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Tasks, Requirements and Design as well as First Results of a Local Seismic and Vibration Impact Monitoring System for a Geothermal Power Plant in the Inhabited Area of Poing, Germany

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ABSTRACT

Ever since the incidents of the failed geothermal wells in Stauffen/Germany 2007 and, in some cases, accompanying seismic events around geothermal plants, German authorities are on the alert. Especially in southern Germany, geothermal plants have a legal obligation to include the erection and operation of a seismic monitoring system in their operational plan. This seismic and vibration monitoring system has to fulfil at least two tasks:

- Monitoring of occurring seismic events (occurrence, strength, location, etc.)

- Measuring of vibration impact on local residents and buildings (according to DIN Norm 4150 part 3)

One part of this obligation is the more or less permanent transmission of data from local seismic monitoring systems to the local (Bavarian) earthquake services. That way the authorities have always the same database of the local monitoring system in addition to information from the regional earthquake monitoring system.

Following these regulations a seismic monitoring system was erected and is being operated by K-UTEC AG Salt Technologies in the area of Poing near Munich in Germany. The first sensor was installed in the middle of December 2016. Already a week later a noticeable seismic event with a Magnitude ML=1.8 was recorded. The location of the seismic event could be estimated with only one installed seismic monitoring station using a geologic model and a particle motion analysis of the seismic body waves to obtain the angle of incidence. Compared to the results of the Bavarian earthquake services and the run-time analysis using the Bavarian regional seismic monitoring stations, the one-station localization capacity is quite good, i.e. a 500 m horizontal difference between the local and regional systems.

The vibration impact on the local vibration monitoring station in about 300 m horizontal distance was less than 0,8 mm/s, which is far below the threshold of the DIN Norm 4150 part 3 (threshold: 5 mm/s).

Near the end of May 2017, a second seismic monitoring station was added to the local seismic monitoring system of the geothermal plant Poing. With these two stations installed it was possible to localize a seismic event in September 2017 with a local Magnitude of ML=2.1. In this case the particle motion was used as well to get the information of the angle of incidence for the seismic body waves. The horizontal distance of the localization difference between the Bavarian seismic monitoring system and the K-UTEC AG system was less than 300 m.

For this seismic event the vibration impact on the local vibration monitoring station at about 200 m horizontal distance was less than 2 mm/s, which is also far below the threshold of the DIN Norm 4150 part 3 (5 mm/s). In this case 15 persons had reported the authorities that they felt the seismic event.

In December 2017 the seismic monitoring network was supplemented with two additional permanent seismic monitoring stations and one mobile seismic monitoring station. The mobile station is used to measure the vibration impact in different buildings in the towns and villages around. Since September 2017 no other seismic event occurred in the local area of Poing.

This work showcases the possibility and reliability of one- and two-station localization systems for seismic events by using state-of-the-art data analysis tools making it possible to detect and localize even small micro-seismic events using a small scale seismic monitoring system setup.

1. INTRODUCTION

In the geothermal project Poing, GPP, the plants of the geothermal cycle have been in operation since the beginning of 2011. At the site of operation, the production well produces thermal water from a depth of around 2,500 to 2,800 m; the final depth of the well is around 3,000 m. The thermal water is pumped to the central heating plant. Here, the thermal water is fed to a heat exchanger to harvest heat and conducted to the reinjection well by means of a pipeline and then reinjected into the same aquifer at a distance of approx. 1,740 m from the production well (direct connection line at Top Malm) almost without pressure. The production rate is continuously and automatically adapted to the heat demand of the district heating supply; max. up to 100 l/s; min. approx. 55 l/s.

Seismic monitoring is required by Bavarian water law for geothermal plants. According to requirements, the measuring station had to be installed in vicinity of the reinjection well. The location of the reinjection well, Poing TH1, is surrounded by intensively used agricultural land. On two sides there are paved roads with limited use, i.e. clearance for agricultural traffic only.

The seismic measuring stations have to comply with requirements of the German DIN standards e.g. DIN 4150, Part 3 and the rules of mining law at a deep well site as well as the "Recommendations for monitoring induced seismicity - Position paper of the FKPE"[i].

The following minimum requirements have to be met:

- 3-component seismometer
- At least 4.5 Hz; up to 80 Hz (corner) frequency
- Gain factor: min. 100 V/m/s
- Calibrated according to DIN 45669, with certificate / test report
- Sampling rate: min. 100 Hz (200 - 500 Hz desired)
- Clock, synchronized, preferably via GPS signal
- A/D converter min. 16 bit
- Data transmission: SEED, SEEDLink

The DIN compliant measurement station Poing TH1 went online in December 2016. In May, October and November of 2017 three additional DIN 4150 Part 3 compliant measuring stations were commissioned and installed. A mobile measuring station has been in use since the end of 2017.

