Passive monitoring using traffic noise recordings - case study on the Steinachtal Bridge

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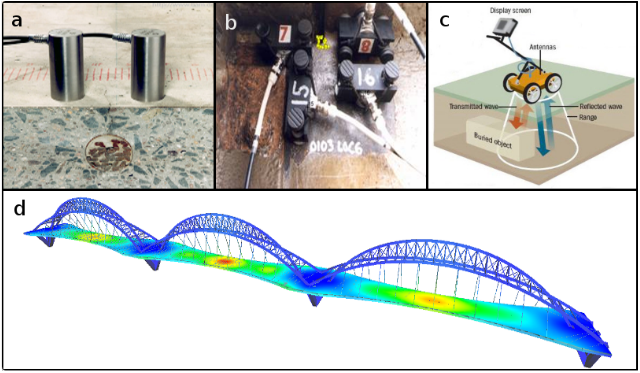
Objective

Is it possible to use ambient and/or traffic noise to monitor small-scale structures?

Motivation

Issue: Combination of **precise** and **permanent** monitoring with a **simple** measurement setup and evaluation technique.

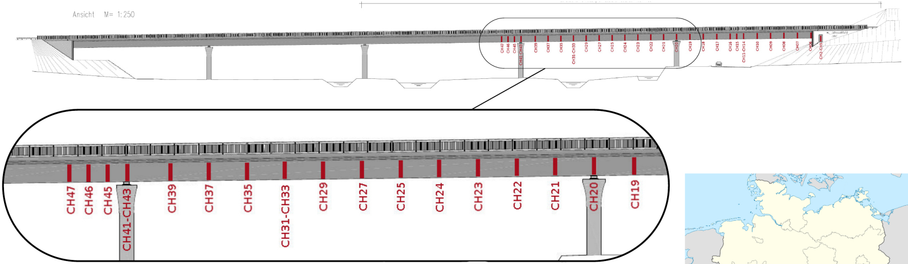


Measurement Setup I

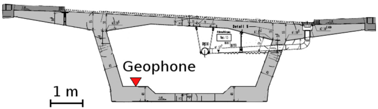
lateral view (Geophone positions)

Measurement Setup I

lateral view (Geophone positions)

