Monitoring and characterizing natural or man-made nanoseismic (M_L < 0.0) sources for engineering purposes

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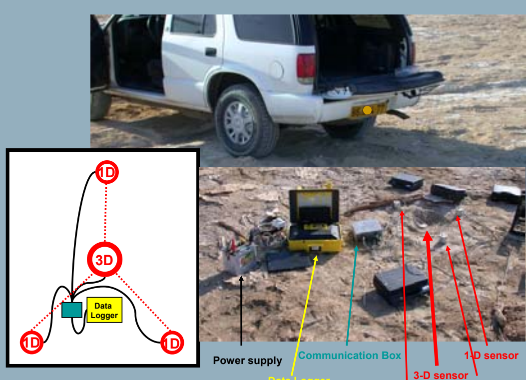
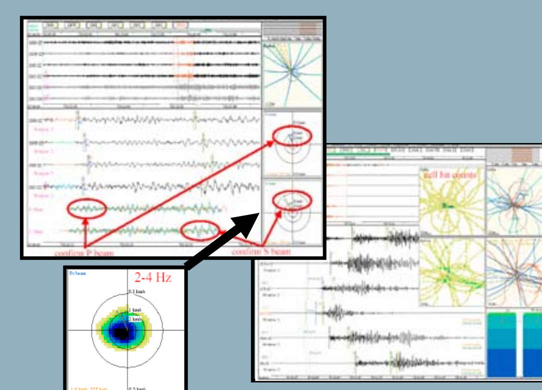
Data acquisition & processing



The concept of nanoseismic monitoring (Joswig, 2005) was developed to detect, characterize and locate sources of seismic energy generated at distances between 10 m and 10 km and with magnitudes down to ML -4.0 (Wust-Bloch and Joswig, 2006). It was designed with the idea that ultimate instrumental portability optimizes SNR conditions by minimizing source-to-sensor distance and allows immediate instrument deployment with minimal logistical constraints. Nanoseismic monitoring integrates data acquisition by SNS [Seismic Navigation Systems] (see left) and data analysis by SparseNet software (Joswig, 1999) (see right).



Data acquisition

SNS [Seismic Navigation System] consist of three single-component short-period seismometers (Lennartz Le-1D) arranged as tripartite array around one central three-component short-period sensor (Lennartz Le-3D). Data detected by this six-channel SNS is acquired by a 24 bit digitizer (*Orion-6* by Nanometrics, *M-24/6* by Lennartz). The array aperture varies as a function of the monitoring tasks, source remoteness and field constrains. For small scale monitoring applications in engineering seismology, an array aperture of 30 to 50 m is optimal.

Data processing

Nanoseismic monitoring is an application of passive seismic field investigations tuned to ultimate sensitivity. It integrates innovative approaches in signal processing (Joswig, 1996; 1999; 2000 & in review) whereby pattern recognition schemes and automated sonogram-based waveform analysis lowers the processing threshold to near 0 dB SNR. By displaying and updating simultaneously the data uncertainty of this over-determined system, *HypoLine* software allows the operator to slide through parameter space, observing in real-time the effect of each parameter change on the solution (Joswig, in review).

