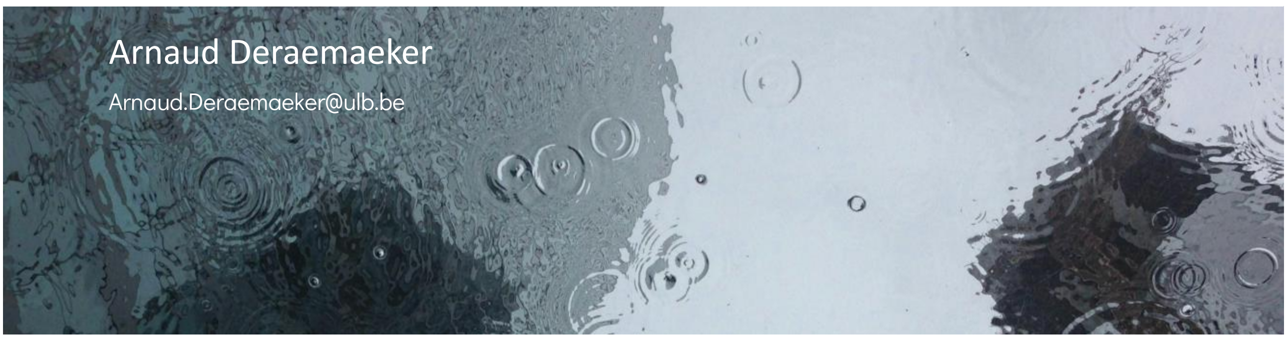
Mitigation of environmental effects in SHM – part II



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CONCRETE MONITORING AND CHARACTERIZATION

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Approaches to concrete monitoring and characterization

Destructive

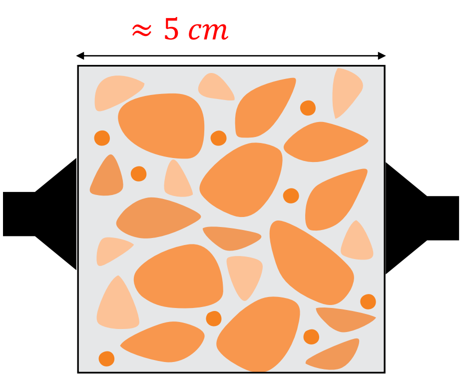
Load vs displ/strain

Non-destructive

Resonant frequency

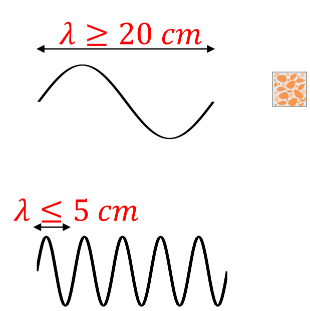
Ultrasonic velocity

Wave propagation in concrete

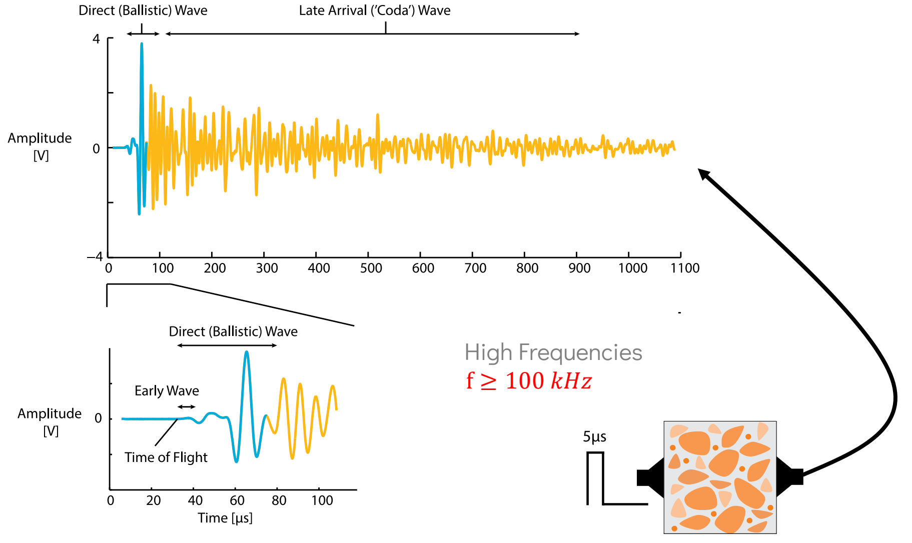


Low Frequencies
$f \leq 20\ kHz$

High Frequencies
$f \geq 100\ kHz$



Wave propagation in concrete



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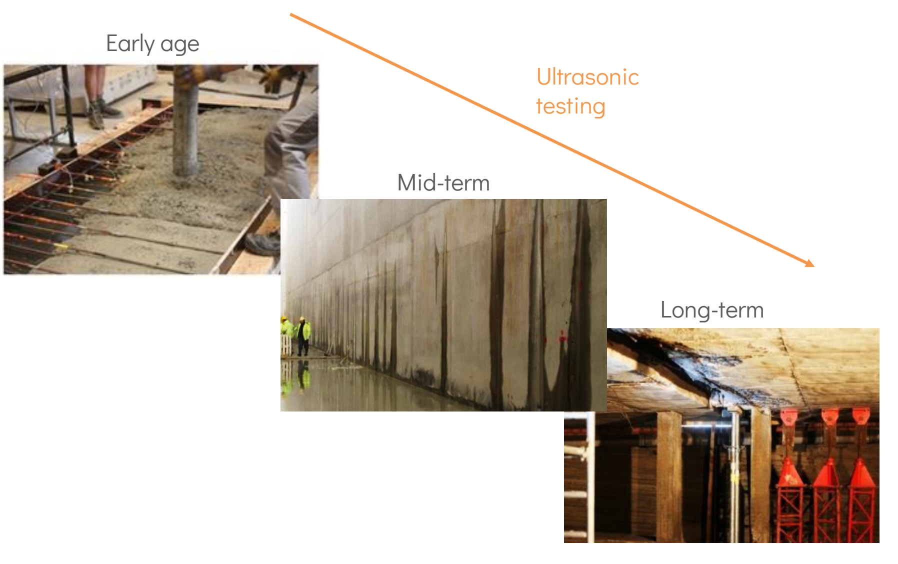
What happens during the lifetime of concrete



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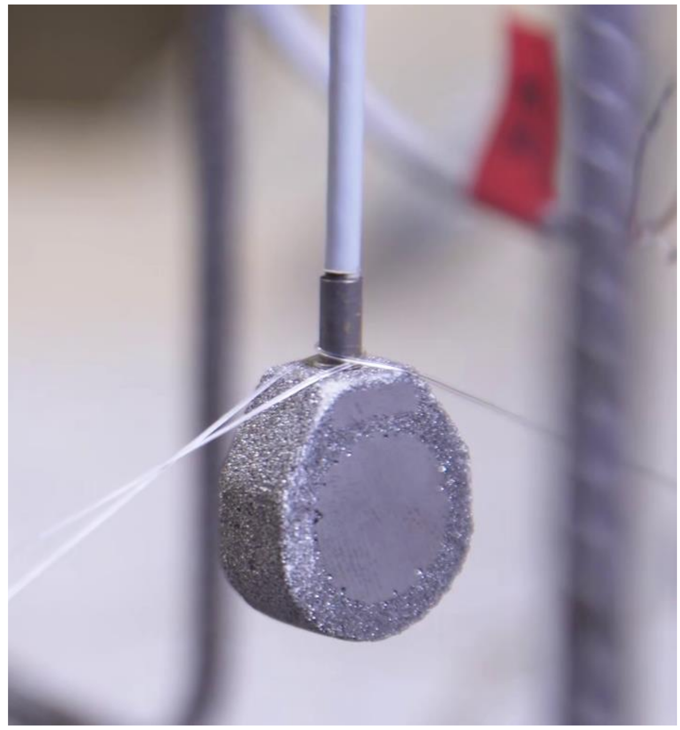
MONITORING WITH EMBEDDED TRANSDUCERS