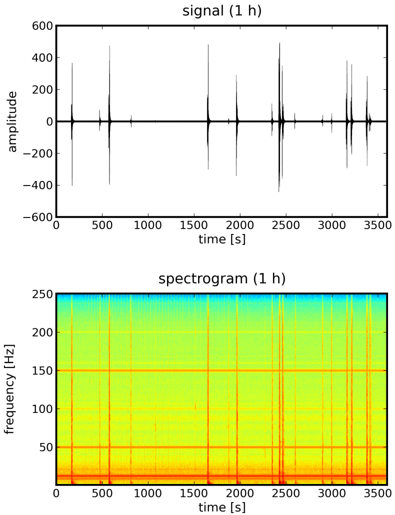


cross-section

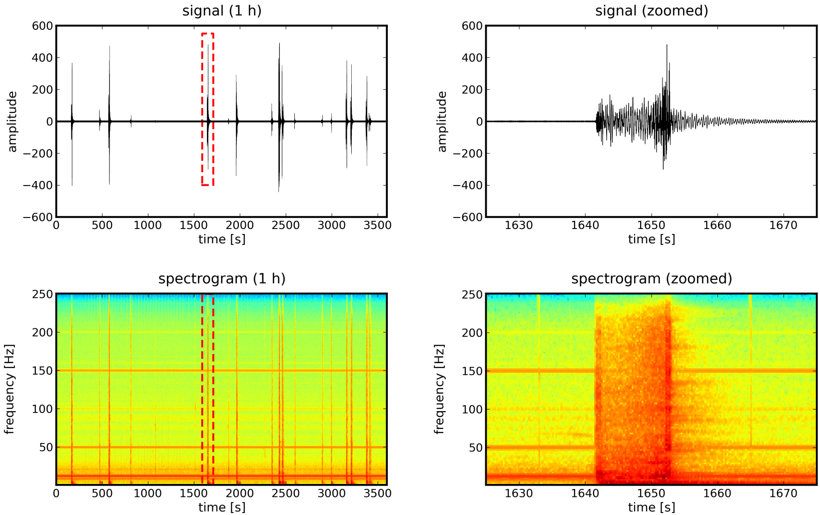


Measurement Setup II: Steinachtal Bridge

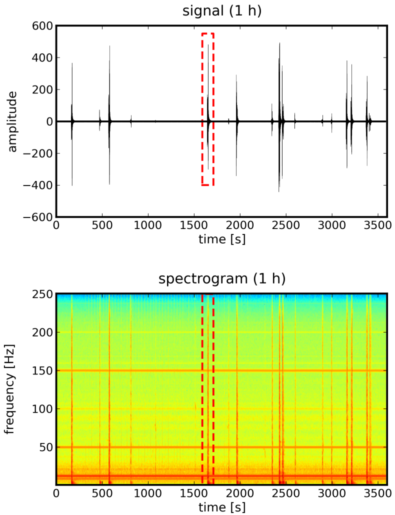
Raw Signal


signal (1 h)
amplitude
600
400
200
0
−200
−400
−600
0
500
1000
1500
2000
2500
3000
3500
time [s]
spectrogram (1 h)
frequency [Hz]
250
200
150
100
50
0
500
1000
1500
2000
2500
3000
3500
time [s]

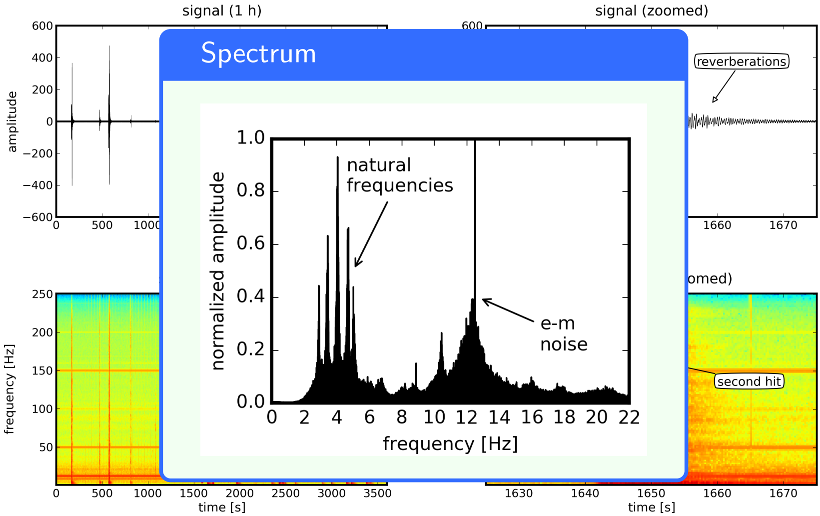
Raw Signal


signal (1 h)
amplitude
time [s]
signal (zoomed)
amplitude
time [s]
spectrogram (1 h)
frequency [Hz]
time [s]
spectrogram (zoomed)
frequency [Hz]
time [s]

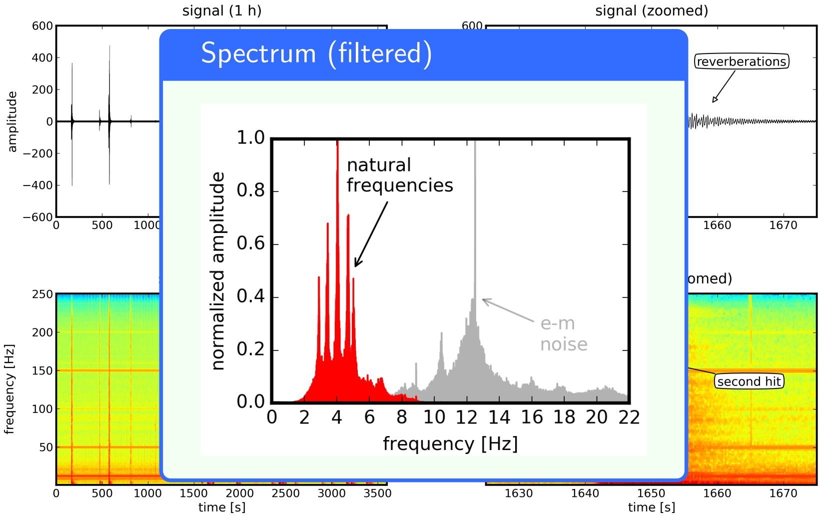
Raw Signal


signal (1 h)
600
400
200
0
−200
−400
−600
amplitude
0 500 1000 1500 2000 2500 3000 3500
time [s]
signal (zoomed)
reverberations
onset
1630 1640 1650 1660 1670
spectrogram (1 h)
250
200
150
100
50
frequency [Hz]
spectrogram (zoomed)
second hit
first hit

