Scientific Objectives

The development of high resolution 3D seismic imaging techniques for the structural exploration around tunnels and boreholes is the main objective of the research activities at the GFZ-Underground-Seismic Lab. Different imaging techniques like 3-component Kirchhoff-Migration or Fresnel-Volume-Migration are tested and modified with respect to their capability to resolve small scale structures within the gneiss block. The galleries also act as potential seismic reflectors for the seismic imaging. The major challenge of seismic imaging in the underground is the spatial ambiguity of the recorded wave field due to limited aperture of seismic source and receiver survey geometry. New imaging techniques are developed to improve the spatial resolution of structural objects. Therefore the measured polarization direction of the three-component data is used to determine points of refection and to restrict the migration operator to the region that physically contributes to a reflection event (Fresnel Volume limit). Thus migration artifacts and crosstalk effects from converted waves can be reduced compared with standard migration schemes. The application of a phased array sources for directional enhancement of seismic wave energy allows a further restriction of the migration operator and therefore leads to a further improvement of resolution. To exploit the full potential of phased array sources for imaging it is important to study the process of wave generation and wave propagation in space. The configuration of receivers at the GFZ-Underground-Seismic Lab offers the possibility to study the radiation pattern of seismic waves around boreholes in the near and far field area. Recently, experiments to quantify the spectral energy of P- and S-waves have been carried out.

Since 2009 a further focus of investigation are tomographic inversion techniques. Experiments to analyze the application of full waveform inversion methods have been done. The task is to detect and to locate changes in rock conditions while drill and construction works within the GFZ-Underground-Seismic Lab have been undertaken. An alternative approach to identify changes in rock condition is the application of coda wave interferometry. Meanwhile several thousands of measurements with permanently fixed magnetostrictive actors have been carried to transmit seismic waves through the gneiss block. Seismic chirp and sweep signals in the frequency range from 300 Hz to 3000 Hz have been applied.

Technical Developments

The GFZ-Underground-Seismic Lab was established in 2008 but continuous measurements have been undertaken since 1998. In the first years high resolution surface seismic sources and different seismic receivers for the application in underground constructions works have been tested. The sources were in-house developed pneumatically driven impact hammers and magnetostrictive vibrators. The signals of these surface sources have been compared with small charges of explosives fired in boreholes. Different geophones, piezoelectric and optical receivers have been compared with respect to their signal amplitude, signal phase characteristics and signal to noise ratio. The objective of other experiments was to study the influence of near surface conditions, different glues for geophone rock anchors as well as mechanically coupling techniques on the signal quality at the galleries surface and in boreholes. A removable mechanical coupling system for 3-component receivers in boreholes was developed and successfully tested at the GFZ-Underground-Seismic Lab. To gain sufficient high data resolution for the following experiments on seismic tomographic and imaging techniques geophone rock anchor were mounted along all galleries. Major progress during the development of the control technique for magnetostrictive actuators has allowed the simultaneous steering of signal amplitudes and phases of multiple vibrators. Based on this technique a prototype of phased array borehole source has been developed and tested in two horizontal boreholes in the GFZ-Underground-Seismic Lab. The measurement results demonstrate the possibility of focusing seismic wave energy in the desired directions. These measurements are to be continued in a new 70 m vertical borehole.