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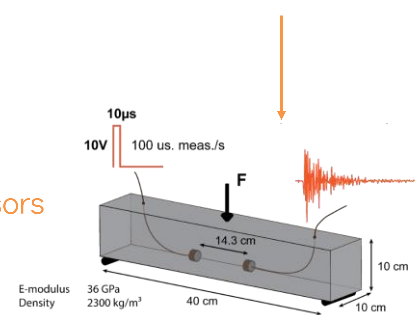
From manual inspection to automated monitoring

Embedded sensors



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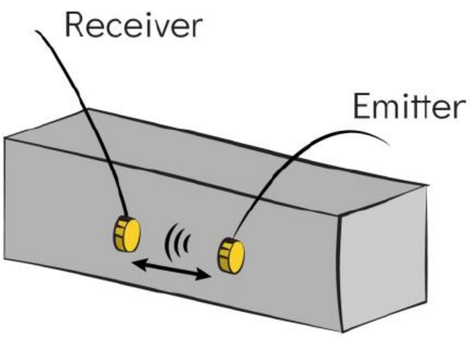
Embedded transducers



- Excellent coupling -> low-voltage
- Repeatability
- Low cost
- Internal measurements
- Protection from environment
- Measurement automation

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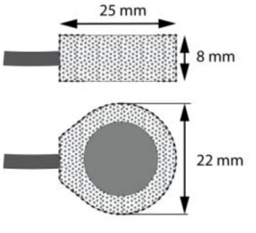
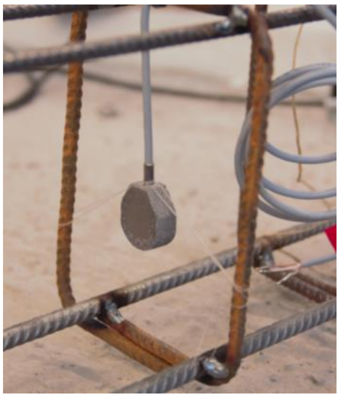
Embedded transducers





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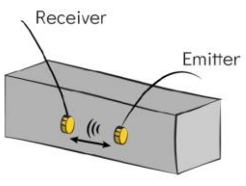
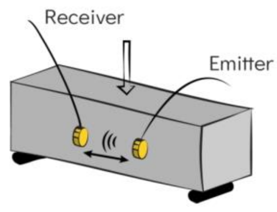
Examples of application

Early-age monitoring of concrete properties

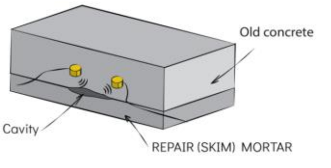


Three-point bending tests



Cylinder compression tests

Monitoring of concrete repair



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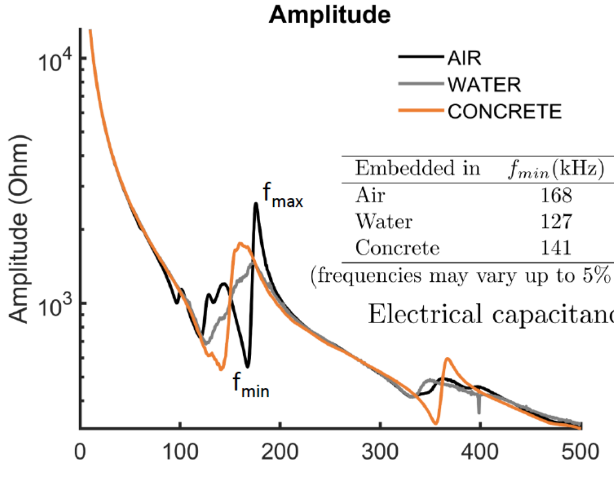
Transducers properties

Electrical impedance curve



Embedded in	f_{min}(kHz)	f_{max}(kHz)
Air	168	176
Water	127	177
Concrete	141	162

(frequencies may vary up to 5% from typical values)

Electrical capacitance 1.12 nF

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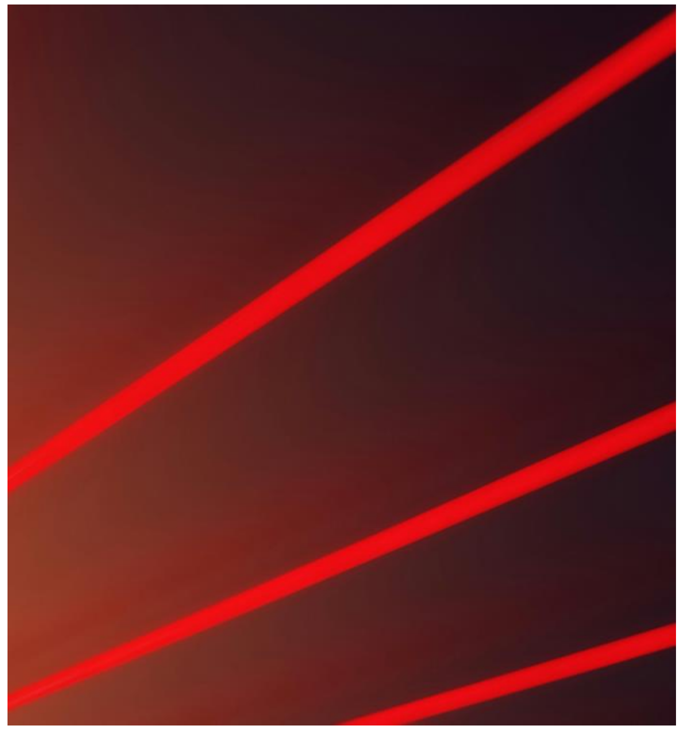
Time stretching



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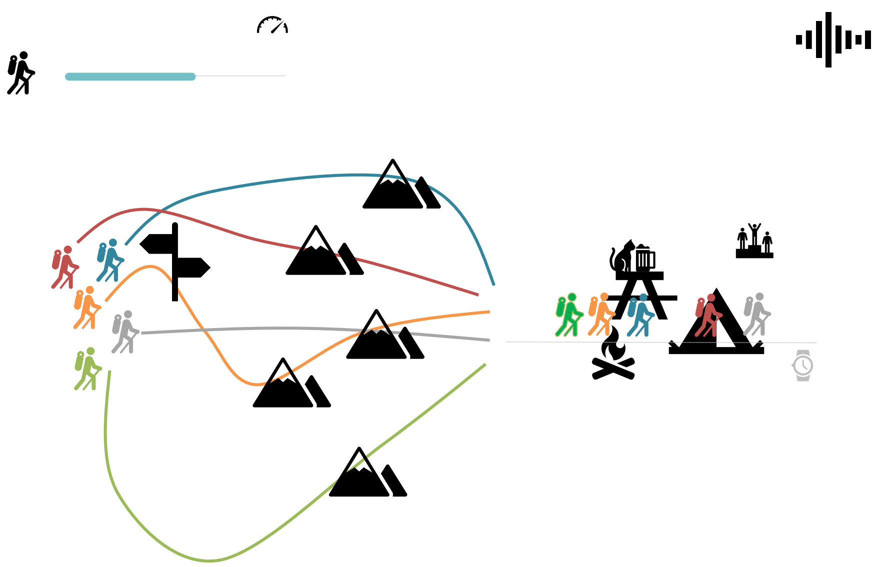
Time stretching with an illustration