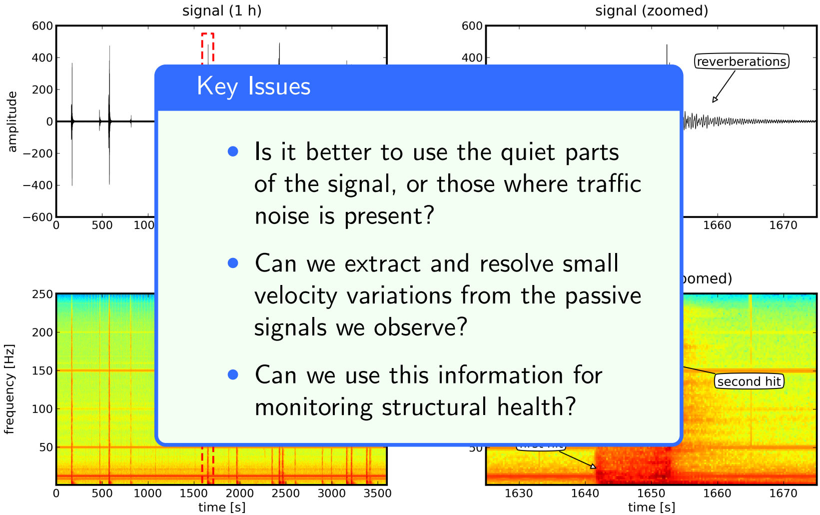
Raw Signal


signal (1 h)
signal (zoomed)
amplitude
600
400
200
0
−200
−400
−600
0
500
1000
reverberations
1660
1670
Spectrum
natural frequencies
e-m noise
normalized amplitude
frequency [Hz]
1.0
0.8
0.6
0.4
0.2
0.0
0 2 4 6 8 10 12 14 16 18 20 22
omed)
frequency [Hz]
250
200
150
100
50
second hit
0 500 1000 1500 2000 2500 3000 3500
time [s]
1630 1640 1650 1660 1670
time [s]

Raw Signal


signal (1 h)
amplitude
time [s]
frequency [Hz]
signal (zoomed)
reverberations
omed)
second hit
time [s]
Spectrum (filtered)
natural frequencies
e-m noise
normalized amplitude
frequency [Hz]

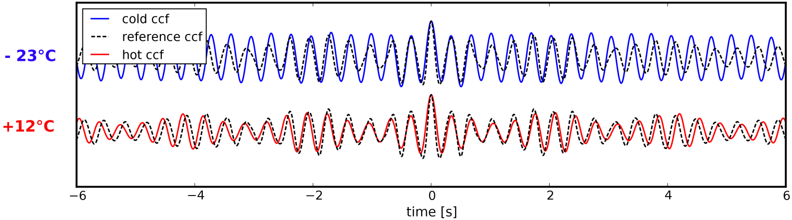
Raw Signal



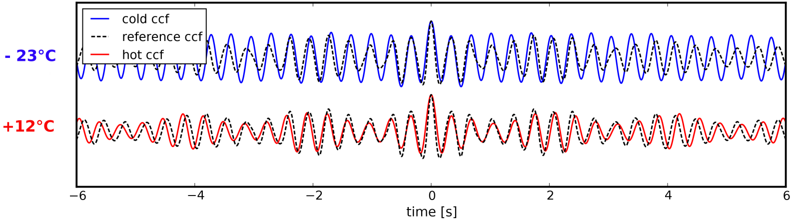
Key Issues

- Is it better to use the quiet parts of the signal, or those where traffic noise is present?
- Can we extract and resolve small velocity variations from the passive signals we observe?
- Can we use this information for monitoring structural health?