2. TECHNOLOGY AND LOCAL SEISMIC SYSTEM

The seismic monitoring system Poing consists of four stationary and one mobile data logger (scheme Figure 1). The data loggers are 24bit data loggers (KutecGeoLog), which are sending their data via 4G mobile data network to a central server.

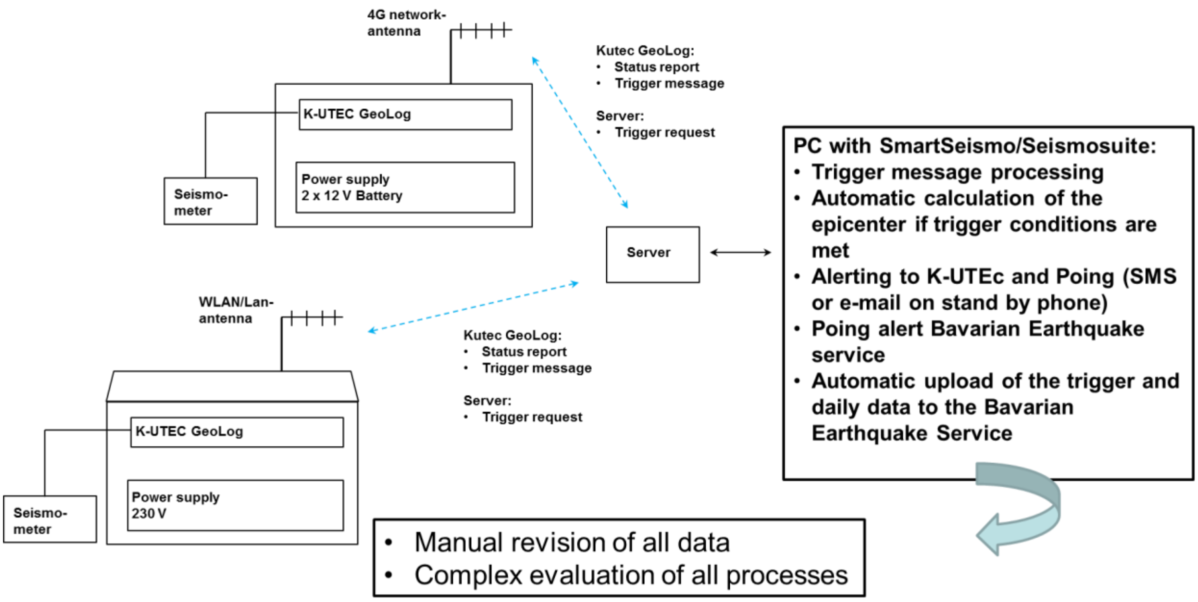

Figure 1: Scheme of the reporting order of the seismic monitoring system Poing

Figure 1 shows how in principle the reporting sequence of the seismic monitoring system is designed. Various power supply and data transmission options can be used.

The sensors were placed in a small shaft and decoupled from the surface to minimize seismic noise. Noise sources can be:

- Road traffic
- Compressors / Industrial plants / Pumps
- Electromagnetic interferences (cathode protection, transformers, etc.)
- Settlements
- Weather (wind, thunderstorms, etc.)

Figure 2: Seismometer bunker

Figure 3: Exemplary seismic station in Poing.

The seismic network surounds the sensible area of the geothermal plant. The stations are also used to monitor and evaluate the impact of seismic events on the inhabited area.