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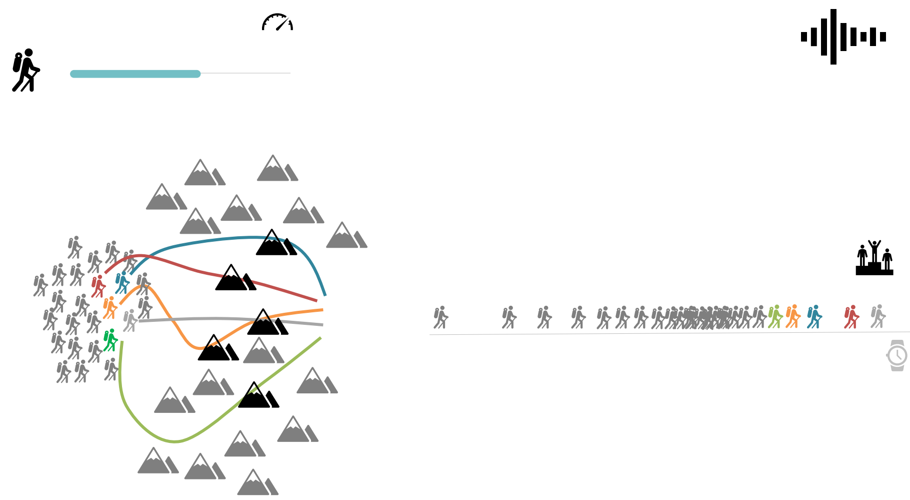
Time stretching with an illustration



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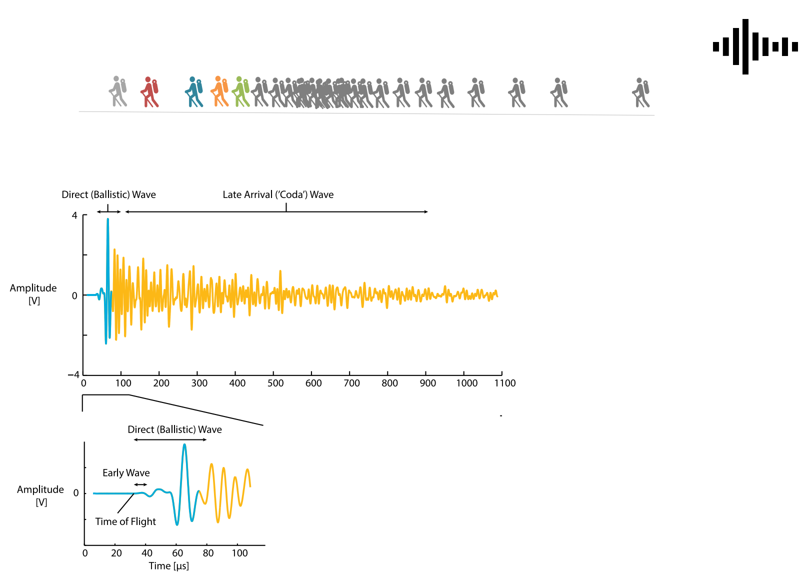
Time stretching with an illustration



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Time stretching with an illustration

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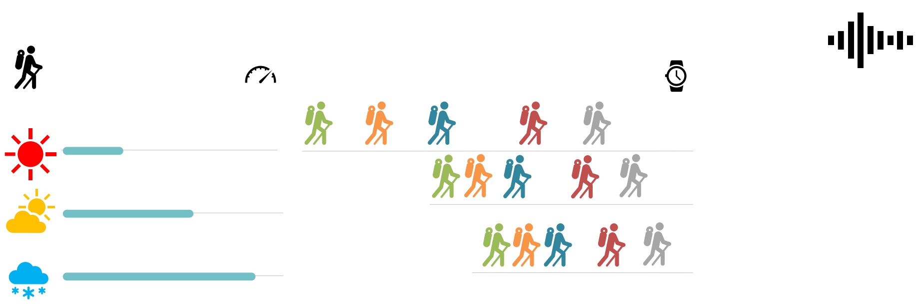
Time stretching with an illustration



- Major hypothesis:

If velocity change due to EF is uniform in the medium, time stretching can be used to compensate fully for them

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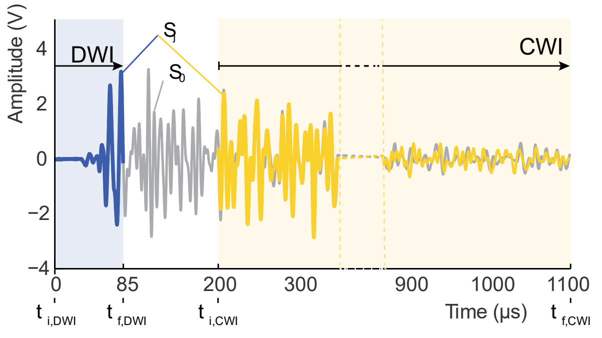
CODA wave interferometry (CWI)

Find ε so that CC(ε) is maximum

$$\mathrm{CC}(\epsilon) = \frac{\int_{t_0}^{t_f} S(t)\, S_0\Big(t\,(1+\epsilon)\Big)\, dt}{\sqrt{\int_{t_0}^{t_f} S^2(t)\, dt \int_{t_0}^{t_f} S_0^2\Big(t\,(1+\epsilon)\Big)\, dt}}$$



Stretching in time

Requires
- A reference signal
- Test repeatability

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CODA wave interferometry (CWI)

$$\mathrm{CC}(\epsilon) = \frac{\int_{t_0}^{t_f} S(t)\, S_0\Big(t\,(1+\epsilon)\Big)\, dt}{\sqrt{\int_{t_0}^{t_f} S^2(t)\, dt \int_{t_0}^{t_f} S_0^2\Big(t\,(1+\epsilon)\Big)\, dt}}$$

- CC(ε) high if general shape has not changed, ε gives information about uniform velocity change in the medium
- CC(ε) decreases when local modifications in the media occur (non uniform velocity change)

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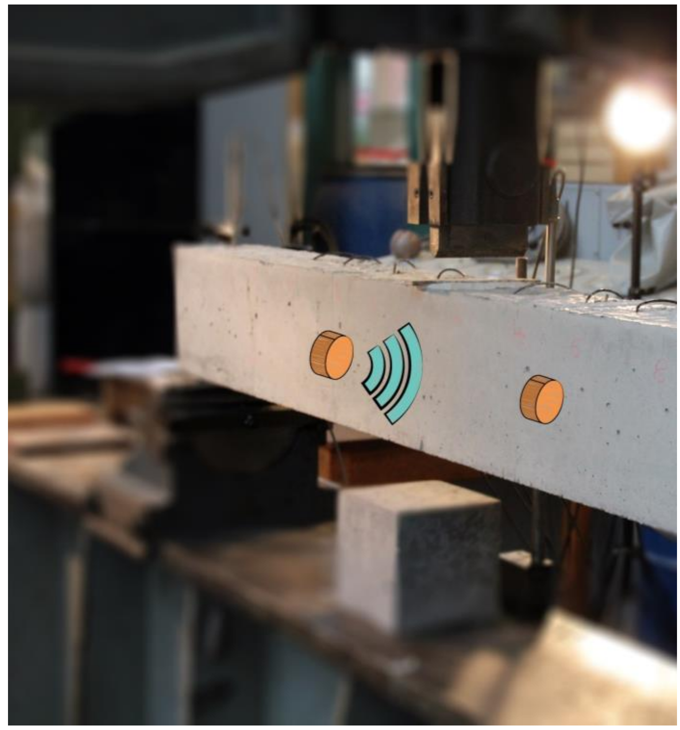
Application for crack detection under changing load



