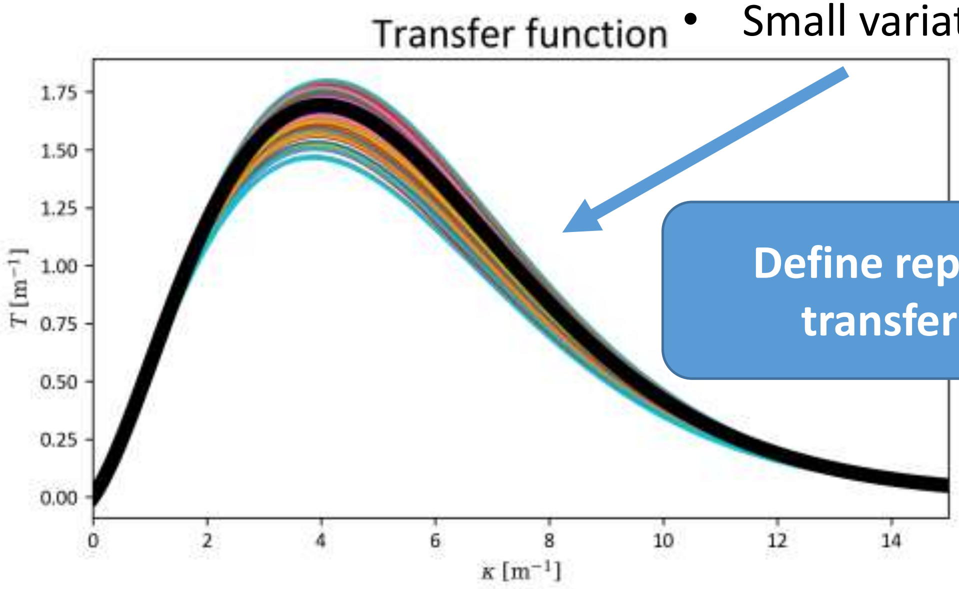
$$\tilde{\epsilon}_{zz}(\kappa) = \tilde{T}(\kappa)\tilde{w}(\kappa) \;\Rightarrow\; \tilde{T}(\kappa) = \frac{\tilde{\epsilon}_{zz}(\kappa)}{\tilde{w}(\kappa)}$$

Calculated from numerical model

100 random combinations of E moduli



- Same shape
- Small variation in magnitude



Define representative transfer function

Representative transfer function

Transfer function: Converts from surface deflection to rutting strain (in Hankel domain)

