ISRM Meeting Paris

Earthquake-triggered rock slope failures: Damage and site effects

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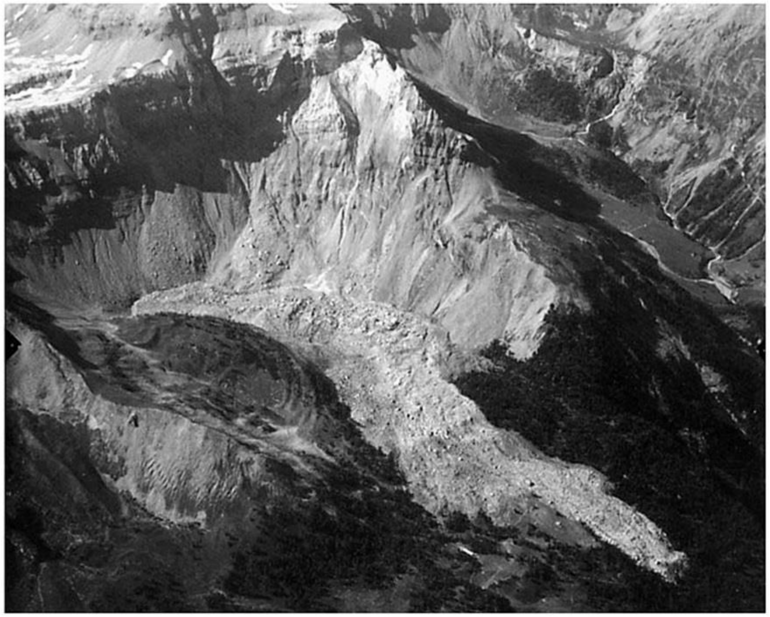


Rawilhorn, Switzerland

Paris, 05.06.2014

Background

- **COGEAR** Project: **Co**upled Seismogenic **Ge**ohazards in **A**lpine **R**egions
- Interdisciplinary project for investigating the hazard chain induced by earthquakes
- Partners: ETH Zürich and ETH Lausanne

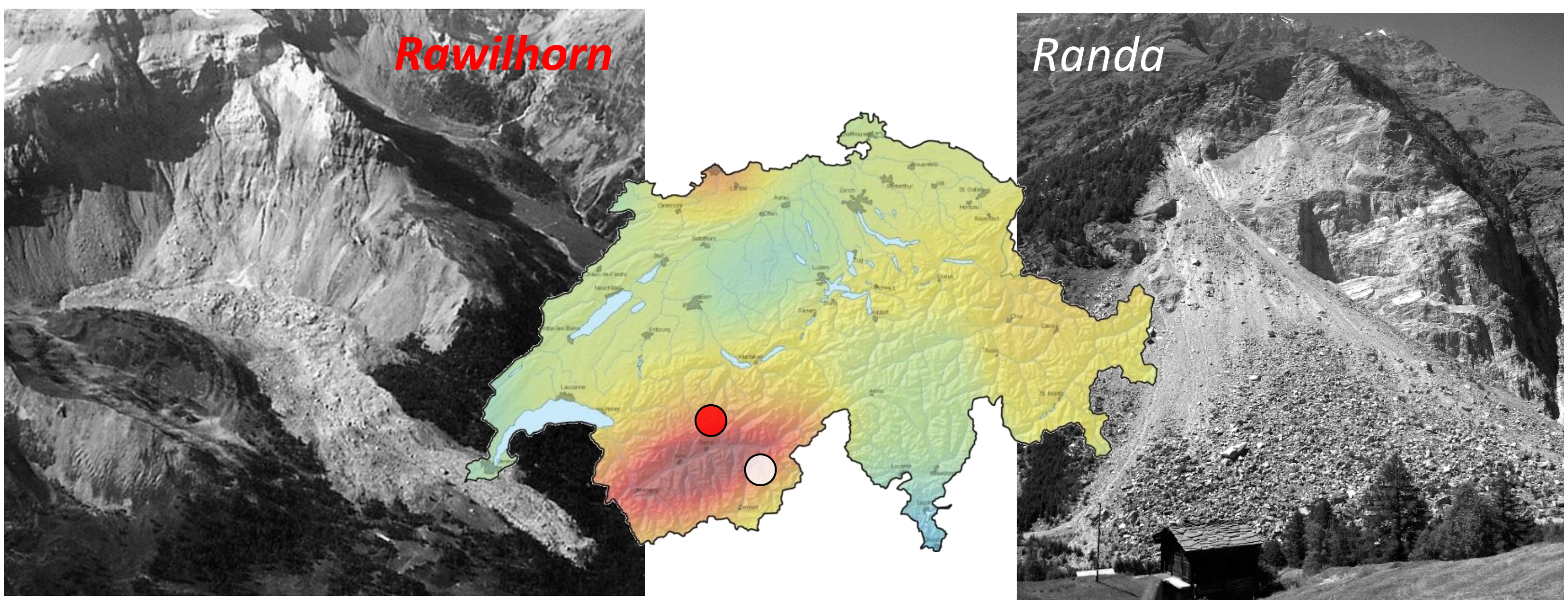
- Hypothesis: Fractures/Damage cause impedance contrasts in rock slopes and related spectral amplification