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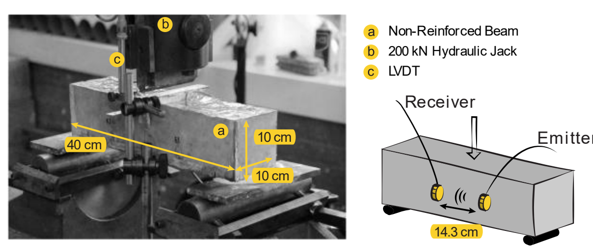
CWI and local cracking

Time stretching:
Find ε so that CC(ε) is maximum

$$\mathrm{CC}(\epsilon) = \frac{\int_{t_0}^{t_f} S(t)\, S_0\Big(t\,(1+\epsilon)\Big)\, dt}{\sqrt{\int_{t_0}^{t_f} S^2(t)\;dt \int_{t_0}^{t_f} S_0^2\Big(t\,(1+\epsilon)\Big)\, dt}}$$



- Major hypothesis:
Velocity change due to applied load is uniform in the region where the waves have travelled (acoustoelastic effect)

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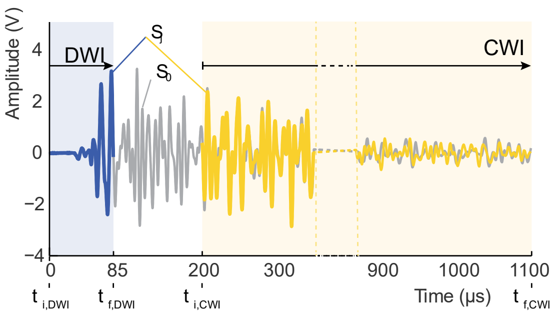
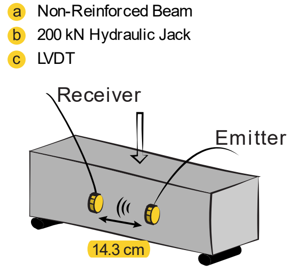
CWI and local cracking





! Influence of boundary conditions

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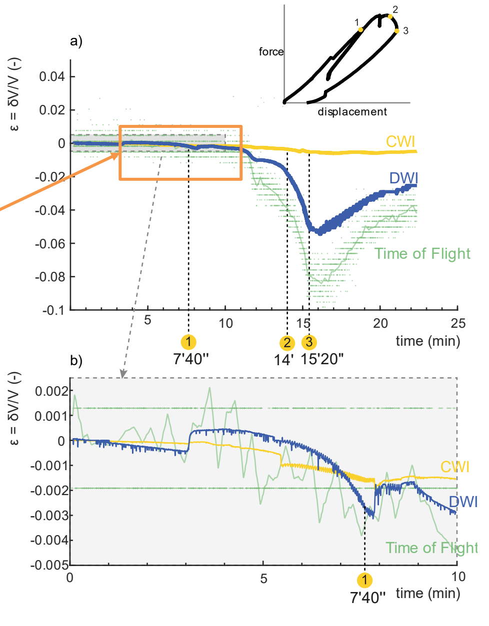
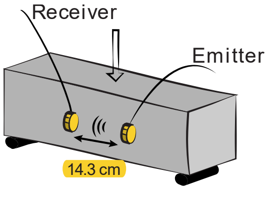
CWI and crack detection

Acoustoelastic effect





[Dumoulin 2019]

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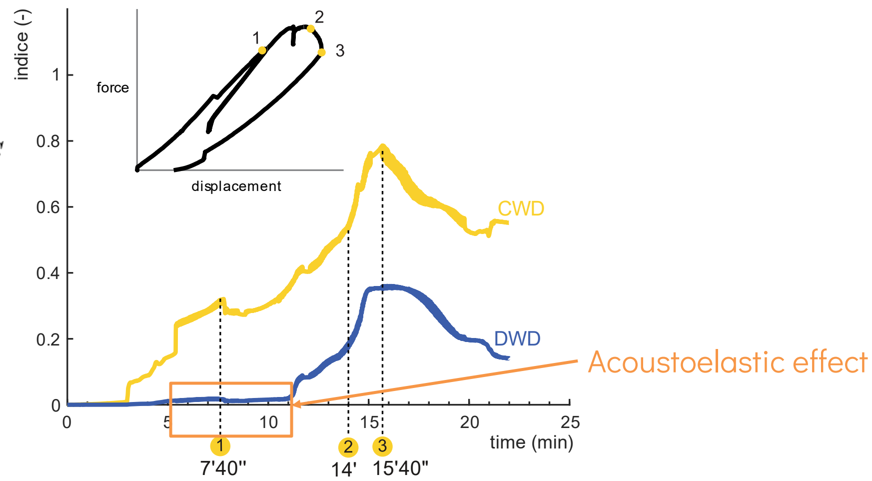
CWI and DWI decorrelations

$$DC = 1 - CC$$



[Dumoulin 2019]

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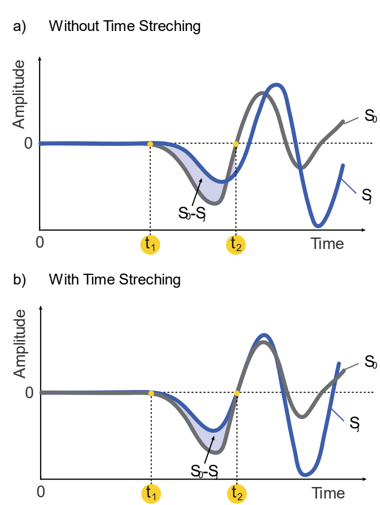
Damage index

$$\mathrm{DI}_j = \sqrt{\frac{\int_{t_1}^{t_2} \left(S_j\left(t\left(1-\epsilon_{max}\right)\right) - S_0\left(t\right)\right)^2 \, dt}{\int_{t_1}^{t_2} S_0^2\left(t\right) \, dt}}$$



[Dumoulin 2019]

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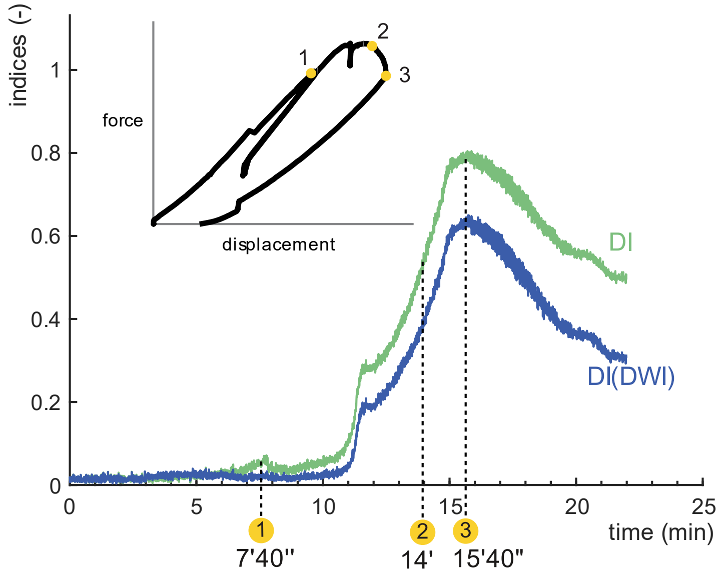
Damage index



Time stretching is efficient to remove acoustoelastic effect

Threshold setting ?

