GTI-Technical Note-4	Passive Seismic Monitoring for Mining Clients: Pit Wall and TSF monitoring, and SCAN

This Technical Note details the advantages of deploying passive seismic monitoring using geophones for critical monitoring applications in the mining industry. Slope stability of sensitive structures is often a primary concern, particularly with **open pit walls** and **tailings storage facilities (TSFs)** in mind. The majority of deployments to date have found a role in monitoring of TSFs, where IMS has played a pioneering role in developing and optimising the technology in this specific context[1,2]. The method has also been adapted for deployment in underground mines, where changing stress conditions are monitored with the **Stress Change through Ambient Noise (SCAN)** service. This document compares IMS's passive seismic capabilities against conventional monitoring technologies, highlighting its unique benefits.

Introduction to Passive Seismic Interferometry

Coda-Wave Interferometry (CWI) is a passive seismic geophysical technique that leverages the ambient noise, naturally occurring and anthropogenic seismic noise (e.g. ocean waves, wind, cultural activity) to monitor changes in the subsurface' wave propagation properties. Unlike active seismic methods that require controlled seismic sources, we passively "listen" to the Earth's continuous vibrations. By cross-correlating continuous signals recorded by an array of microseismic sensors, CWI can construct stable, repeatable seismic response functions between pairs of sensors that can be analyzed for slight changes and developing trends. In particular, phase changes in the late coda can be used to measure changes in seismic velocity. In slope stability monitoring this is interpreted as a proxy for material stiffness, whereas in underground mines where SCAN services are deployed, the changes in velocity are more often due to changes in stress conditions.

Advantages of CWI for Pit Wall Stability and TSF Monitoring

CWI offers several distinct advantages for monitoring sensitive structures:

- **Non-invasive and Non-destructive:** CWI is a passive method, requiring no active seismic sources (e.g., explosives, vibrators). This makes it ideal for environmentally sensitive areas, operational sites where disruptions are undesirable, and locations where access for active source deployment is challenging.
- **Continuous and Real-time Monitoring:** Once deployed, CWI systems can continuously acquire data, providing near real-time insights into subsurface changes. This continuous monitoring capability allows for early detection of instability or changes in material properties that could precede a larger failure, enhancing safety and enabling timely intervention.
- **Cost-Effective (Long-Term):** While initial sensor deployment may involve some cost, the long-term operational costs of CWI are low.
- **Depth sensitivity:** Although sensors are typical on surface, CWI is sensitive to changes at depths on the order of the seismic wavelengths detected in contrast to many techniques that are only sensitive to surface deformation.
- **Sensitivity to Material Property Changes:** Seismic velocity is directly influenced by the stiffness, density, and fluid content of the material. Changes in these properties, often indicative of increasing stress/loading, fracturing, or water saturation (e.g. due to rainfall infiltration in a landslide), can be detected by CWI before visible surface deformation occurs. This provides a crucial early warning capability.

---

[1] Ouellet, S.M., Dettmer, J., Olivier, G., DeWit, T. and Lato, M., 2022. Advanced monitoring of tailings dam performance using seismic noise and stress models. *Communications Earth & Environment*, *3*(1), p.301.

[2] Olivier, G., Brenguier, F., de Wit, T. and Lynch, R., 2017. Monitoring the stability of tailings dam walls with ambient seismic noise. *The Leading Edge*, *36*(4), pp.350a1-350a6.

Golden Taurus Ingeniería, S.L | Calle Tremp, 42B, 28040 Madrid

info@golden-taurus.com | www.golden-taurus.com

- **All-Weather and Day/Night Operation:** Unlike optical or radar-based methods, ANT is unaffected by weather conditions (rain, fog, snow) or lighting. This ensures continuous monitoring capability regardless of environmental factors, which is critical for consistent risk assessment.
- **Remote Deployment and Reduced Human Exposure:** Microseismic sensors can be deployed in hazardous or remote locations, minimizing the need for personnel to enter high-risk zones, such as active pit walls or unstable landslide areas.
- **Detection of Subsurface Flow Paths and Water Accumulation:** Changes in seismic velocity can indicate the presence and movement of water within the subsurface, which is a major contributing factor to many geotechnical failures. This allows for identification of potential seepage paths or zones of water accumulation that could lead to instability in TSFs or landslides.

Direct Comparison with Other Monitoring Technologies

The following offers a direct comparison of passive seismic interferometry (CWI, specifically) with other commonly used geotechnical monitoring technologies that are often deployed in conjunction with CWI and serve complimentary functions:

1. Ground-based Radar (GBR)

- **Advantages of GBR:** Provides high-precision, real-time surface displacement data, effective for monitoring active movement zones in open-pit mines and landslides. Unaffected by dust or light.
- **Limitations of GBR:**
  - **Surface-focused:** Primarily measures surface displacement, offering limited insight into subsurface processes.
  - **Line-of-sight dependency:** Requires a clear line of sight to the target, which can be challenging in complex terrain, with vegetation, or in areas with obstructed views.
  - **Atmospheric effects:** Can be affected by atmospheric conditions (e.g. humidity, temperature gradients) that introduce noise into measurements.
- **CWI Advantage:** Sensitive to volumetric material properties, detecting changes *within* the rock mass or soil column, not just on the surface, and is not limited by line-of-sight.