Shaking Intensity and transient changes

(1) Earthquake properties (magnitude, epicentral distance, focal depth)

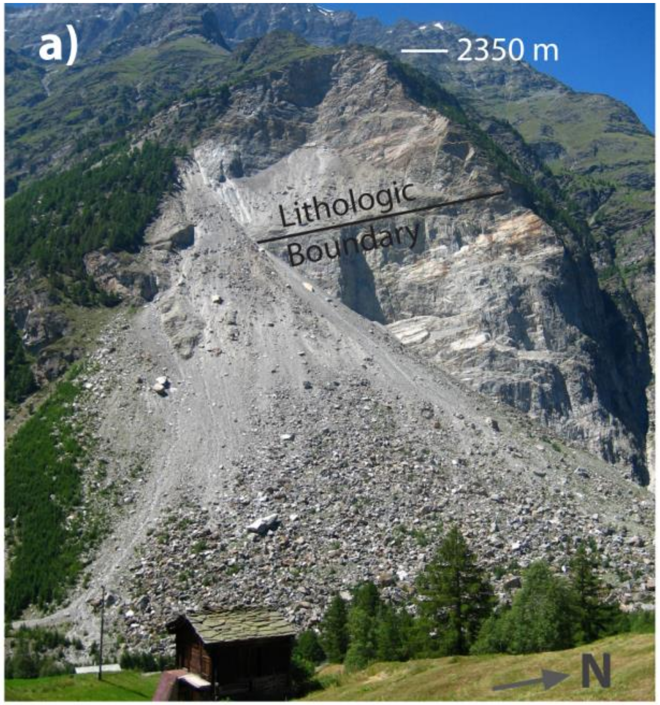
(2) Modifications of wavefield by site effects (change in frequency content) caused by compliant fractures stemming from ongoing rock slope deformations→ example Randa

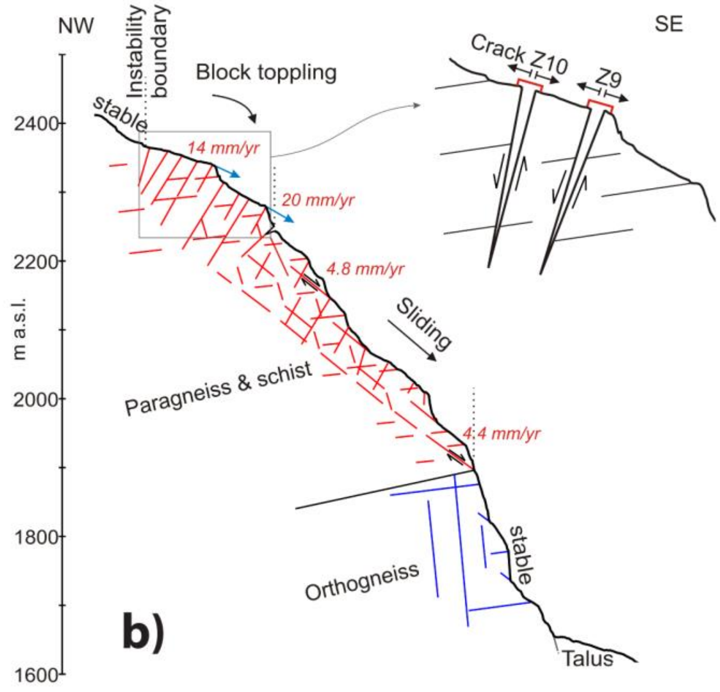
(3) Mechanistic link between earthquake induced fracturing and subsequent site effects → example Rawilhorn



The role of compliant fractures

(1) Two large events in April, May 1991
(2) 5 million m^3 remained unstable (Paragneiss)
(3) 10 years of scientific research