[Dumoulin 2019] 27

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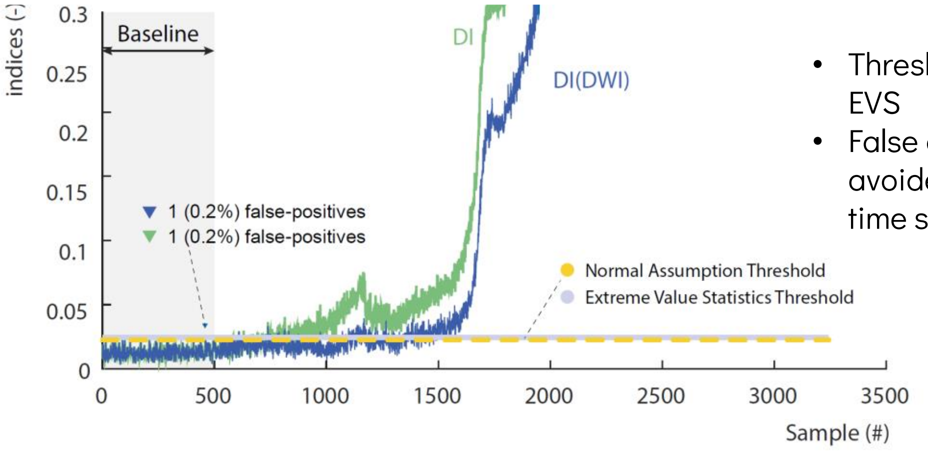
Threshold for damage detection



- Threshold using EVS
- False alarms avoided using time stretching

[Deraemaeker et al, SMART 2019, Paris] 28

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Application for repair assessment in Rogier tunnel

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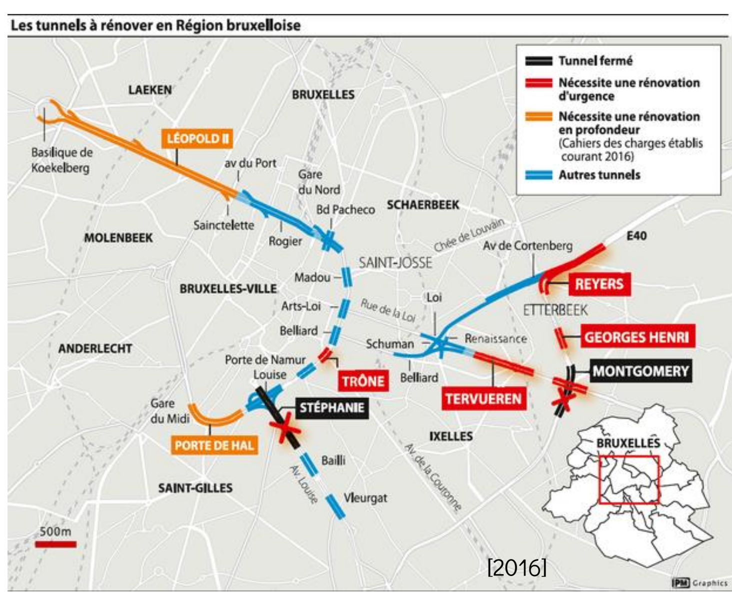
The crisis of the tunnels in Brussels



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Maintenance of civil infrastructure

- Aging infrastructure (50 years lifetime)
- Inspection is not generalized and limited to visual inspection

Maintenance of tunnels in Brussels

- Level 1 : visual inspection
- Level 2 : chemical/mechanical tests on samples

→ Necessitates to close the tunnels
→ Used to decide on repair actions

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Advanced maintenance strategies

- Reduce the unavailability of the infrastructure and the impact on mobility
- Extend the lifetime of the structure

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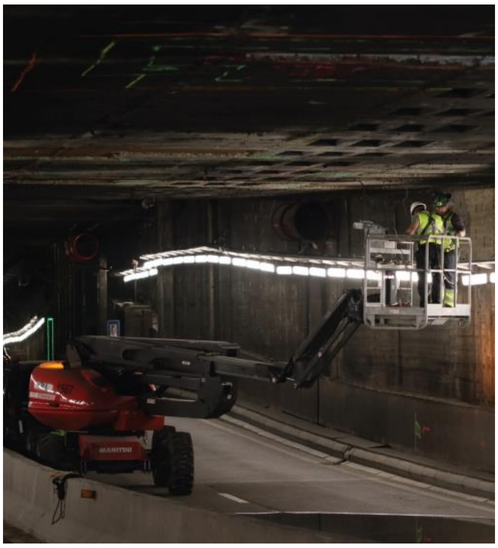
Rogier tunnel



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Rogier: the cork driver approach

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Repair work

- Destruction of bad quality concrete
- Passivation of reinforcement bars
- New concrete
- Crack injection

→ How to assess :

- quality of repair
- evolution of properties over time

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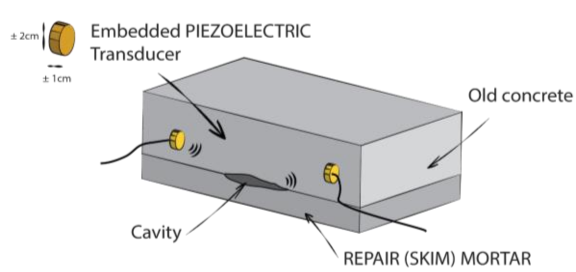
Repair monitoring



- Major hypothesis:

Velocity change due to EF is uniform in the region where the waves have travelled.

BRUXELLES MOBILITÉ
SERVICE PUBLIC RÉGIONAL DE BRUXELLES

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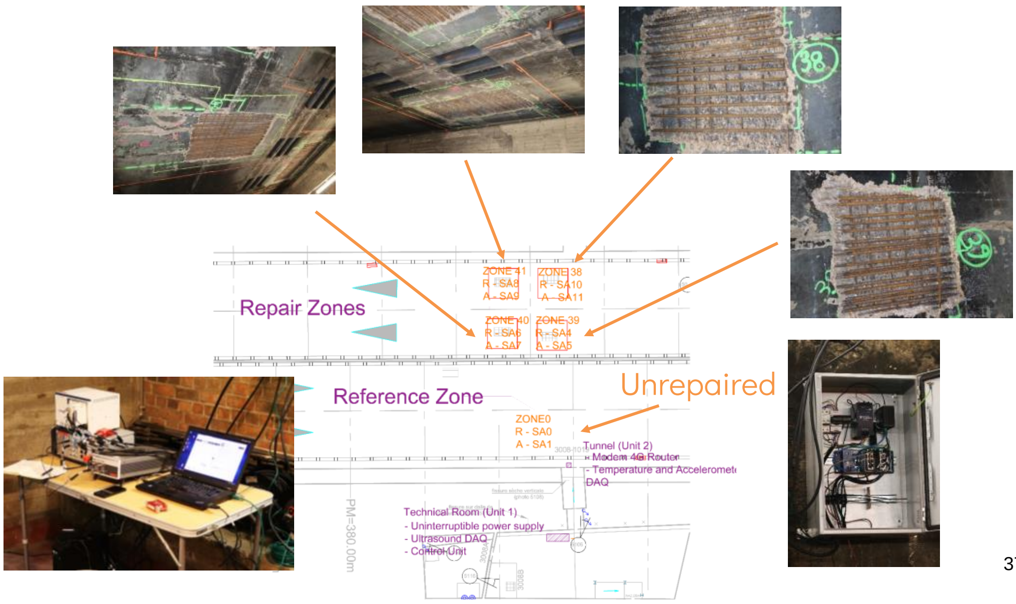
Repaired zones