Applications of nanoseismic monitoring for engineering puropses

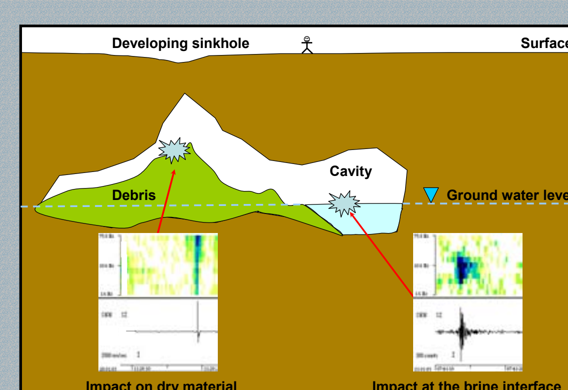
Sinkholes & cavitation

Sinkholes and cavitation activity monitoring

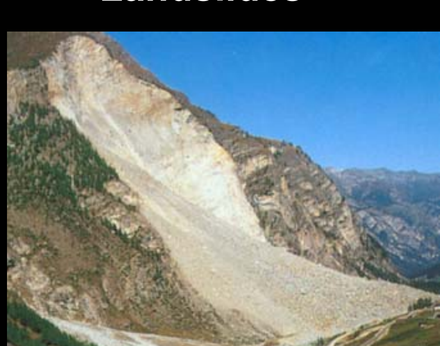
Nanoseismic monitoring techniques were applied to detect extremely low-energy signals (M_L > -4.0) generated by near-surface cavitation and sinkhole activity taking place in unconsolidated, layered media along the Dead Sea shores (Wust-Bloch and Joswig, 2006). Dozens of such events are recorded within a radius of 200 m per hour.
Following signal characterization, for which a series of source processes were simulated in the field under controlled conditions, the waveform analysis by sonograms recognizes two main groups of nanoseismic events:

- impacts on dry material
- impacts in liquid

In addition to their association with specific source processes, these events can be precisely located and their source energy quantified, using an extended M_L scale (Wust-Bloch and Joswig, 2006). It is now possible to monitor subsurface material failures before sinkhole collapse since the discrimination of impact signals on the basis of their frequency content is indicative of the maturity of the cavitation process.

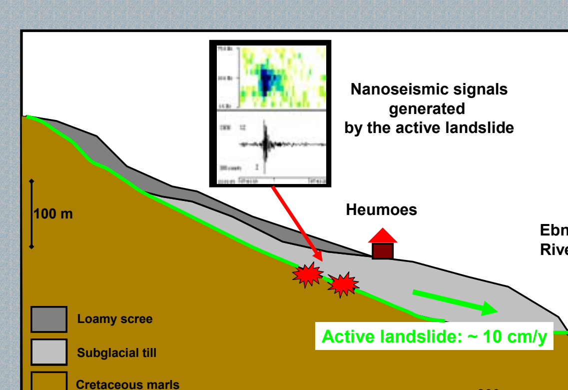


Landslides



Landslides and slope instabilities monitoring

Nanoseismic monitoring techniques were applied to monitor active landslides of different types and sizes in the Austrian alps. Very low-energy spiky signals (M_L > -3.0) were recorded at the surface of large rocky mountain slopes (see left) and of a sliding masses of unconsolidated glacial sediments. Two types of nanoseismic activity were detected.
In the case of large unstable rock masses failing in under-saturated conditions, nanoseismic events were recorded randomly in time at the low rate of a few events per day (Schmieder, 2006).
The Heumoes landslide (see right) consists of a mass of unconsolidated glacial and scree material which slides on marls, whose hydrological and geotechnical activity as been closely monitored (Lindenmaier et al, 2004). Nanoseismic activity recorded simultaneously by two SNS correlates well with rainfalls and piezometers readings (Walter, 2006). In fact, a very low back-ground nanoseismic activity, increases significantly, shortly after precipitations and remain at a high level for several days.
On all sites, event re-location by master event techniques corroborates with geological estimations of failure plane estimates or with boreholes data.



Cliff failure

Cliff failure monitoring

Nanoseismic monitoring techniques were applied to detect cliff failure along the Mediterranean coast (see left). Near the archeological site of Apollonia, a large section of the cliff failed and collapsed into the sea (see right). The remaining cliff displayed a 10 m high over-hanging section near the top of the cliff showing signs of activity: blocks impact on the beach and 5-10 cm wide tensile cracks are open at the surface near the cliff edge.
Ten days after the initial cliff failure, hundreds of spiky, high-frequency nanoseismic signals (-3.8 < M_L < -2.2) are detected per day.
Event locations were carried out by matching data sets recorded simultaneously by 3 SNS and using relocation by master-event techniques supported by precise velocity models. The 3-D geometric distribution of these events, together with comparative signal characterization and estimations of the source energy, suggest that the signals recorded are generated by brittle failure taking place along tensile cracks, within the top 20 m of the cliff.