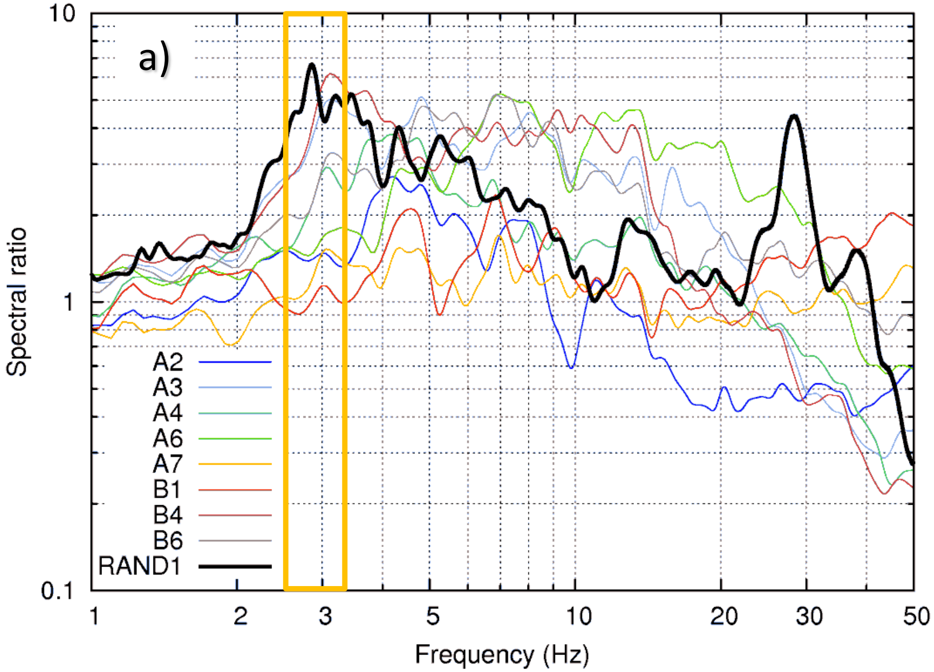


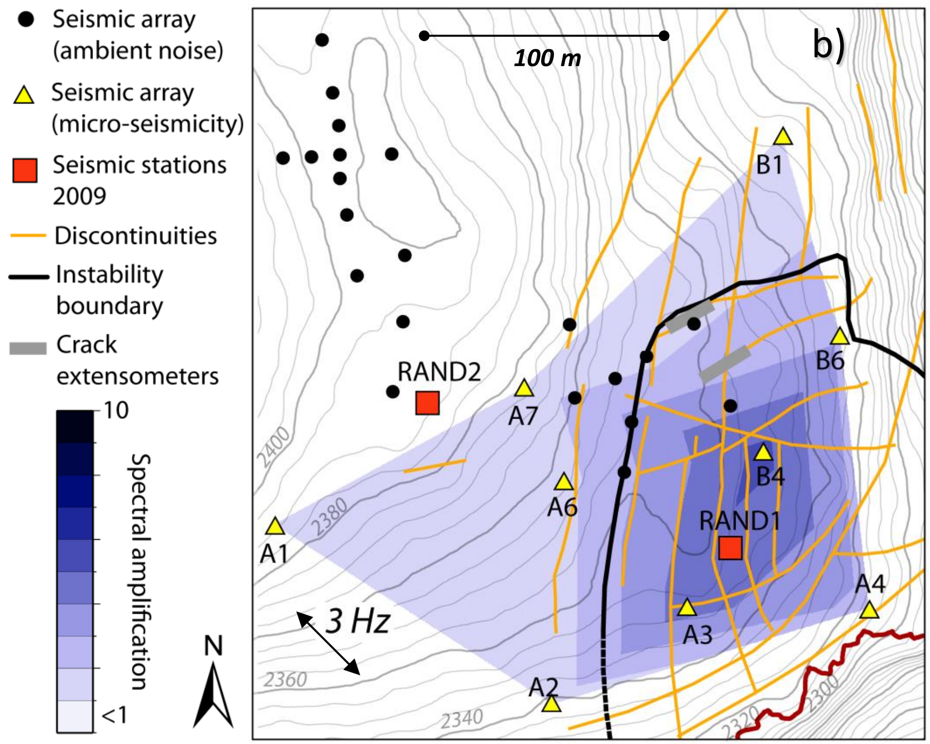
Moore et al. 2011

The role of compliant fractures

(a) Mean site-to-reference spectral ratios for all stations vs. frequency.

(b) Layout of measurements shown with key discontinuities and instability boundary. SRSR from earthquake recordings are shown at 3 Hz and azimuth of 135°.