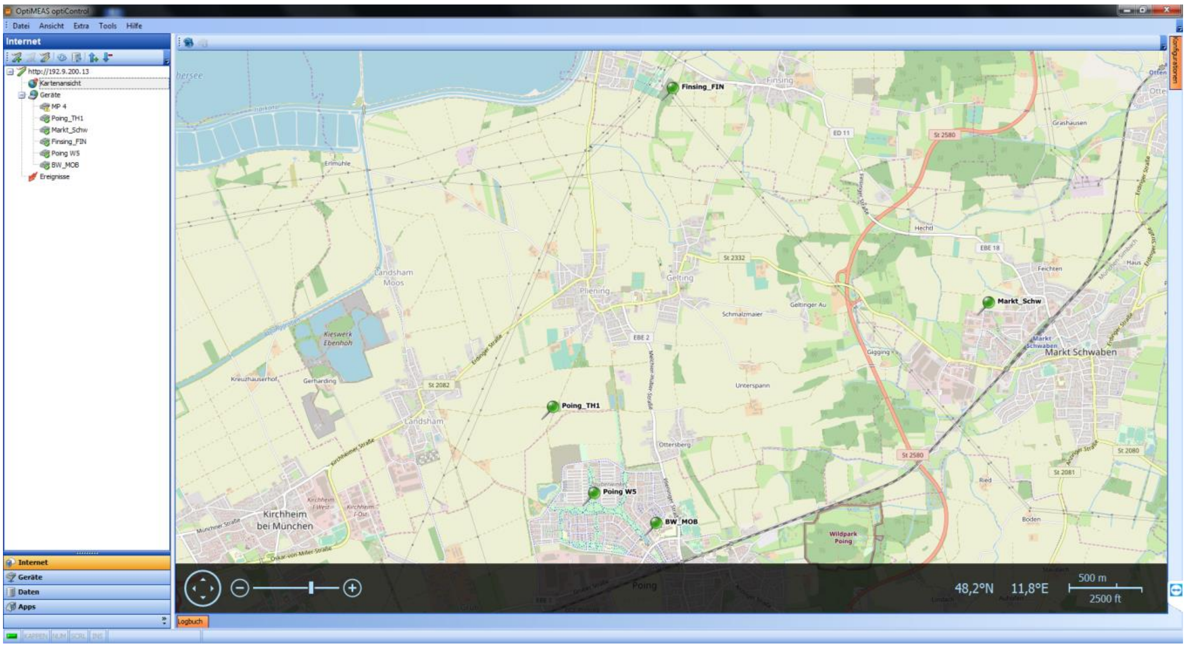

Figure 4: Position and status of the seismic monitoring stations.

3. SOFTWARE

The Software for the data acquisition and data evaluation was developed by K-UTEC AG [ii] over the last years. The Software comprises the following packages:

- optiControl
- optiCloud Server
- SmartSeismo
- SeismoSuite

The data logger firmware is parameterized with the optiControl package, see Figure 5.

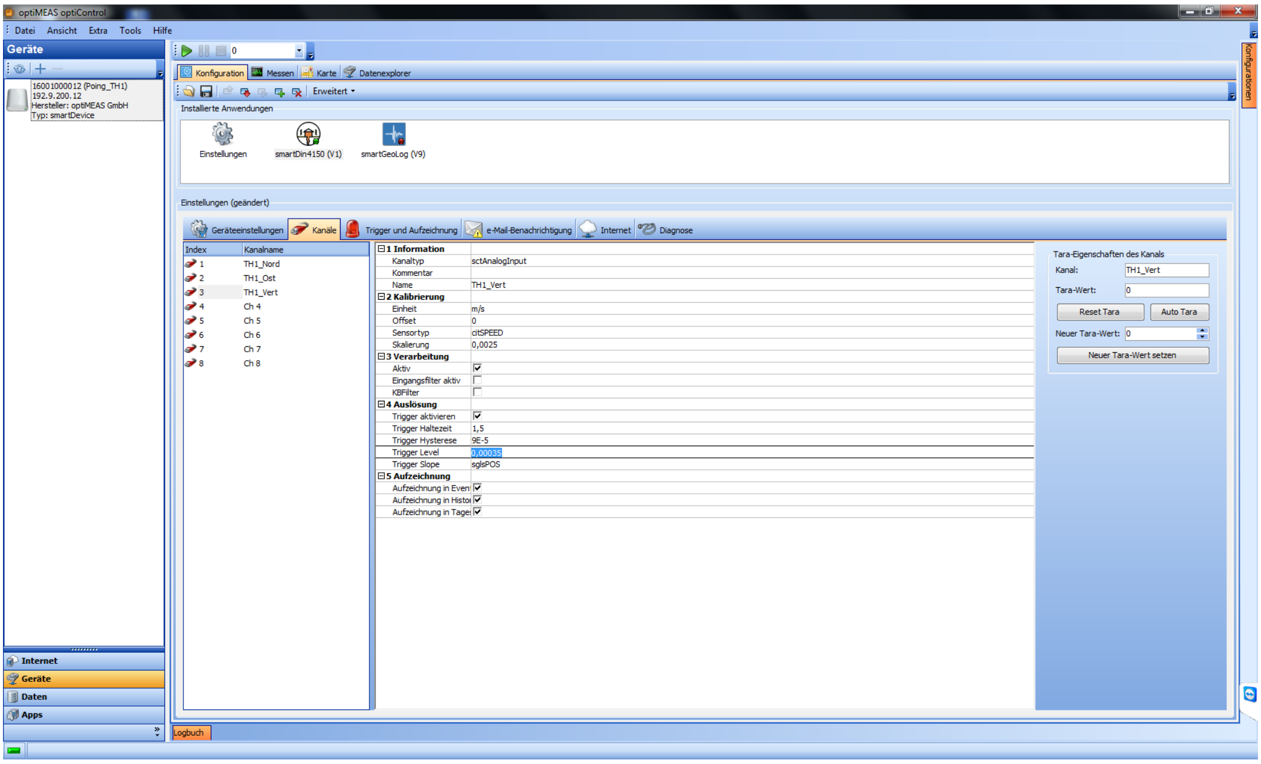

Figure 5: optiControl parameter window.

