Large fractures mapping around tunnels by detailed 3D seismic imaging

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20 November 2015
ONKALO
In-situ Rock Characterization Facility

- Spent nuclear fuel repository at Olkiluoto, in Finland
- Research and demonstration programs are conducted during construction
- Primary Objective: Ensure that the bedrock is suitable for the final disposal
• The Äspö Hard Rock Laboratory (HRL), in Sweden is a ‘dress rehearsal’ for the construction of a final repository for spent nuclear fuel

• There is no spent nuclear fuel in the Äspö HRL
Focus on Long Fractures

Large fractures could experience secondary movements which could affect the mechanical integrity of the disposal canisters.

Large fractures need to be identified during construction of the deposition tunnels and the deposition holes.

FPI – Full Perimeter Intersection

Rejected positions

New positions
Objectives of the Seismic Investigations

- Detect seismically responsive deformation structures and large fractures before the excavation of deposition tunnels
- Test and improve existing seismic survey techniques
- Develop a methodology for characterising relevant rock features
- Identify needs for additional development
Long Fractures: are they visible?

Large fracture: two rough rock walls with similar physical properties lying against each other through a number of contact zones.

If ideally the walls copy each other’s shape so that they touch over a large area, the fracture will be seismically invisible, because of the continuity of physical properties across it.

If the same ideal walls are set even very slightly apart so that they do not touch at all, the fracture becomes an ideal reflector.

Very thin fractures can produce a seismic response even with wavelengths orders of magnitude larger than their apertures.
Large fractures mapping around tunnels by detailed 3D seismic imaging

3D image point (IP) migration

Horizontal plane migrated sections

- Cross-hole
- Single-hole

3D side-scan
Seismic measurements in ONKALO, 2013

Tunnel setup

The VIBSIST-200

Receivers plastered in holes (25 – 28cm deep)

The VIBSIST-20

MH-70

Detailed 3D seismic imaging

Tunnel setup
ONKALO, BFZ300

Brittle fault zone OL-BFZ300 was firstly discovered during the geological mapping in ONKALO.

The fault zone is composed of core zone (single fracture with hydrothermal quartz and sulphides) and intensely fractured influence zone.
Based on the 3D seismic surveys carried out in the demonstration area the BFZ300 was modelled to continue 60 m further from the northernmost pilot hole.

Also the southern extent of the zone was modelled based on several similarly oriented fractures that cut the tunnel perimeter in different tunnel sections.

Seismic surveys provide continuity information for fractures detected from tunnel walls and boreholes.
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Seismic reflection investigations in ONKALO, 2013

By using the 3-component geophones with source locations along tunnel walls, as well as, within horizontal boreholes in the rock it was possible to image geological seismic reflectors at many different orientations.

Receiver gather: Modeled times (black) and picked times (green) match well, as a measure of accurate tomographic reconstruction.
Seismic measurements in ÄSPÖ HRL, 2013

Tunnel setup

The VIBSIST-200

Receivers plastered in holes (25 – 28cm deep)

Receivers glued on wall
Synthetic seismogram from density and sonic velocity from borehole geophysics show an anomaly at the location of the FPI:s.

Tunnel radar show no clear reflector caused by the FPI:s.

In resistivity tomogram exists a low resistivity continuous anomaly with same trend as the FPI:s. Green dots are grounding points.
Seismic reflection investigations in ÄSPÖ HRL, 2014 – Data processing

• Lower seismic velocities may indicate increased porosity, increased occurrence of brittle fracturing, alteration, and higher water content.

• Increased velocities and density are associated to lithology variation, for example increase in iron content in mafic rock types.

P-wave velocity distribution derived by tomographic inversion

Velocity range is shown from 4900 (red) to 5900 m/s (blue)

Example of a fault cutting the receiver line in TASA tunnel
Seismic tomo. Low velocity anomalies with same trend as the FPI:s.
Seismic tomo.
Low velocity anomalies with same trend as the FPI:s. Trend coincides with the orientation of deformation zone DZ.1
Seismic reflection investigations in ÄSPÖ HRL, 2014 – Data interpretation
Seismic reflection investigations in ÄSPÖ HRL, 2014 – Data interpretation
Discussion

• Novel acquisition tools, measuring routines, processing techniques and interpretation approaches needed to be developed and put to test:
  – Highly accurate, time efficient and repeatable tunnel-wall and borehole seismic sources,
  – Very diverse frequency, multi-component receivers (10 Hz – 40000 Hz) and rock coupling methods,
  – Processing & Imaging techniques that work in a truly 3D environment, with target features displaying very diverse orientation and character
  – Interpretation tools able to verify and reciprocally validate results of various geoscientific disciplines.
The study was primarily meant to **Ensure that the bedrock is suitable for the final disposal.** The desired result has been a model of rock features characterized by orientation, size and extent.

Fractures producing large seismic responses can generally be associated with high hydraulic conductivity but do not necessarily have large transverse dimensions. Within this study, very small-scale features, even single fractures, could demonstrably be detected.

Brittle deformation zones and large fractures are generally heterogeneous in their detailed structure, making their characterization a challenging task. Bedrock characterizations comprised **geology, geophysics, hydrogeology** and **geochemistry**, in addition to seismics.
Thank you!

The work presented here is part of bedrock characterization for spent nuclear fuel disposal in Olkiluoto, Finland and Äspö HRL, Sweden. The authors wish to thank Posiva and SKB for the support during the surveys and permission granted to present this material.
The 3D Image Point (IP) transform retains reflection and/or diffraction patterns produced only by physically possible features on a user-defined velocity model. Migrated images can be computed directly from the transformed IP space.