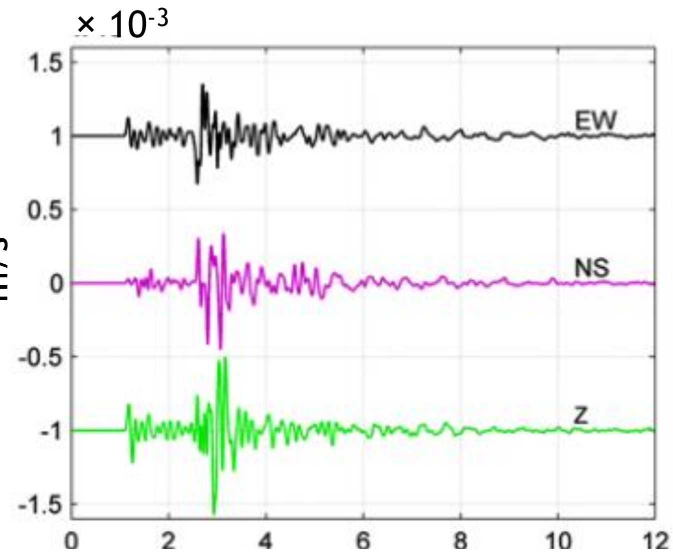


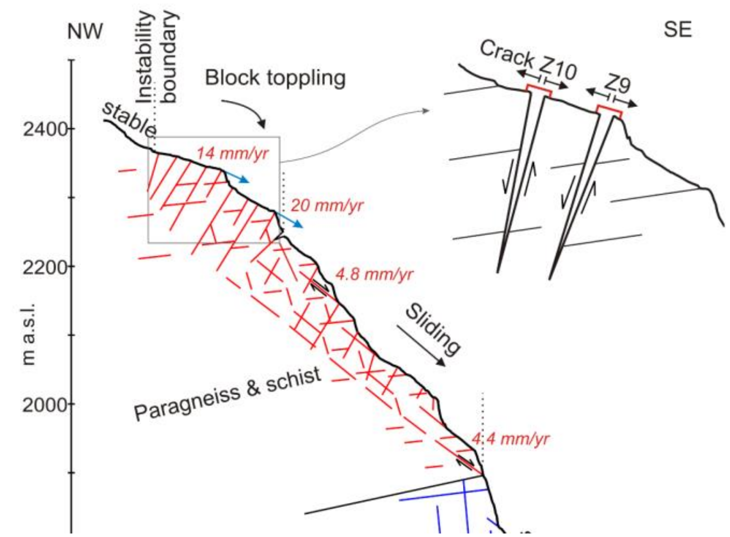
A1 & RAND2: reference station

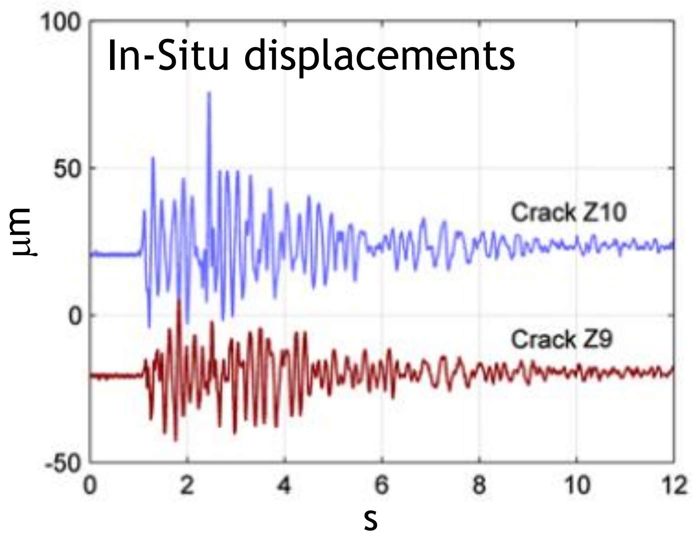
Ambient vibration measurements suggest a dominant spectral peak at 3 Hz and polarization direction of 135°