Communication between data loggers and server is managed by optiCloud. Here, trigger conditions can be set as a combination of several data loggers to avoid unnecessary noise triggers.

The SmartSeismo package organizes triggered and continuously recorded data and manages the upload of mSeed data to Bavarian Earthquake Services. This software package allows furthermore the alerting via e-mail/SMS/etc. if the threshold values are met. SeismoSuite processes and evaluates the data automatically, semi-automatically or manually. It can operate as service in the background or as stand-alone program for manual revision.

4. SEISMIC EVENT EXAMPLES

The geothermal plant in Poing has operated continuously since 2012. Groundwater extraction already started in 2011 with a long-term pumping test.

There have been three local seismic events since December 2016 which have been registered by the Bavarian Earthquake Service.:

- 03/Dec/2016 (M=2,1)
- 20/Dec/2016 (M=1,8)
- 09/Sep/2017 (M=2,1)

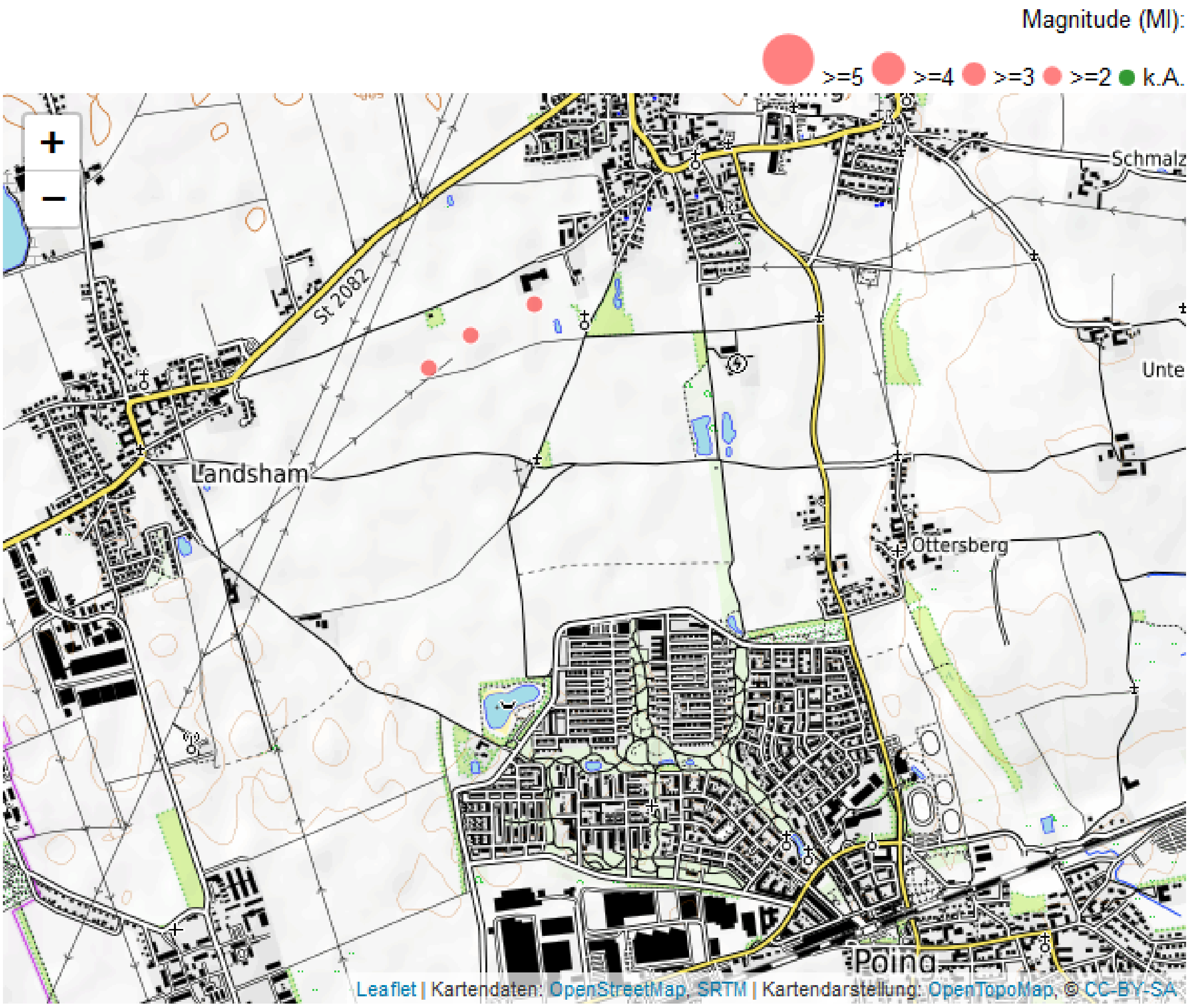

Figure 6: Localization of the Bavarian Earthquake Services of the seismic events in the area Poing [iii]

The local network has been in operation since mid-December 2016, so that the last two events have been recorded and the data transferred to the authorithies.