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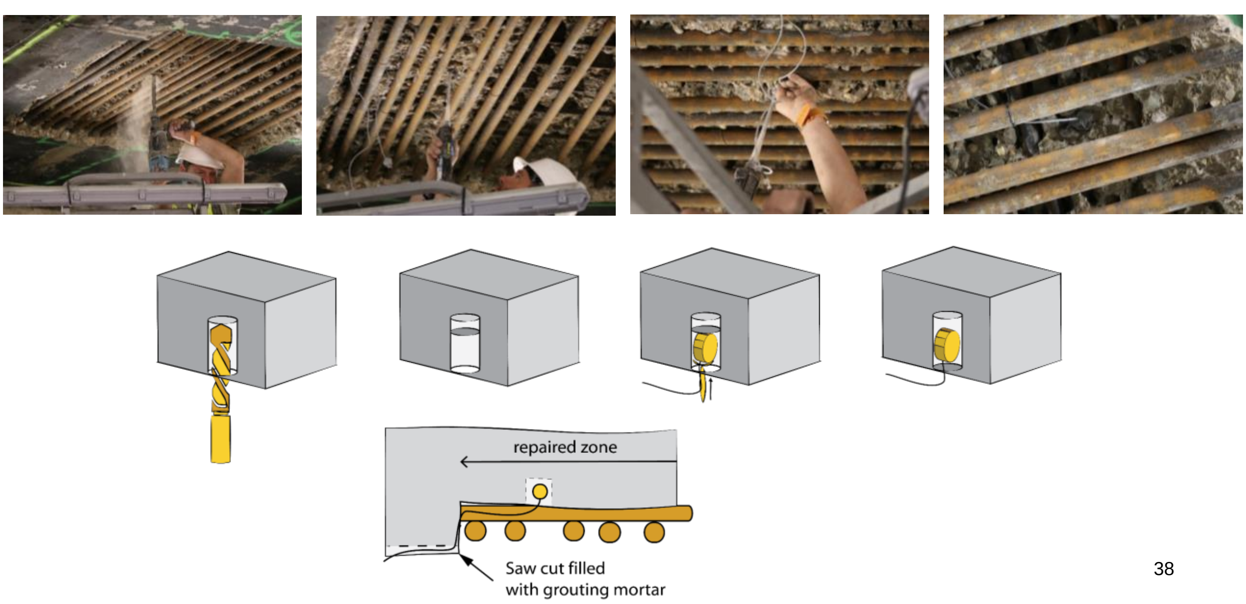
Transducers installation



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Real-time monitoring

Measurement every 30 minutes :

- Pulse at different amplitudes
- Burst at different amplitudes and frequencies

(remote access to reconfigure)

- Automated data processing remotely (BATir server)
- Automated reports sent by email (during the night)

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Damage indexes

Find ε so that CC(ε) is maximum

$$\mathrm{CC}(\epsilon) = \frac{\int_{t_0}^{t_f} S(t)\, S_0\Big(t\,(1+\epsilon)\Big)\ dt}{\sqrt{\int_{t_0}^{t_f} S^2(t)\ dt \int_{t_0}^{t_f} S_0^2\Big(t\,(1+\epsilon)\Big)\ dt}}$$

$$\frac{\Delta v}{v} = -\varepsilon \qquad\qquad DC = 1 - CC$$

40

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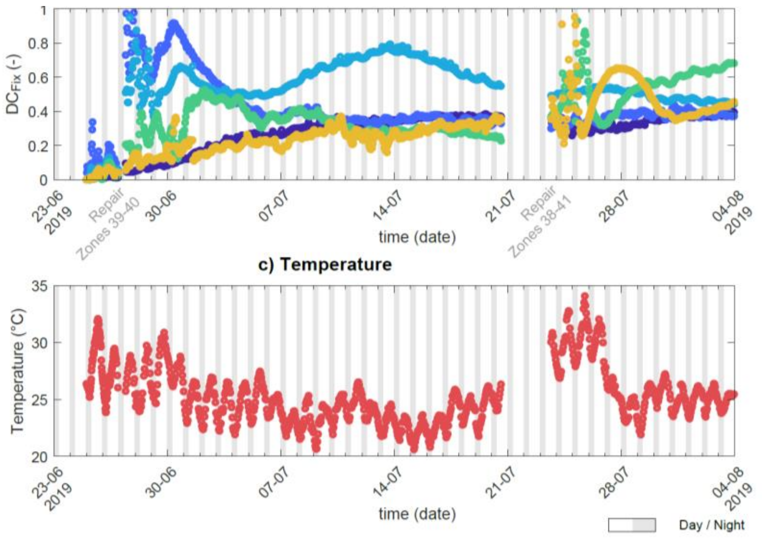
28 days monitoring



- DC reacts to repairs
- But also to EF, even when time stretching is used

Major hypothesis is not valid.

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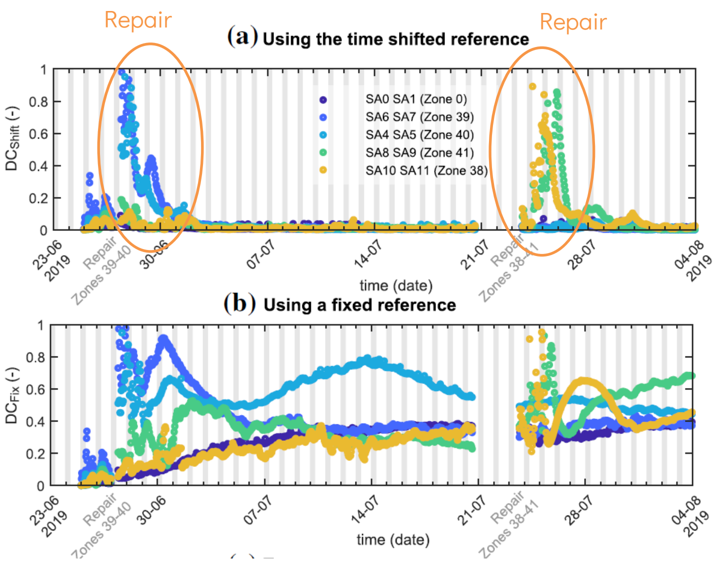
Time shifted reference



Reference : average of stretched signals during last 48h

EF efficiently filtered

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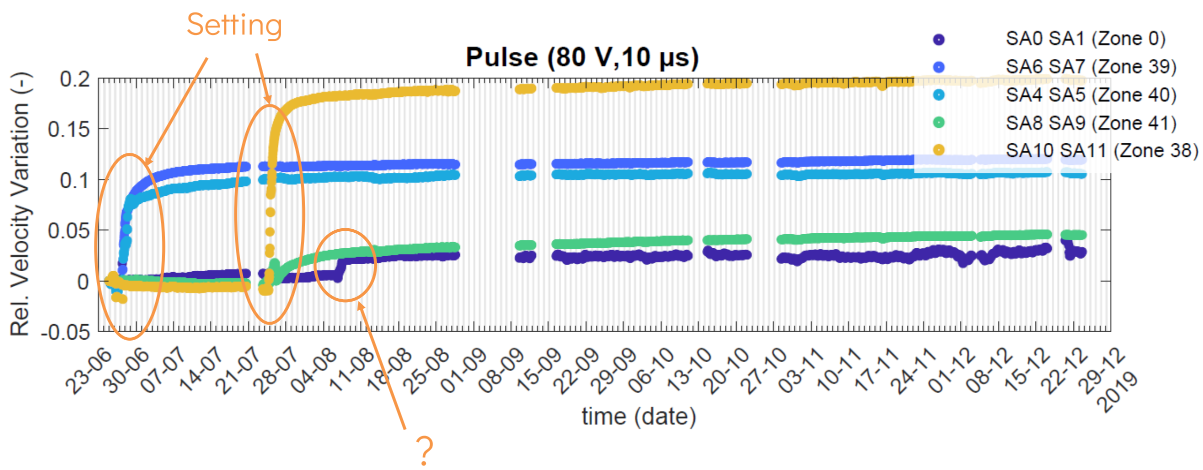
Velocity variation