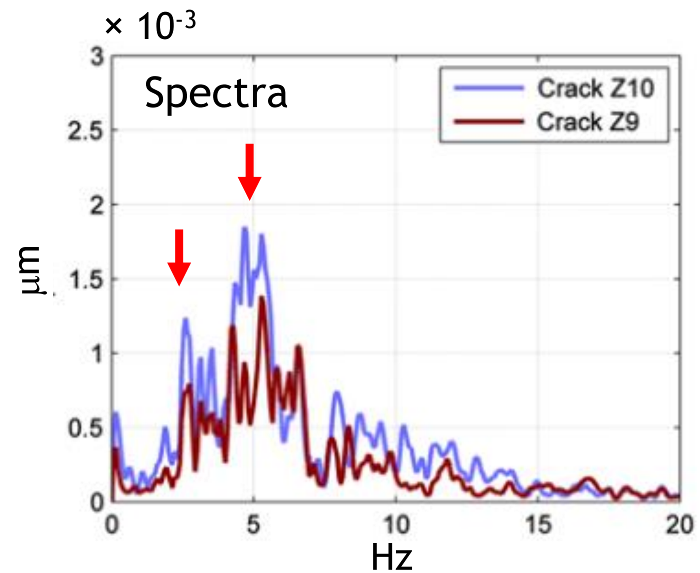
The role of compliant fractures

Earthquake May 2010; *Mw* 3.2









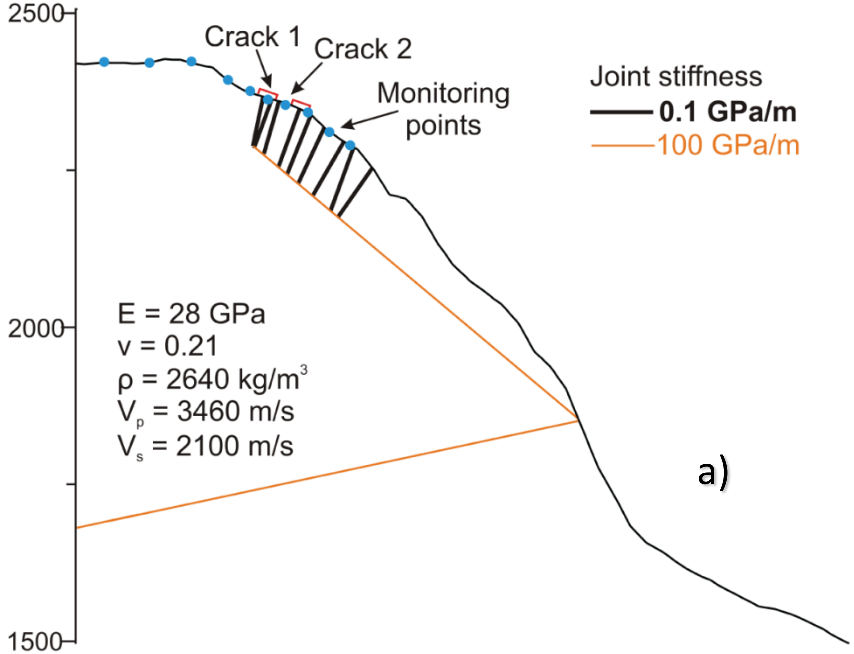
Moore et al. 2011

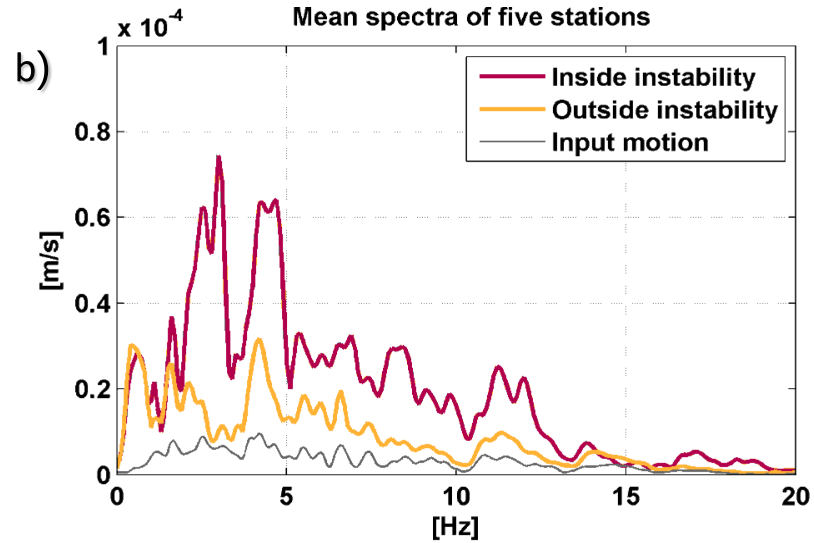
The role of compliant fractures

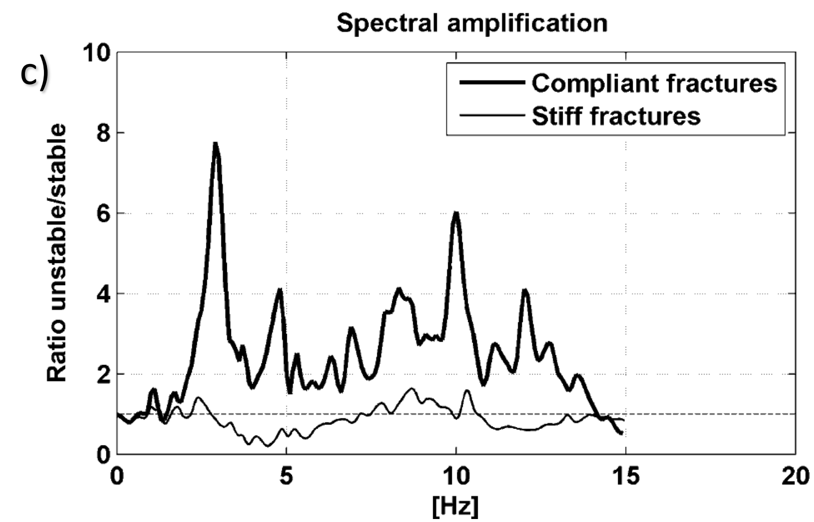
(a) Simplified model of the Randa instability implemented in UDEC (may 2010 earthquake)

(b) Mean spectra of monitoring points.

(c) Modeled spectral amplification comparing stations within and outside the instability and assuming compliant or stiff fractures.

