High Resolution Seismic Profiling for Tunnel Engineering at Olkiluoto, Finland

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Summary

The ONKALO tunnel is the underground rock characterisation facility being built for rock characterisation for the final disposal of spent nuclear fuel at Olkiluoto, in Finland. The bedrock is studied, during the construction phase, by geology, geophysics, hydro-geology and geochemistry. The research is meant to help ensure the suitability of the bedrock for the final disposal. It also helps to identify the areas where the construction of the final disposal tunnels is the most cost-effective. A pilot test of high resolution seismic was done, consisting of reflection imaging ahead and aside of the tunnel and refraction imaging along the same line, 100m long, with sources stations spaced at 1m. Refraction imaging was done from two groups of 10 shots, recorded by the 100m long receiver array. Fractures were imaged several tens of meters away.

Introduction

Posiva investigates the bedrock on the final disposal site at Olkiluoto (Figure 1) and develops technical release barriers for the final disposal of spent fuel. The purpose of the R&D efforts is to ensure compliance with the requirements set forth for the long-term safety of final disposal. The excavation of the underground rock characterisation facility ONKALO is part of the site investigations carried out in Olkiluoto. These focus on the bedrock and groundwater conditions prevailing on the final disposal site and how construction work affects them.

Figure 1. Left: Location of the Olkiluoto site (red mark) in eastern Finland and Right: of the ONKALO site (marked with the green oval) at Olkiluoto.

Seismic reflection surveys performed along tunnels provide in-depth images of rock discontinuities in front and aside ongoing excavation works. The main objective of the surveys performed in the Onkalo tunnel at Olkiluoto was to image, by reflection seismics, mechanically weak and hydraulically conductive zones. Refraction velocity profiles were also produced along the tunnel wall. In situ determinations of P- and S- velocity distributions and associated ray paths were derived and dynamic values for compression and shear moduli were inferred.
Reflection and refraction seismic surveys along the ONKALO tunnel wall

The reflection imaging ahead and aside the tunnel was done, from a 100m long line of receivers, spaced at 1m intervals placed in short boreholes drilled in the tunnel wall. Seismic signals were produced by a hand-held VIBSIST-20 seismic source at, 100 source locations, also spaced at 1m intervals. For the refraction imaging, two groups of 10 shots were added at each side of the 100m long reflection line.

The Vibsist-20 is an electromechanical time-distributed, swept-impact source, which achieves relatively large energy levels in spite of its small size by summing several hundreds of impacts to form a record. Impact series of with duration of 15 seconds were used. The total energy of a record reached approximately 5000J, sufficient for reaching an investigation distance of several hundreds of meters. The recording was done on a DMT Summit II system.

Figure 2. Location of tunnel seismic test, along the ONKALO tunnel wall, at chainage 1720 - 1820 m (vertical depth 170 – 180 m)

Figure 3. a) Summit II Plus acquisition system in the Onkalo tunnel, b) 2-component receiver units were installed in the wall, c) the Vibsist-20 seismic source and d) a Tamrock boomer used as seismic source.
In order to provide a truly 3D imaging coverage, the linear geometry of the tunnel setup should be expanded by sources and receivers placed outside the receiver line. Signals were therefore also recorded from the boomer used to drill the excavation blasting holes. This proved to be a viable seismic source with a penetration and signal quality and characteristics comparable with the VIBSIST-20. Drilling blasting holes can be used as a handy alternative for routine seismic investigations during tunneling production.

**Results**

Refraction velocity tomograms were reconstructed from the P- and S-wave first arrivals (Figure 4). Velocity values of 5400 m/s to 6200 m/s for P-waves and 3000 m/s to 3500 m/s for S-waves (blue color areas in Figure 4) are identical with values determined in laboratory on samples from pilot drill holes near the tunnel seismic test (closer than 300m along tunnel or 30m vertically). The red areas in Figure 4 depict low velocity zones (less then 4500 m/s for P-waves and less then 2900 m/s for S-waves) bordering the tunnel. The thickness of this zone is approximately 1m. Due to the confinement of the low velocities to the immediate vicinity of the tunnel, the maximum depth reached by refraction tomography is of the order of 10m.

![P-wave tomographic section](image1)

![S-wave tomographic section](image2)

**Figure 4. P & S wave refraction tomograms derived from the seismic data.**

Tomograms of Young’s modulus and Shear Modulus were also computed, using a local density model derived from geological data (Figure 5). The values obtained for the dynamic parameters are well within the typical range known for the Olkiluoto bedrock and display the same low velocity zone in the vicinity of the tunnel as the velocity tomograms.

![Shear modulus section](image3)

![Young modulus section](image4)

**Figure 5. Shear & Young modulus tomograms derived from the seismic data.**

The seismic reflection data were processed as migrated reflection profiles, with an imaging range of approximately 100m from the tunnel (Figure 6).

Migrated Images are 2D representations, bound to cylindrical symmetry. Therefore, the actual location of the reflecting events identifiable in these sections cannot be obtained without external information.
Expert interpretation and correlation with the site model derived independently from geophysical investigations over the past decade [Posiva, 2003] shown good matches of current identified features with previous 3D VSP survey results [Enescu, 2007].

Figure 6. Left: Horizontal component migrated profile with P-wave tomographic section and Right: vertical component migrated profile with S-wave tomographic section.

Most of the known brittle fracture zones, lithological contacts, hydraulically conductive zones, electrically conductive zones (according to mise-à-la-masse surveys) and long fractures were confirmed by seismics (Figure 7). However, not all features displayed by seismics could be identified with known structures.

Figure 7. Left: Seismic results vs. known features above and below the tunnel. View to NW and Right: Seismic results vs. known features to the north of the tunnel. View from above.

Conclusions

As a conclusion of the pilot test, seismic surveys along the tunnel were deemed as technically and economically sound means for rock mass characterization.

The use of exploration and production drilling as reliable and low-cost seismic sources opens the way to the use of seismics on a routine basis with tunneling works. High quality results can be obtained tunnel conditions during production.

The good results of this first test lead to the performance of a larger and more complex survey during the summer of 2009. The ultimate goal is to integrate several investigation methods, including in the future passive and active seismic imaging. Integrating the repeatability achievable with active sources with the wide spatial distribution of microseismic events could form a truly widely covered and well constrained image of the rockmass deformations throughout the volume of interest.
References


