Generalities

In civil engineering works, the presence of subsurface anomalies (voids, karsts, breaks of tabularity…) can cause great hazards:
- Underestimating foundation dimensions leading to building collapse
- Sink holes, abandoned mines (…) leading to catastrophic buildings or roads collapse

In all situations, the presence of cavity represents a potential for a sink hole to collapse sooner or later, and it is necessary to detect the void for public safety during and after the engineering design work.

The detection and localization of these anomalies is now possible with a new and patented process applied on the surface wave (Rayleigh wave) properties measurements developed by Sismocean.

The surface waves are guided waves propagating at the surface ground over a thickness close to wavelength (λ). When a site consists of several layers with different characteristics, the wave is known as dispersive.

This means that the propagation velocity is dependent to the depth and as a consequence its frequency. The wavelengths have different penetration depths (low frequency: strong penetration, high frequency: small penetration). The SISMOCEAN new process uses the dispersive patterns of the surface wave to locate underground anomalies.

DCOS analysis

The DCOS method is based on a statistical analysis of the surface wave energy distribution and does not need any numerical model inversion (there is no hypothesis about the geology of the ground).

The ambient seismic (micro tremor), natural, or produced by the human activity (road, industries …) noise is used to detect the underground anomalies. Dedicated QC software is used to visualize the energy distribution (frequency versus phase velocity) of the surface waves contained in the micro tremor.

A streamer composed of 96 equally spaced geophones is deployed. The DCOS processing is applied to 24 or 48 receivers using a sliding window to extract each group of traces (panels).

The energy distribution is computed in both directions for each panel: direct (from #1 to #24) and reverse. The energy distribution is analysed by a statistical approach using half of the geophones from the extracted panel.

When there is no anomaly, the energy received by the two parts of the antenna is similar. On the contrary, the presence of an underground inhomogeneity will modify the energy distribution.

The windows’ length for the DCOS analysis is adapted depending to the penetration required:
- 24 channels for shallow penetration (up to 11-12 m),
- 48 channels for deep penetration (up to 23-24 m).

For one display composed of 96 receivers the trace extraction gives:
- 73 DCOS analyses using 24 channels,
- 49 DCOS analyses using 48 channels.

The distance between each DCOS analysis is the same as the space between receivers.
**Underground anomalies detection - DCOS**

**Key features**
- Detection and localization of several types of underground inhomogeneities: natural cavities, karsts artificial man-made cavities, under consolidated soils, break of the tabularity...
- Cavities might be dry, air filled, soft sediment filled or partially water filled.
- One DCOS analysis for each and every panel extraction.
- DCOS analysis isn't time consuming and is performed without any numerical model inversion (no hypothesis about the geology).
- The natural or anthropic seismic noise is used to perform the DCOS analysis. This process allows working in industrial environments.
- Noise generated by a car running along the streamer can also be used.

**Operation**

**Operations (clear space)**
Deployment of the equipment: 1h00 – 1h30 (first display), 30 min to 1h00 for the others.
Acquisition for one display: 10 – 30 min

**DCOS Analysis**
Processing 1 display # 3 h – 4h

<table>
<thead>
<tr>
<th>Penetration investigated</th>
<th># DCOS analysis</th>
<th>Analysis length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow</td>
<td>11-12 m</td>
<td>73</td>
</tr>
<tr>
<td>Deep</td>
<td>23-24 m</td>
<td>49</td>
</tr>
</tbody>
</table>

Distance between each DCOS analysis and space between each receiver are identical: **one analysis every 2 meters.**

**Equipments**

Land equipment
- Multi-channel streamer with 96 equally spaced geophones (2 m spacing), 190 m total length,
- Seismic source: seismic noise (micro tremor),
- Seismic recorder (4 Geometrics GEODES),
- On-line Quality-control Software,
- Laptop computer.

Analysis
DCOS Software processing running on PC workstation

**Applications**

Studies of construction sites:
- Site qualification for rough works,
- Karsts detection (air or water filled),
- Artificial cavities detection (old mining shafts, underground buildings, tunnels, buried tanks, drums, pipelines…),
- Local under-compressed sediment detection,
- Underground anomalies cartography.

Embankments study:
- Embankments evaluation,
- Anomalies localization (void, cavities, under consolidated areas …).

Linear works study:
- Evaluation of the roadways, railways, tracks and tunnels,
- Localization of voids to prevent soils subsidence.

**MASW and DCOS**

With the same data collected, a classical MASW interpretation analysis can be performed (see SismOcean’s land surface wave document).

The combination of both MASW and DCOS interpretations enables to refine some DCOS’s output: under consolidated areas, local variation of the geology.
DCOS Results Analysis

Shallow investigation: man-made cavities

The depth is expressed according to the surface wave wavelength (depth ≈ 1/2 wavelength).

Shallow and deep investigation: Geotechnical correlation

2D results at constant depth

DCOS analysis:
- is performed for every extracted panel (73 for shallow investigation, 49 for deep investigation),
- spacing is equal to the receiver spacing (1 analysis every 2 meters),
- isn’t time consuming and does not require numerical inversions.

DCOS analysis is well adapted for the detection and localization of any underground inhomogeneities such as: natural or man-made cavities, under-consolidated areas, local variation of the geology...

Running the DCOS analysis can be performed on any place with accessible clear surface.
In an industrial environment the method takes advantage using the ambient seismic noise (micro seismic) with an average maximum penetration about 20 m.

At this time, about 10 kilometres of studies were carried out using DCOS analysis (karst, urban site, 4 validation test sites known proposed and checked with success by French railways).