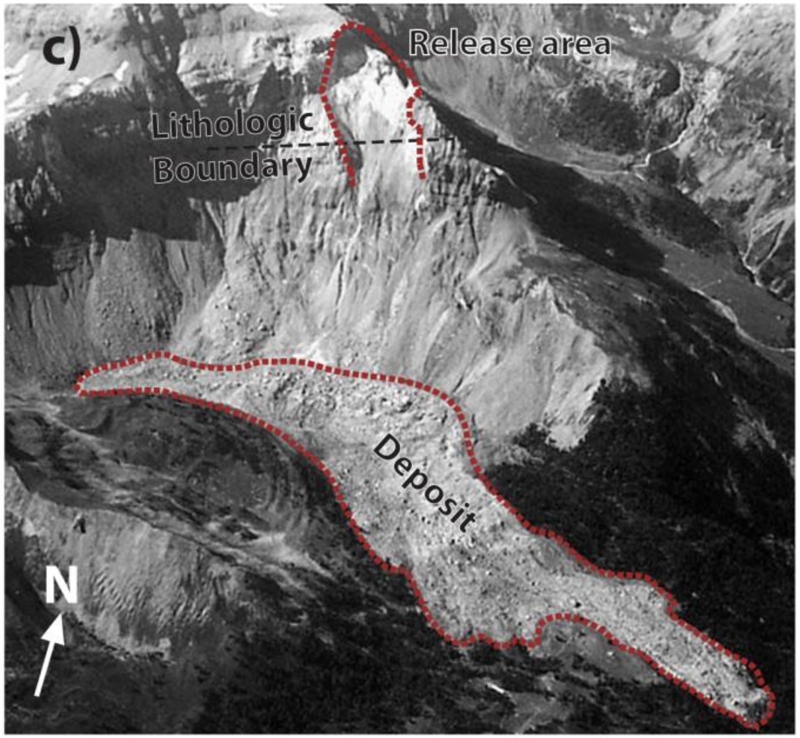






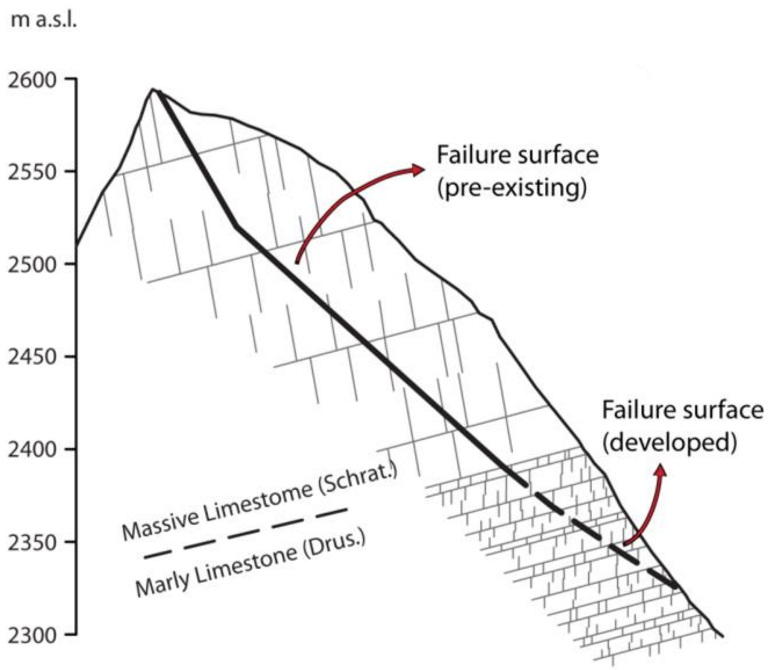
Earthquake induced fracturing and subsequent site effects

1) 1946 Sierre earthquake (M_w 6.1) triggered several catastrophic events.
2) Four month later a M_w 6.0 aftershock produced a large rock avalanche from the Rawilhorn.
3) In total 3 strong earthquakes (M_w > 5.0) during the month preceding failure
4) 5 million m^3 of sedimentary rock.
5) Run-out distance of 1.5 km downstream and 0.7 km upstream.



→ Repeat seismic loading plays a role in rock mass strength degradation

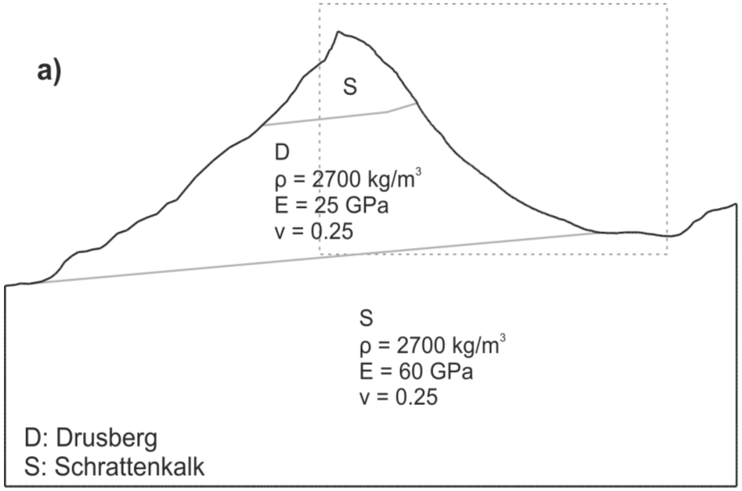
Earthquake induced fracturing and subsequent site effects

