Surveillance des risques naturels :
nouvelles méthodes géophysiques?

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Partenariats :
Environmental seismology: What can we learn on earth surface processes with ambient noise?

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\section*{Abstract}

Environmental seismology consists in studying the mechanical vibrations that originate from, or that have been affected by external causes, that is to say causes outside the solid Earth. This includes for instance the coupling between the solid Earth and the cryosphere, or the hydrosphere the anthroposphere and the specific sources of vibration developing there. Environmental seismology also addresses the modifications of the wave propagation due to environmental forcing such as temperature and hydrology. Recent developments in data processing, together with increasing computational power and sensor concentration have led to original observations that allow for the development of this new field of seismology. In this article, we will particularly review how we can track and interpret tiny changes in the subsurface of the Earth related to external changes from modifications of the seismic wave propagation, with application to geomechanics, hydrology, and natural hazard. We will particularly demonstrate that, using ambient noise, we can track 1) thermal variations in the subsoil in buildings or in rock columns; 2) the temporal and spatial evolution of a water table; 3) the evolution of the rigidity of the soil constituting a landslide, and especially the drop of rigidity preceding a failure event.
1. Analyse vibratoire
2. Variation de vitesse / bruit de fond sismique
3. Mesure de déformation : Technologie RFID
Mechanical vibration = Elasticity + mass

\[ f = \sqrt{\frac{\text{rigidity}}{\text{mass}}} \]
Engineering seismology -> buildings
1. Seismic vibration

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1. Seismic vibration

Resonance Frequency

(a) $f$ (Hz)

(b) $T$ (°C) vs Rainfall (mm/day)

1. Seismic vibration

F $\leftrightarrow$ rear fracture

bulk damage/fracturation (rigidity )

thermal effect $\uparrow$ $\downarrow$ $\uparrow$ $\downarrow$
1. Seismic vibration

$F \leftrightarrow \text{rear fracture}$

bulk damage/fracturation (rigidity)

thermal effect

$T^\circ \rightarrow \text{rigidity}$....But...
1. Seismic vibration

\[ F \Leftrightarrow \text{rear fracture} \]

bulk damage/fracturation (rigidity)

thermal effect

\[ T^\circ \Rightarrow \text{rigidity} \quad \ldots \quad \text{But...} \]

\[ T^\circ \Rightarrow \text{thermal dilation} \Rightarrow \text{local stress} \Rightarrow \text{rigidity} \]
1. Seismic vibration

La Bourne Gorges
1. Seismic vibration

Unstable rock compartment
Column re-inforcement

Continuous seismic station

Seismic Sensors

Reinforcement
Column re-inforcement
1. Seismic vibration

Before T° correction

After T° correction

\[ \text{Date [dd/mm]} \]
1. Seismic vibration

Before $T^\circ$ correction

After $T^\circ$ correction

Work quality control + long term monitoring

1. Analyse vibratoire
2. Variation de vitesse / bruit de fond sismique
3. Mesure de déformation : Technologie RFID
2. \(dV/V\) from ambient seismic noise

\[ v = \sqrt{\frac{\text{rigidité}}{\text{densité}}} \]

- \(dV/V < 0\)
  - \(\Rightarrow\) Increase of density (water content)?
  - \(\Rightarrow\) Decrease of stress
  - \(\Rightarrow\) Decrease of rigidity (fracturation/damage)
2. $dV/V$ from ambient seismic noise

Time of flight

Seismic velocity

$$v = \sqrt{\frac{\text{rigidité}}{\text{densité}}}$$

- $dV/V < 0$
  - $\rightarrow$ Increase of density (water content)?
  - $\rightarrow$ Increase of temperature
  - $\rightarrow$ Decrease of stress
  - $\rightarrow$ Decrease of rigidity (fracturation/damage)

Need repeatable sources + precise/sensitive signals..
2. dV/V from ambient seismic noise

Workflow

- Ambient noise
- Frequency Whitening
  - Amplitude clipping / 1-bit
- Daily X-correlation
- Averaging
Les Diablerets (Suisse)
2. $dV/V$ from ambient seismic noise

Mainsant et al, JGR (2012)
Fluctuations +/- 2%
Drying during summer

Mainsant et al, JGR (2012)
2. $dV/V$ from ambient seismic noise

Winter: Moisture / freezing / snow...

Mainsant et al, JGR (2012)
2. $dV/V$ from ambient seismic noise

![Graph showing $dV/V$ (%) vs. time, with a large decrease highlighted with a red circle and a grey box indicating no data in the region from 22/04/10 to 08/11/10.]

**Large decrease => Liquefaction?**

Mainsant et al, JGR (2012)
2. $dV/V$ from ambient seismic noise

5 days precursory signal

See also NOELIE BONTEMPS’S poster!

Mainsant et al, JGR (2012)
2. $dV/V$ from ambient seismic noise

Mainsant et al, JGR (2012)
Permafrost monitoring

![Graph showing monitoring data with indicators for brutal snow melt and saturation plus destabilization. The graphs depict changes in dV/V (%) and coherence over time from January 2016 to January 2017.](image-url)
1. Analyse vibratoire

2. Variation de vitesse / bruit de fond sismique

3. Mesure de déformation : Technologie RFID
How ? Phase-Distance equivalence

In optimum conditions:

\[ \varphi_{\text{air}} = -\frac{4\pi f}{v} d \]

With:

- \( \varphi_{\text{air}} \) phase shift in the air (rad);
- \( d \) tag-base distance;
- \( v \) radio wave velocity in the air (\( \approx c \));
- \( f \) carrier frequency (865-868 MHz).

\[ \varphi_{\text{measured}} = \varphi_{\text{instruments}} + \varphi_{\text{air}} \]

Variation in time \( \rightarrow \) small radial displacements
Modulo \( 2\pi \) \( \rightarrow \) accurate, but ambiguous
1. Tag

Temperature effects on the phase

2. Coaxial cable

Moisture effects

- Water evaporating very slowly
- Water dropping

- Water on hydrophobic tag
- Water on unmodified tag
- No water
3. Monitoring RFID

b) PO

240 m
Extensometer

Base station

19 tags

Base station

Tags

Pont-Bourquin
Switzerland
Validation of displacements

Conclusions:
- Displacement is coherent with standard techniques.
- RFID is more stable than wire extensometer

NB: The 5-cm offset between RFID and extensometer is a true displacement (verified from theodolite)
Phase of all tags along time

3. Monitoring RFID

E. Larose
Merci !

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Whitening = frequency normalization
1-bit normalization

Larose et al, JAP 2004
Amplitude clipping (rms)
2. dV/V from ambient seismic noise

Amplitude clipping (rms)

Larose et al, JAP 2004