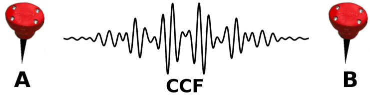
CWI & Cross-correlations



CWI & Cross-correlations



Hourly cross-correlations for receiver pairs

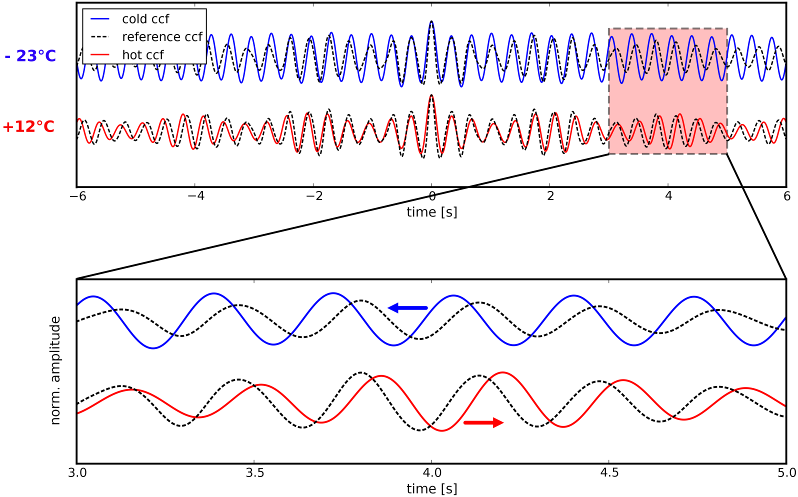


Unilateral sources and reverberations

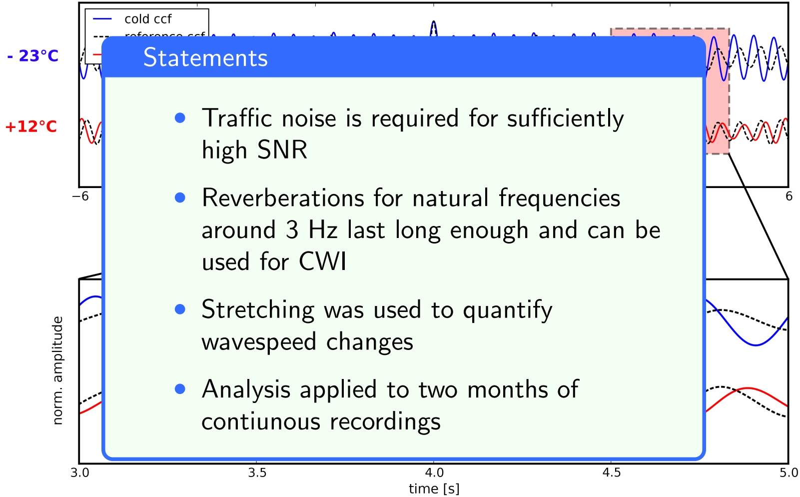
$\Downarrow$

No Green's function retrieval

CWI & Cross-correlations



CWI & Cross-correlations

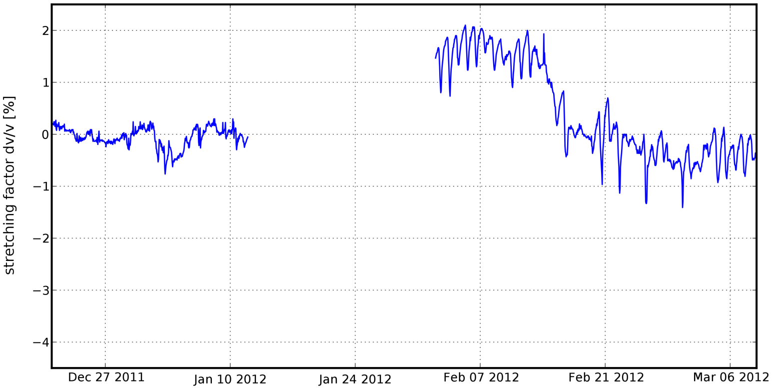


Statements

- Traffic noise is required for sufficiently high SNR
- Reverberations for natural frequencies around 3 Hz last long enough and can be used for CWI
- Stretching was used to quantify wavespeed changes
- Analysis applied to two months of contiunous recordings