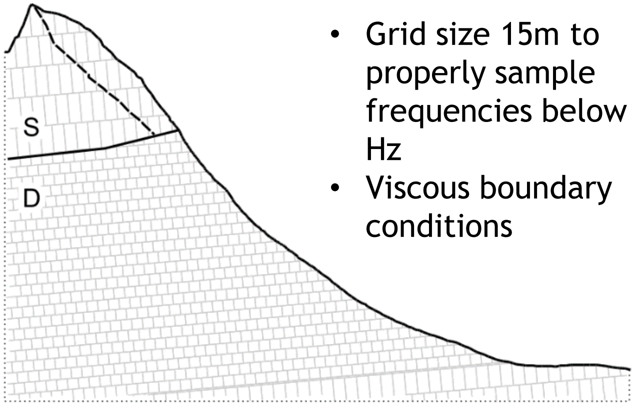


Earthquake induced fracturing and subsequent site effects

Procedure:

1. Evaluate the dynamic response of the rock slope when all joints are assigned uniformly stiff values.
2. Apply a realistic earthquake input motion and model the distribution
   of joints that open in tension.
3. Reduce the shear and normal stiffness of these new open joints and again evaluate the dynamic response of the rock slope.





- Grid size 15m to properly sample frequencies below 20 Hz
- Viscous boundary conditions

Earthquake induced fracturing and subsequent site effects

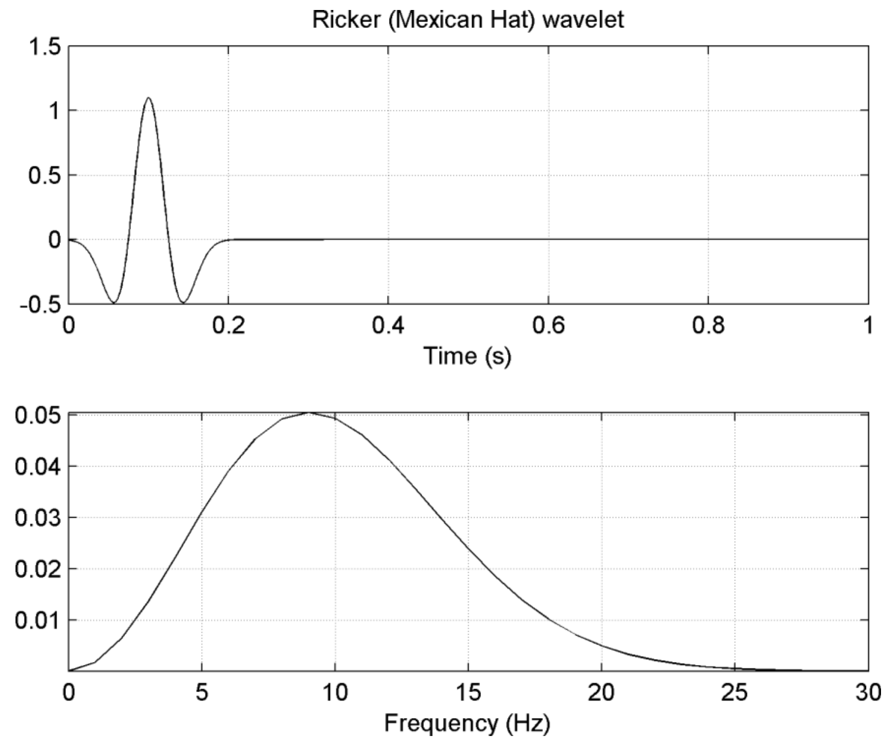
Evaluate the dynamic response of the rock slope:

Appropriate input motion that uniformly excites the ground over the target frequencies (1 to 20 Hz)

Real earthquake may contain sporadic spectral information

→ Ricker wavelet was used

→ Offers short time-series input and a smoothly varying spectral response



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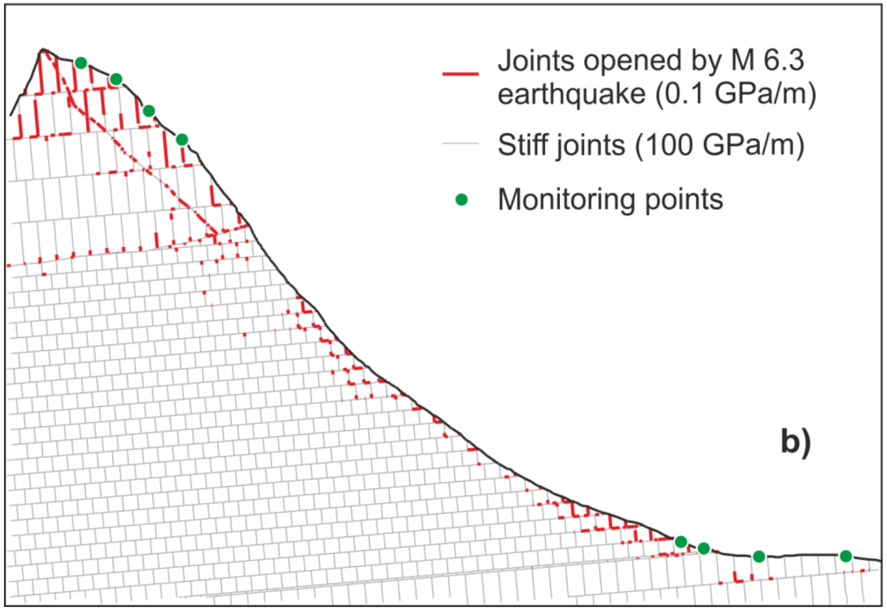