EF efficiently filtered : velocity variations due to setting only

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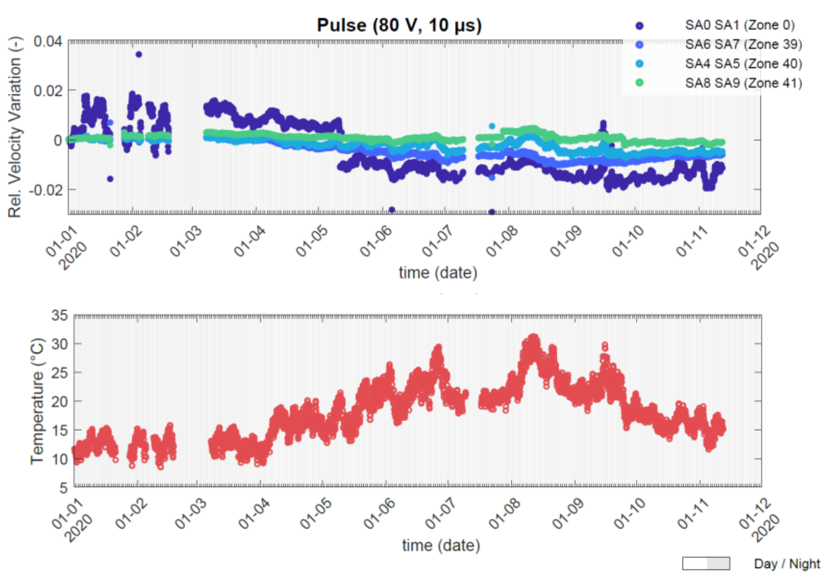
Velocity variation – long term



Trend similar to
conrete blocks

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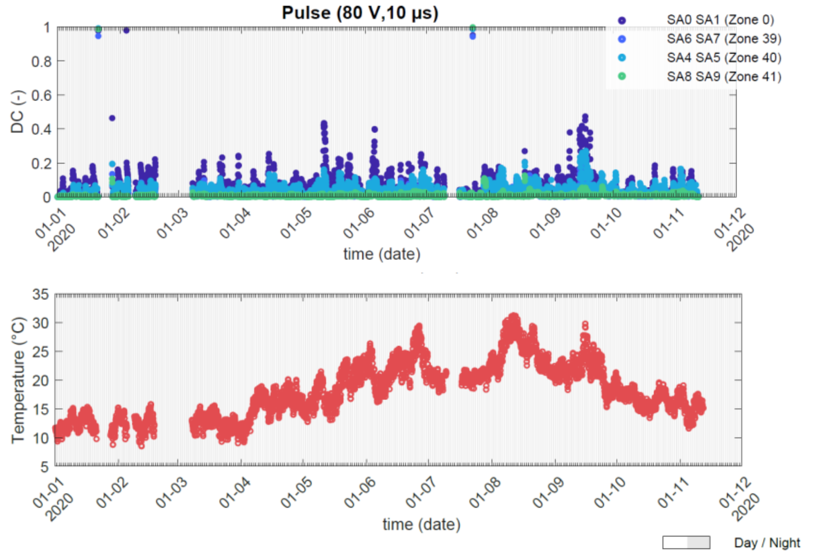
DC – long term



DC is still high, in particular for hot temperatures

45

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Cork driver and swiss knife

DC is still high, in particular for hot temperatures

+

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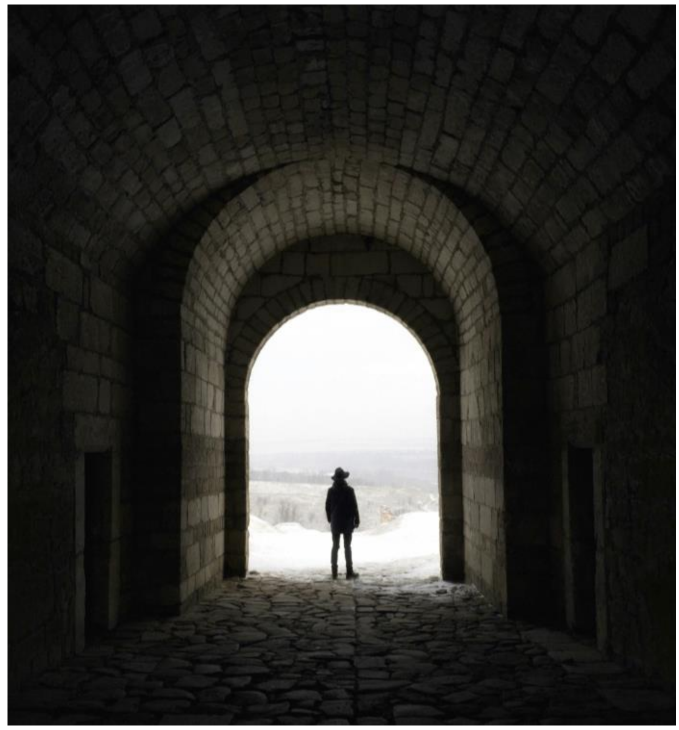
Rogier: the swiss knife approach



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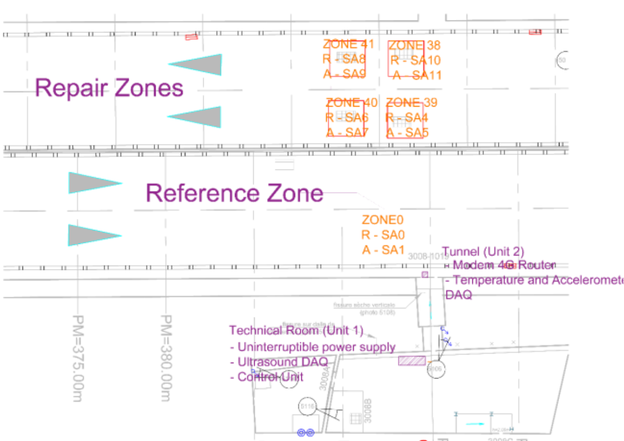
Main idea



- 4 zones (signal lost in zone 38)
- 3 excitation signals

Vector of 12 features

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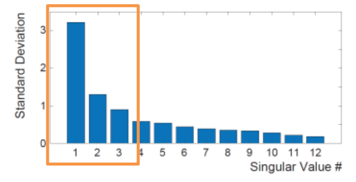
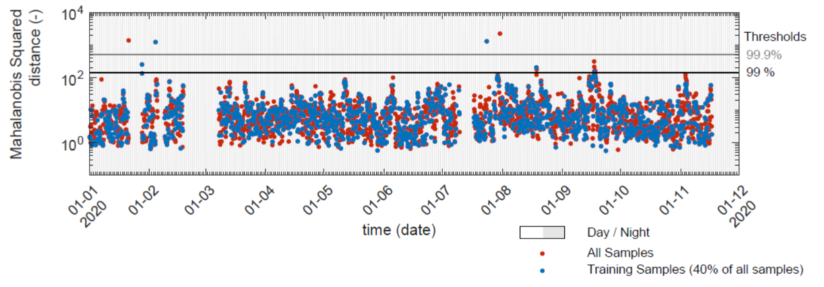
Main idea

Vector of 12 features



Natural filtering with Mahalanobis squared distance

Threshold using EVS



Global indicator → Local indicator ?