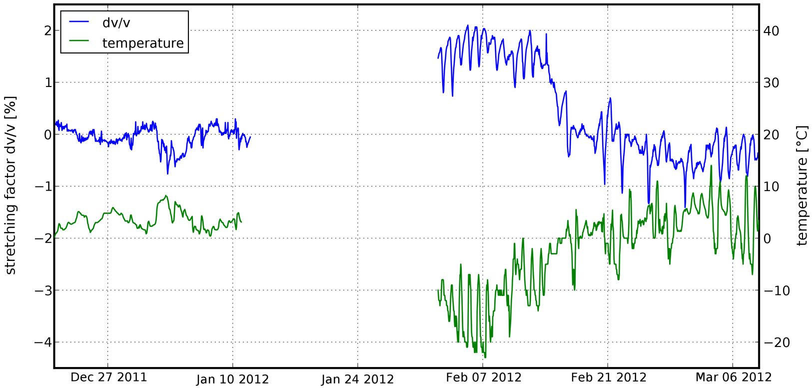
Observed Results

Velocity variation $\frac{\Delta v}{v}$



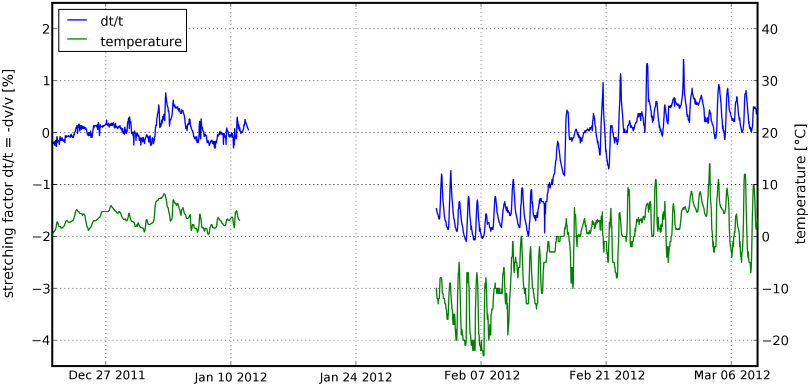
Observed Results

Velocity variation $\frac{\Delta v}{v}$ VS **Temperature**



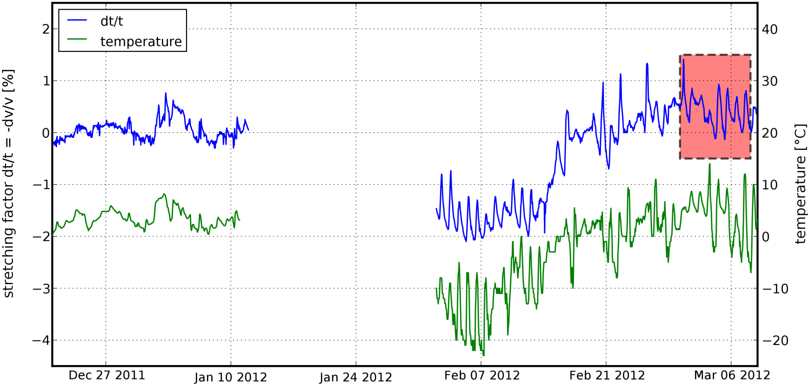
Observed Results

Velocity variation $\frac{\Delta t}{t}$ **VS** **Temperature**



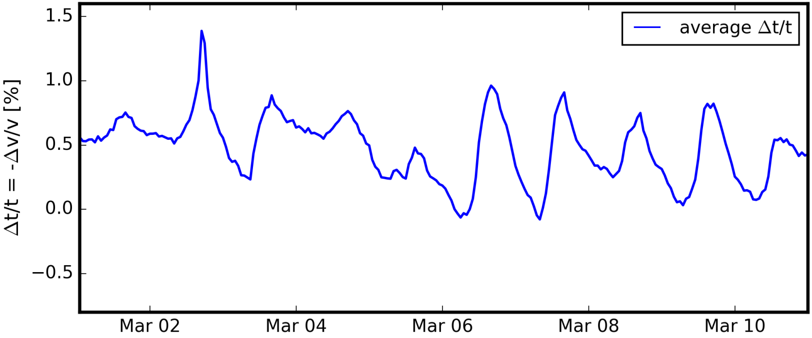
Observed Results

Velocity variation $\frac{\Delta t}{t}$ VS **Temperature**



March 2012

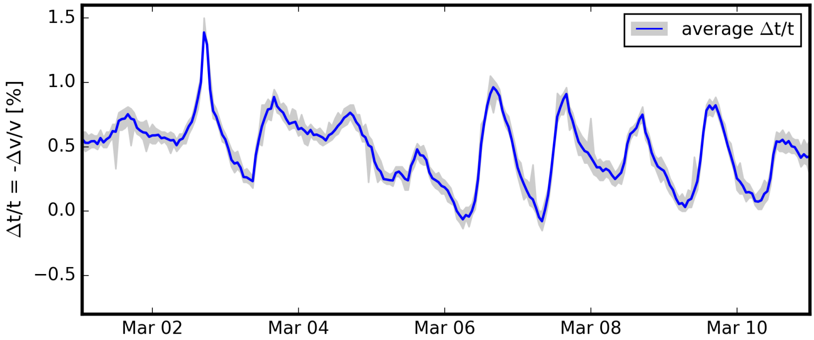
Velocity variation $\frac{\Delta t}{t}$



March 2012

Velocity variation $\frac{\Delta t}{t}$

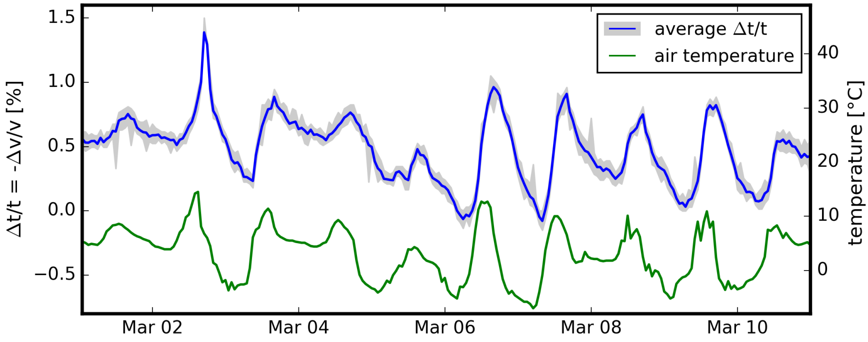
Deviation
(32 receiver pairs)