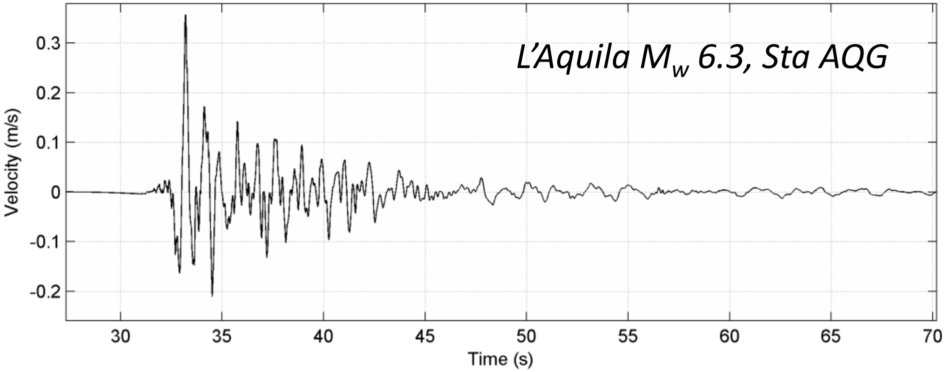

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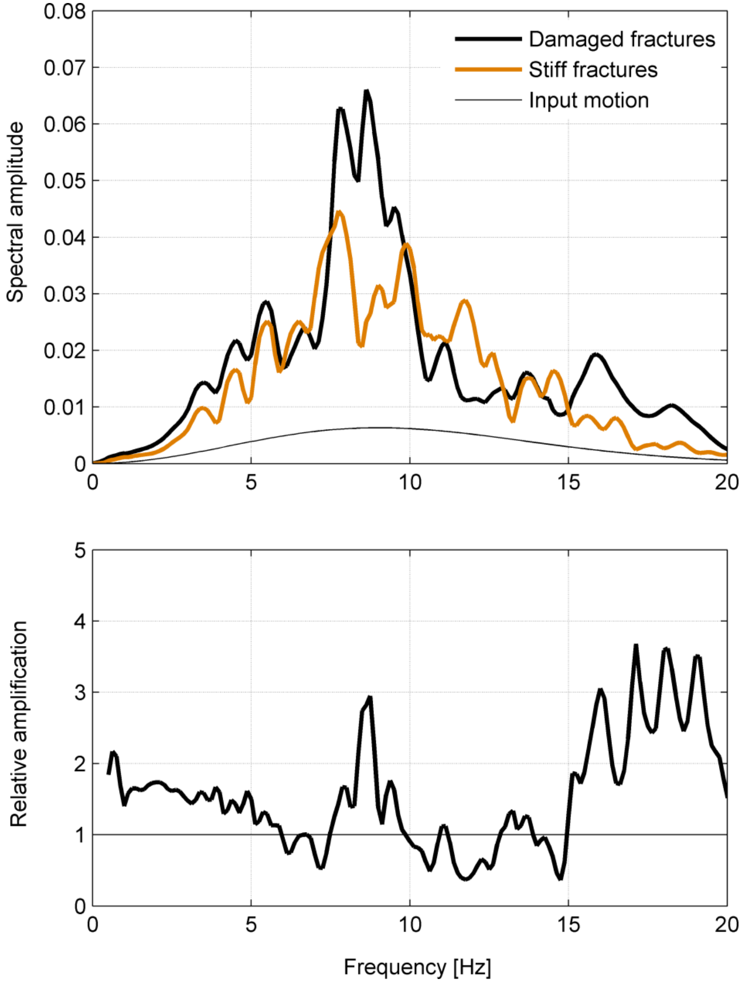

Summary

- Combined results demonstrate the important role of **compliant fractures** in hard- rock slopes in generating significant **site effects** (here spectral amplifications).
- These fractures can originate from **ongoing slope deformation**, as at Randa, or from damage caused by **previous earthquakes**, as at Rawilhorn.
- Open, compliant fractures create **anisotropy in bulk rock mass elastic properties**, and break the rock mass into blocks that vibrate at their resonant frequency.
- Ground motions can be **amplified by factors of nearly 10** at certain frequencies, meaning that seismic slope stability models ignoring this effect may significantly underestimate the potential for earthquake-triggered failure.

Thank you for your attention

Preonzo, Switzerland