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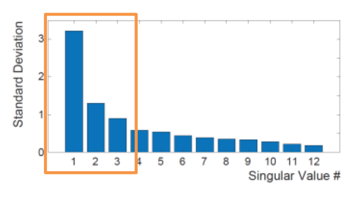
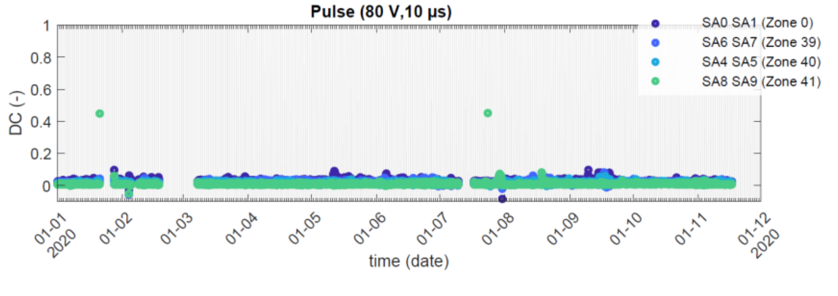
Back transformation and individual features

Filtered back transformation

$$\{y_i\} = [U]\,\{\eta_i'\} \qquad \{\eta_i'\} = \{\eta_i\}\,\frac{1/\sigma_i^2}{\sum_{i=1}^{n} 1/\sigma_i^2}$$





Filtered back transformation on DCs

50

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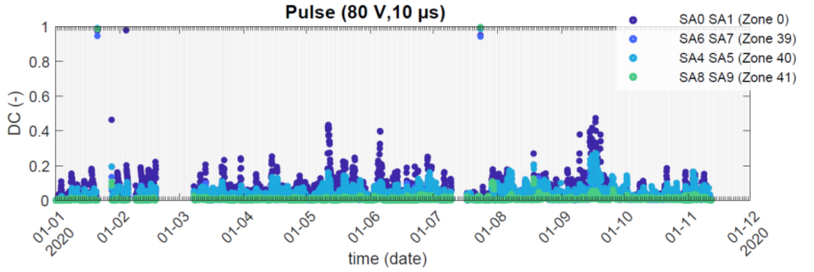
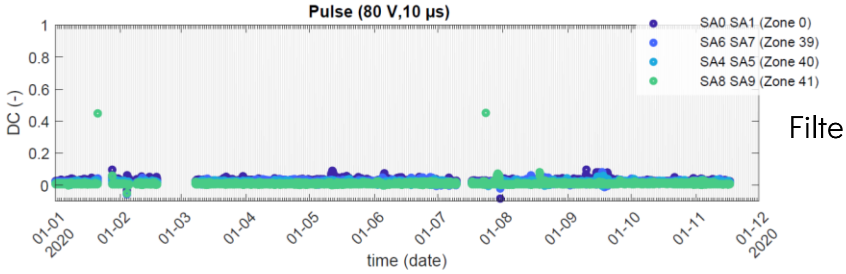
Back transformation and individual features





Filtered back transformation

Sensitivity to EF is greatly reduced, possibility to set threshold

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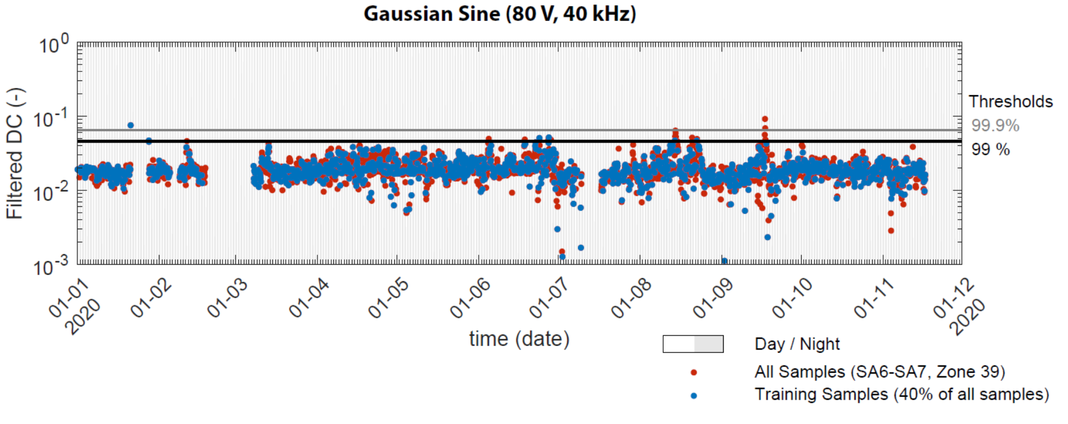
Back transformation and individual features

Threshold using
EVS - Zone 39



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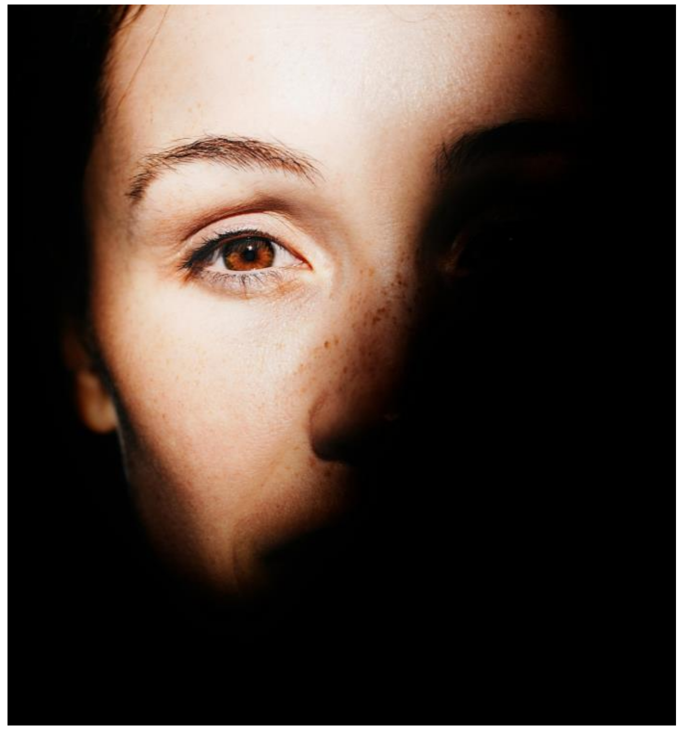
Conclusions and outlook



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Conclusion and outlook

Time stretching
With average
moving reference

+ PCA

→

- Efficient filtering of EF
- Possibility to set thresholds

Open questions:

- Time window for moving average
- Alternative methods (PhD thesis Jitendra Sharma)
- Can damage be detected after filtering of EF ? (climatic chamber tests on small specimen)

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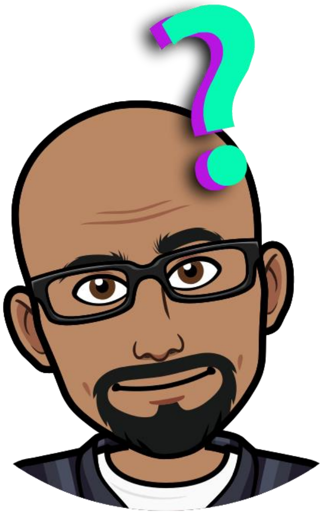

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