March 2012

Velocity variation $\frac{\Delta t}{t}$ **Temperature**

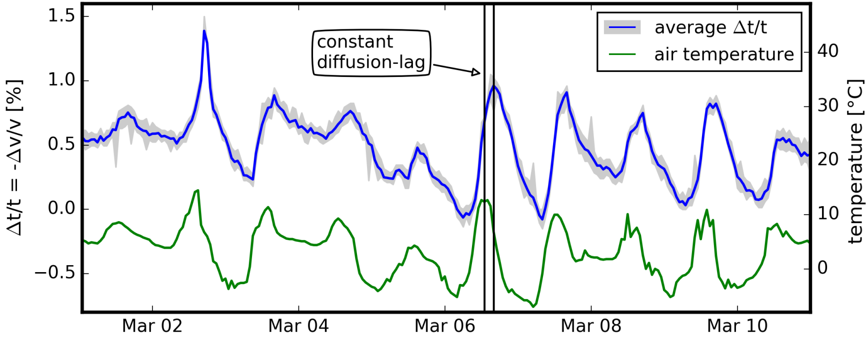
Deviation (32 receiver pairs)



March 2012

Velocity variation $\frac{\Delta t}{t}$ **Temperature**

Deviation (32 receiver pairs)



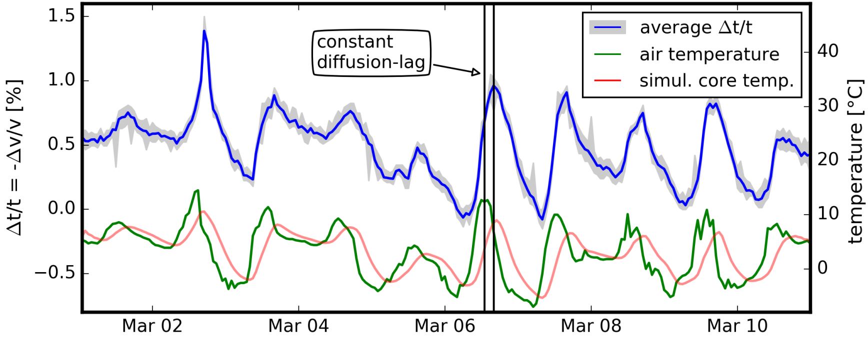
March 2012

Velocity variation $\frac{\Delta t}{t}$

Deviation (32 receiver pairs)

Temperature

Simulated core temperature



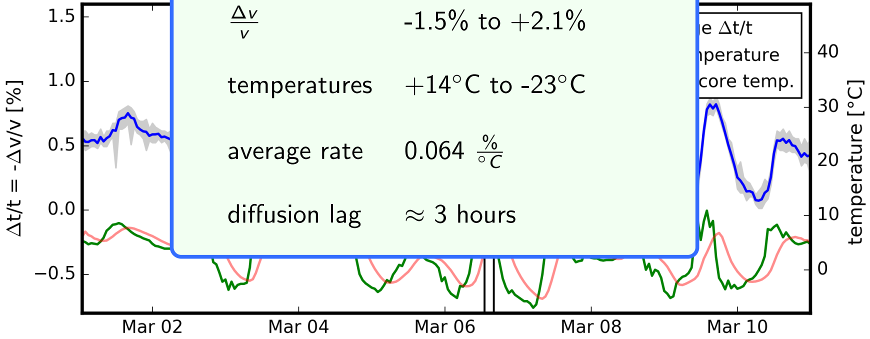
March 2012

Velocity variation $\frac{\Delta t}{t}$

Temperature

Simulated core temperature

Deviation (32 receiver pa



Overall Results

$\frac{\Delta v}{v}$	-1.5% to +2.1%
temperatures	+14°C to -23°C
average rate	$0.064 \ \frac{\%}{^\circ C}$
diffusion lag	$\approx$ 3 hours

Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge

Instrument stability

Temperature dependence of geophones

Msmt range

-1.5 to +2.3 %

Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge
$\Rightarrow$ Effect in the order of $\mathbf{6\text{-}14} \cdot \mathbf{10^{-4}} \frac{\%}{^\circ C}$ for steel-reinforced concrete

$\ll$

Msmt range

-1.5 to +2.3 %

Instrument stability

Temperature dependence of geophones

Reliability Tests

Thermal expansion

Expansion/Contraction of the bridge
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$\ll$