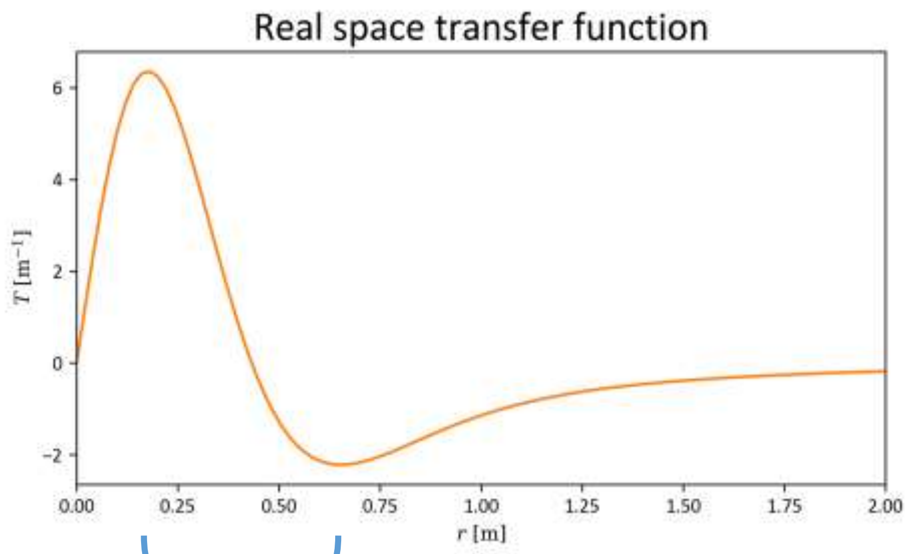
For $w \to \epsilon_{zz}(r = 0)$

Can derive similar transfer functions for other strain components

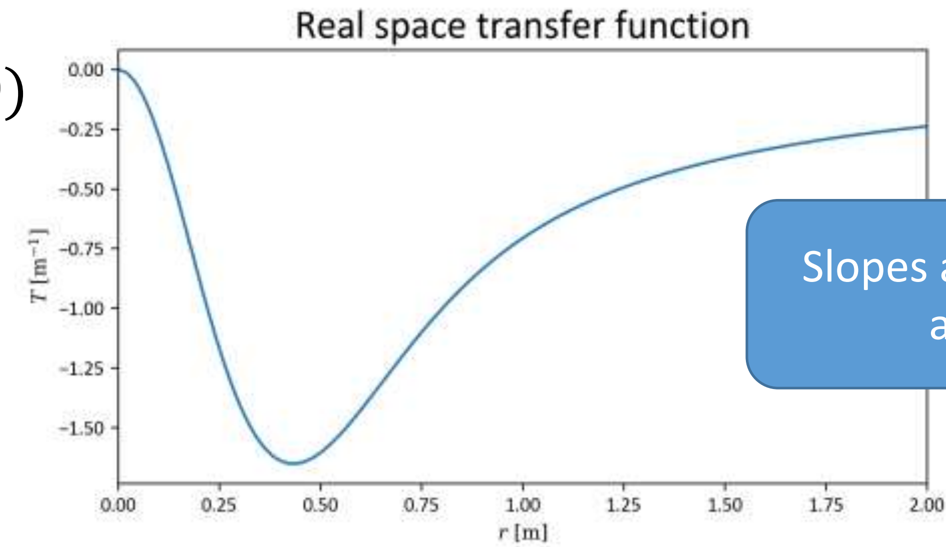
$) = \int \partial_r w($

Or in words: ϵ_{zz} is found by integrating the measured sl

For $\frac{dw}{dx} \to \epsilon_{zz}(r = 0)$



Finite difference slope



Slopes at intermediate distances are most important

Agrees with Nahsimifar *et al.*:

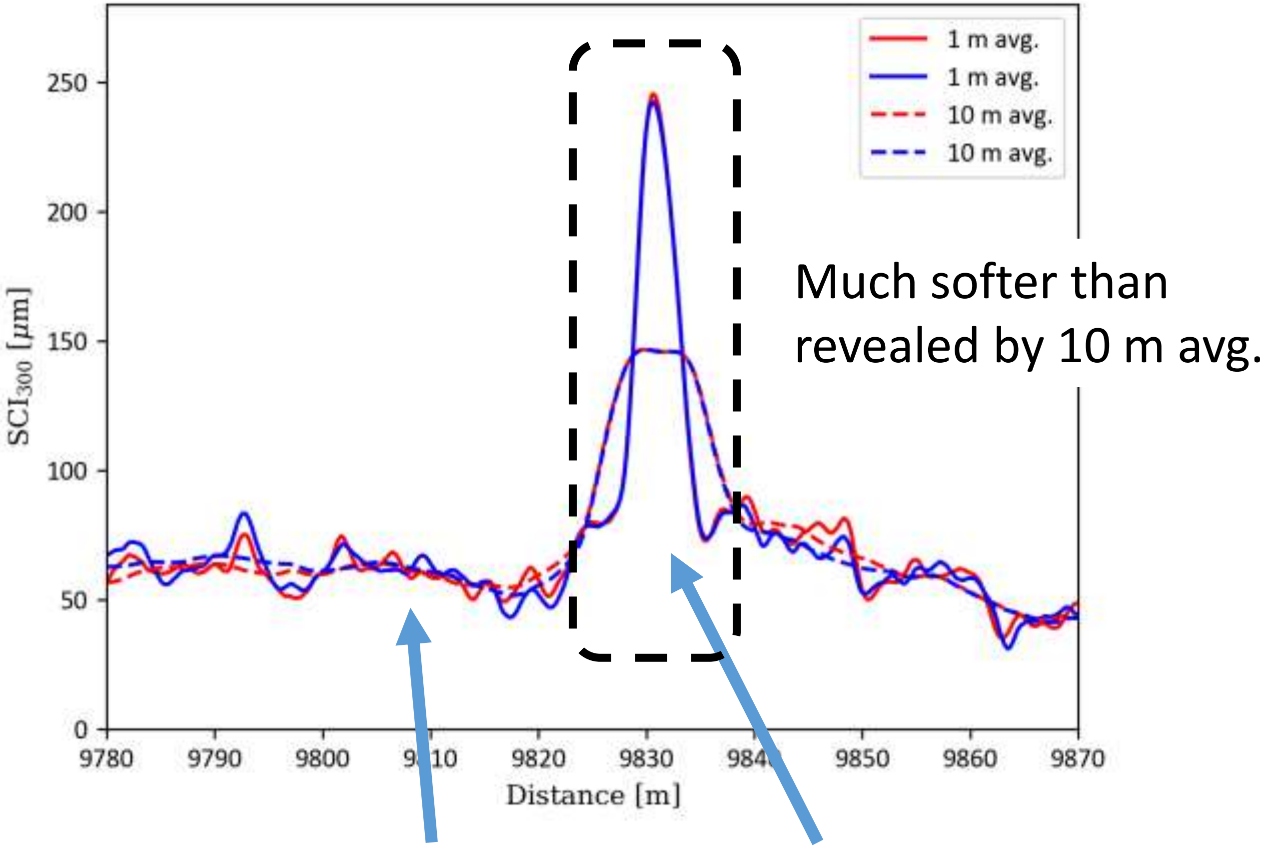
$\epsilon_{zz} \propto w_{900} - w_{300}$

Smaller reporting intervals

- Localized defects might not be visible in 10 m averages
- New sensors allow us to export in 1 m sections

- Damage $\sim \epsilon_{xx}^4 \propto (SCI_{300})^4$
- Section will fail 8 times faster than expected from 10 m averages (and 160 times faster than expected from point measurements with 50 m spacing)

Surface curvature index



Summary and conclusion

- Visco-elastic back-calculation at network level
- Strains under moving load
- Usable indices directly from slopes
- 1 meter data allows local defects to be identified