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Automated Full Waveform Detection and Location Algorithm of Acoustic Emissions from Hydraulic Fracturing Experiment

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Abstract

A near field network with 11 acoustic emission (AE) sensors was installed for the in situ underground experiment (Nova project 54-14-1) that took place 410 m below surface in the Äspö Hard Rock Laboratory, Sweden. The acquisition system for the piezo-electrical sensors has been improved to record signals with 1 MHz sampling rate, to detect signals produced by weaker sources and enhance the microseismic catalogue. The acquisition system was capable to operate in trigger and continuous mode. The basic idea of the experiment was to compare hydraulic fracturing growth and induced seismicity under controlled conditions for different loading scenarios as conventional versus progressive, and pulse-like water injections. In this work, we consider continuous recordings and apply recently developed automated full waveform detection and location algorithms which are based on the stacking of characteristic functions calculated from squared amplitudes. Waveform stacking and coherence techniques are adapted to detect and locate AE signals for massive datasets with extremely high sampling. We significantly increase the detection rate in comparison to trigger mode routines. Most detection concentrated during the fluid injection occurred around the fracking stages. Frequency-magnitude distribution characteristics are investigated using a relative magnitude scale estimated from the amplitude recorded at AE sensors. We demonstrate that the stacking of characteristic functions yields to a significant improvement of the detection and location also in presence of noisy records, supporting the adoption of similar techniques for other induced and natural seismic activity monitoring systems.

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Keywords: Hydraulic fracturing, induced seismicity, acoustic emission, full waveform detection, detection performance

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1. Introduction

An in situ hydraulic fracturing experiment was performed at Äspö Hard Rock Laboratory (Sweden) aiming at optimizing geothermal heat exchange in crystalline rock mass [1]. A near field network with 11 acoustic emission (AE) sensors was installed 410 m below surface to map the seismic response of hydraulic fractures for different fluid injection scenarios (Figure 1). The location of the experimental tunnel TASN is seen from which four long boreholes were drilled sub-parallel to orientation of minimum horizontal compressive stress. The middle borehole (Figure 1, blue line) serves as hydraulic testing borehole and was drilled to a total length of 28.40 meter, down dipping -4°. The rest of monitoring boreholes were drilled with inclination upwards to allow water outflow from AE sensor chains. This geometry in the predetermined stress state allows propagating hydraulic fractures perpendicular to the hydraulic testing borehole, in the direction of maximum horizontal compressive stress, and in a direction towards the monitoring boreholes.

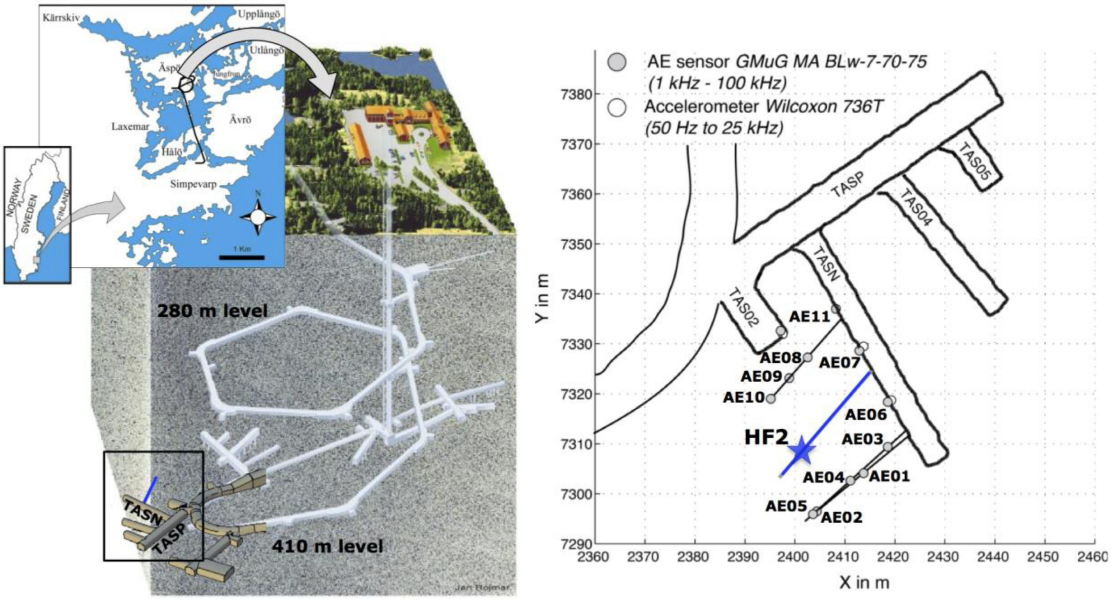

Fig. 1. Test site for hydraulic fracturing in an experimental tunnel of Äspö Hard Rock Laboratory, Sweden (left). [elaborated after http://www.skb.se/upload/publications/pdf/Aspo_Laboratory.pdf]. Sensors are employed in the near-field (right): a blue line indicates the hydraulic testing borehole, the blue star identifies the fluid injection segment corresponding to the HF2 experiment.

The basic idea of the experiment was to compare hydraulic fracturing growth and induced seismicity under controlled conditions in a horizontal borehole 30 meter long for continuous fluid injection versus progressive fluid injection, and dynamic pulse hydraulic fracturing [1]. The in-situ AE monitoring network consists of eleven AE sensors (GMuG MA BLw-7-70-75) and four accelerometers (Wilcoxon 736T). AE sensors employed are uniaxial side-view sensors for borehole installation, developed by GMuG for sensitive recording in the frequency range 1 kHz to 100 kHz and capable to monitor fractures from centimeter to meter scale. Sampling rates were extended to 1 MHz and all sensors are installed inside boreholes. Eight AE sensors are installed in long monitoring boreholes, surrounding the fracturing borehole. The remaining sensors are installed in short boreholes near the tunnel roof. Data was recorded using the measuring system GMuG AE-System that is suitable both for continuous recording of data and recording in trigger mode. In this work, we present the results obtained during the conventional, continuous water-injection experiment HF2 (Hydraulic Fracture 2) in Ävrö granodiorite, and discuss the detection performance using a recently developed automated full waveform detection algorithm.