Msmt range

-1.5 to +2.3 %

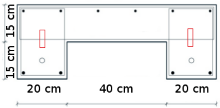
$<$

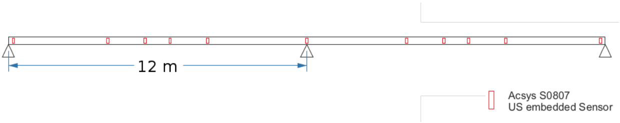
Instrument stability

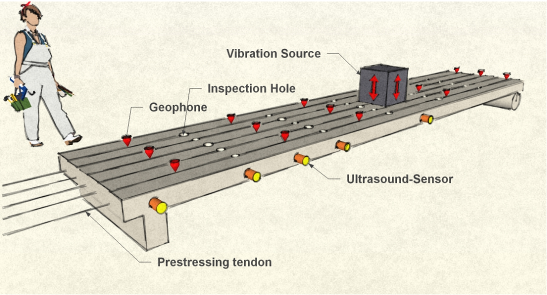
Temperature dependence of geophones
$\Rightarrow$ Apparent delay of max. **0.52 %** for extreme shifts in corner frequency.

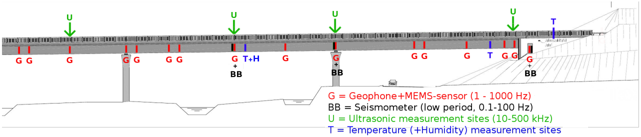
Conclusions

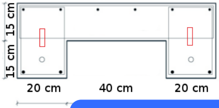
- Resolution of velocity variations is possible via cross-correlations from ambient traffic noise on a bridge
- Captured small velocity variations caused by temperature fluctuations:
  relative velocity $\frac{\Delta v}{v}$: -1.5% to +2.1%
  temperature range: +14°C to -23°C
- Strong correlation between temperature and $\frac{\Delta v}{v}$ series
- Advantages: high temporal resolution, high accuracy, low logistical effort

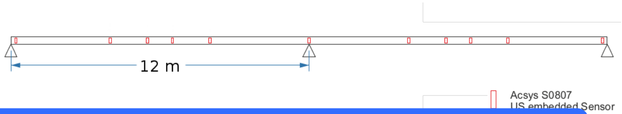

15 cm
15 cm
20 cm
40 cm
20 cm


12 m
Acsys S0807
US embedded Sensor


Vibration Source
Inspection Hole
Geophone
Ultrasound-Sensor
Prestressing tendon


U
G G
G
G G
G G
G
+
BB
T+H
T
G = Geophone+MEMS-sensor (1 - 1000 Hz)
BB = Seismometer (low period, 0.1-100 Hz)
U = Ultrasonic measurement sites (10-500 kHz)
T = Temperature (+Humidity) measurement sites



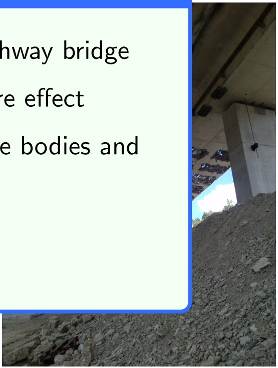


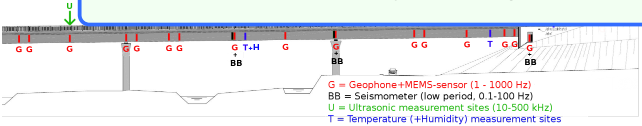
Perspective - aspired project

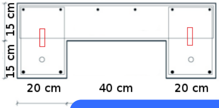
- Long-term (> 1 year) monitoring of a highway bridge

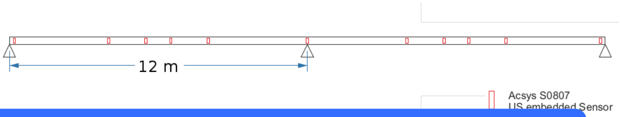
  ⇒ improve characterization of temperature effect
- Extensive damage-scenario tests on sample bodies and expired structures
- Numerical simulations

  ⇒ confirm reliability of damage detection





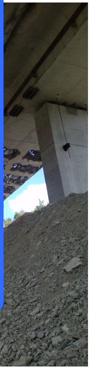


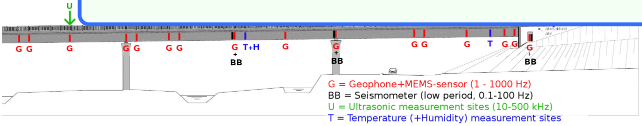


Perspective - aspired project

Aim

Detect corrosion-induced **decrease in prestressing** and associated **concrete crack** evolution