2. Robotic Total Stations / Prism Monitoring

- **Advantages:** High precision point measurements, relatively inexpensive for sparse networks, capable of automated, continuous monitoring.
- **Limitations:**
  - **Point-based:** Only provides displacement data at discrete prism locations, potentially missing deformation between points or deeper within the structure.
  - **Line-of-sight dependency:** Requires clear line of sight to prisms, susceptible to obstruction (vegetation, dust, equipment).
  - **Vulnerable to damage:** Prisms can be dislodged or damaged by ground movement, rockfall, or site activities.
  - **No subsurface information:** Provides no information about internal material changes or deeper deformation mechanisms.
- **CWI Advantage:** Offers continuous spatial coverage and depth sensitivity, providing a more complete view of stability compared to discrete point measurements.

3. LIDAR (Light Detection and Ranging)

- **Advantages:** Generates highly detailed 3D point clouds of the surface, excellent for topographic mapping, volume calculations, and detecting large-scale surface changes. Can be drone-mounted for rapid data acquisition over large areas.
- **Limitations:**
  - **Surface-focused:** Primarily captures surface geometry and changes, with limited insight to subsurface conditions.
  - **Weather and lighting dependency:** Affected by heavy rain, fog, and dust, and often requires good lighting conditions for optimal data quality.

    - **Data processing intensity:** Large datasets require significant processing power and expertise.
- **CWI Advantage:** Provides insights into subsurface changes and within an array of sensors changes can be localized, complementing LIDAR's surface-level information.

4. Satellite InSAR (Interferometric Synthetic Aperture Radar)

- **Advantages:** Covers very large areas, can detect subtle ground deformation (millimeter-level) over long periods, and can be used for remote and inaccessible areas. Historical data archives are often available.
- **Limitations:**
    - **Line-of-sight dependency:** Measures displacement along the satellite's line of sight, making it less sensitive to horizontal movements perpendicular to the satellite's path.
    - **Temporal resolution:** Data acquisition frequency is dictated by satellite revisit times (days to weeks), which may not be sufficient for rapidly developing instabilities.
    - **Atmospheric effects:** Prone to atmospheric distortion, requiring sophisticated processing to mitigate.
    - **Vegetation penetration:** Dense vegetation can significantly reduce data quality.
    - **Surface-focused:** Like GBR and LIDAR, it primarily monitors surface deformation and provides limited information on subsurface processes.
- **CWI Advantage:** Offers high temporal resolution and provides insights into subsurface changes, crucial for understanding the precursors to surface deformation.

5. Extensometers and Inclinometers

- **Advantages:** Provide direct, in-situ measurements of displacement or deformation at specific points or along a borehole. Extensometers measure axial deformation, while inclinometers measure lateral deformation with depth. Highly accurate for localized monitoring.
- **Limitations:**
    - **Point or line measurements:** Only provide data at the instrument's location, offering limited spatial coverage.
    - **Invasive installation:** Require boreholes, which can be costly, time-consuming, and potentially disturb the ground.
    - **Labor-intensive (manual):** Some types require manual readings, leading to less frequent data and increased personnel exposure.
    - **Limited predictive capability:** While they measure movement, they don't necessarily provide early warning of material property changes that precede movement.
- **CWI Advantage:** Offers a broader, non-invasive, and continuous spatial and volumetric view of subsurface stability, complementing the highly localized data from extensometers and inclinometers.

6. Photogrammetry and 3D Models

- **Advantages:** Creates detailed 3D models of the surface from overlapping photographs, useful for visual inspection, change detection, and volume calculations. Drone-based photogrammetry allows for safe and rapid data collection.
- **Limitations:**
    - **Surface-focused:** Primarily captures surface features and deformation, providing no direct subsurface information.
    - **Lighting and weather dependency:** Affected by poor lighting, shadows, and weather conditions (e.g. fog, rain).
    - **Vegetation occlusion:** Dense vegetation can obscure the ground surface, making accurate measurements difficult.
    - **Scale and accuracy:** Accuracy can vary depending on image resolution, camera calibration, and ground control points.
- **CWI Advantage:** Provides critical subsurface information on material changes and depth sensitivity, which photogrammetry cannot achieve.

Golden Taurus Ingeniería, S.L | Calle Tremp, 42B, 28040 Madrid
info@golden-taurus.com | www.golden-taurus.com

Advantages of deploying CWI for SCAN services in underground mines

The CWI method has also been adapted for underground mines. Here, far below the surface, changes in the rockmass are typically due to changing stress conditions created by active mining processes, with increased loading driving an i*ncrease in seismic velocities*. In contrast, de-stressing the environment is often accompanied by seismic activity and fracturing driving *decreases in the observed seismic velocities*. A critical advantage is that these methods do not rely on seismicity in order to enable measurement. Even in shallow, seismically inactive soft rock mining environments the method can be deployed and existing seismic monitoring systems can be used to deliver these services without interfering with the primary objective of seismic monitoring.

Conclusion

Passive Seismic Coda-Wave Interferometry (CWI) presents a powerful and increasingly viable technology for geotechnical monitoring. Its non-invasive, continuous, volumetric, and subsurface-sensitive capabilities offer significant advantages over traditional methods, particularly for early warning of stability issues in pit walls, landslides, and TSFs, and has also been adapted to monitor stress conditions in underground mines. While other technologies excel in specific aspects (e.g. surface deformation measurement, point-specific displacement), CWI provides a unique and complementary understanding of the subsurface, making it a valuable tool for comprehensive and proactive geotechnical risk management. Integrating CWI with other monitoring techniques can create a robust, multi-layered monitoring strategy that maximizes safety and operational efficiency in critical geotechnical environments.

Contact : info@golden-taurus.com