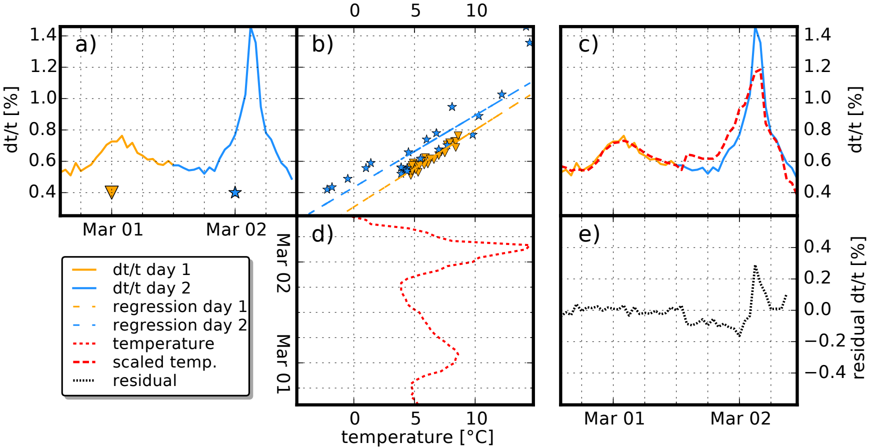




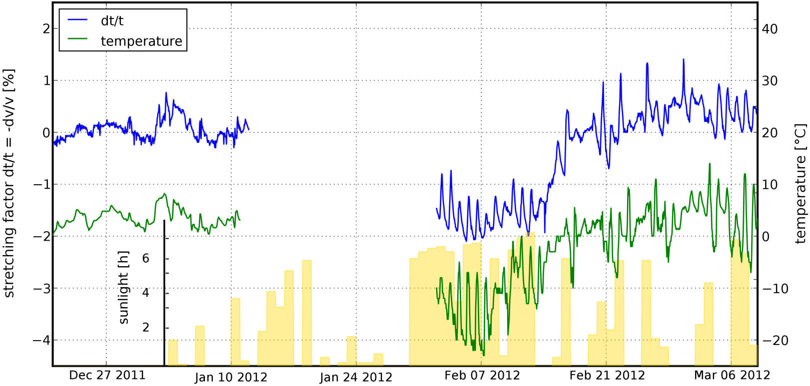
Questions

Thank you!

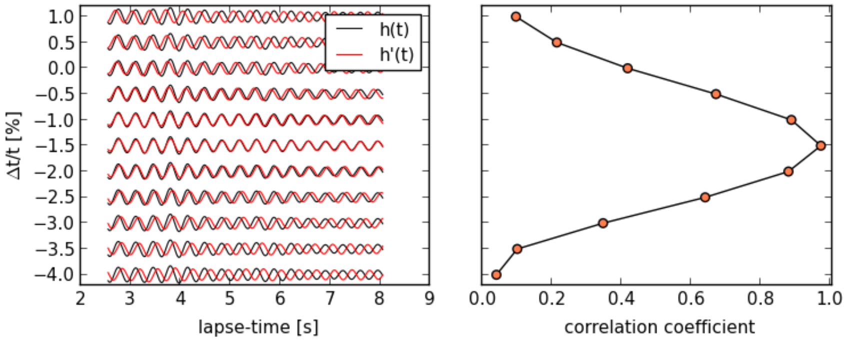
Temperature reduction



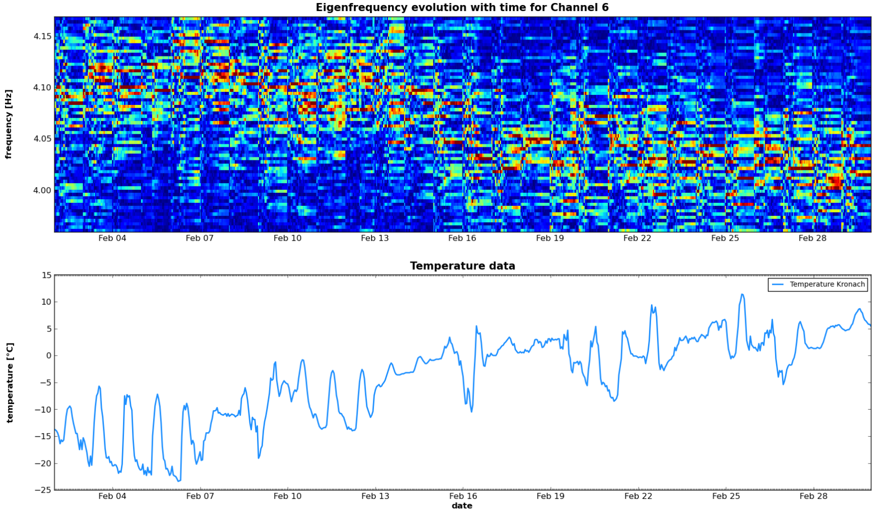
Daily Sunlight



Stretching Method



Eigenfrequency Evolution



Instrument Stability Test

Frequency Response of GS-11D 4.5Hz 380Ω vertical component Geophone