Furthermore, a number of seismic events from outside the monitoring area were recorded and recognized.

The distinction between long-range and short-range earthquakes is made via:

- Operating times
- Running time (P-S distance)
- particle motion
- frequency

4.1 seismic event Poing 09/Sep/17

The seismic event of the 9th of September 2017 was recorded by two local seismic stations of the monitoring network Poing, which were available at this time. The Bavarian Earthquake Service calculated the position with the regional Bavarian seismic network.

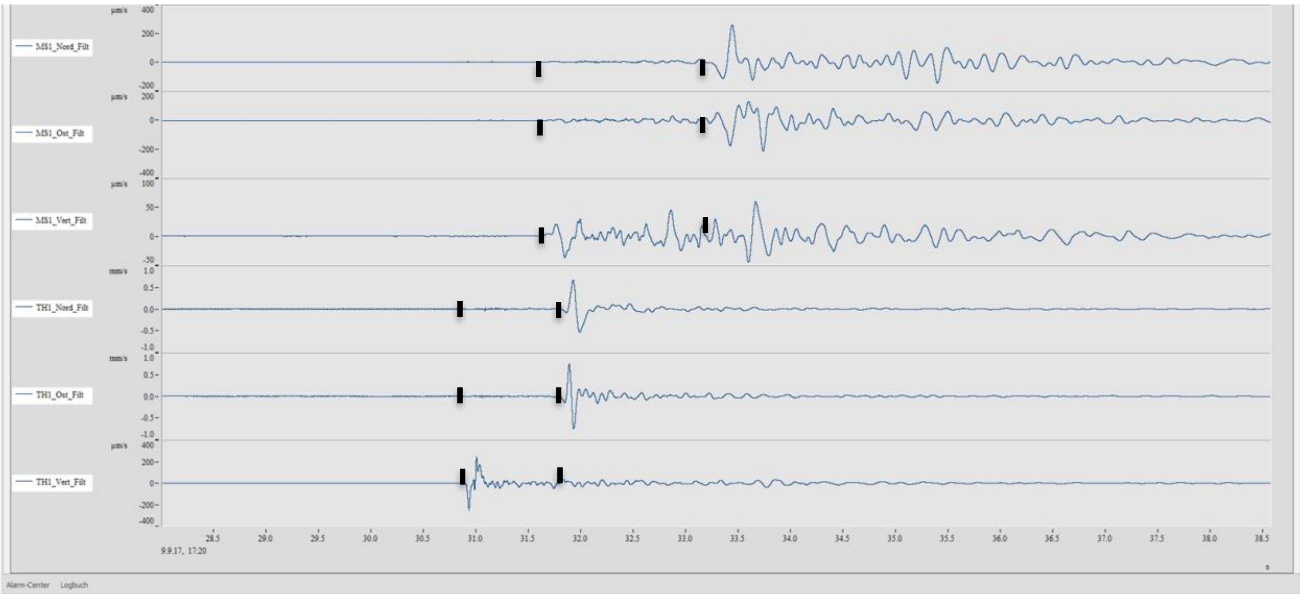

Figure 7: Seismic recording of the seismic event of 9th of September 2017.

To figure out the location of the seismic event with less than 3 or 4 seismic stations additional information about the local situation are necessary:

- Known parameters (geological setting, wave velocities, technology, ...)
- Good signal to noise ratio
- Adequate software tool

A very powerful tool to locate the seismic event position with less than 3 seismic stations can be the particle motion evaluation. With this information the angle of incidence of the propagating waves can be determined. In Figure 9 the incident wave is projected onto the horizontal and two vertical planes and their respective projected angles are given. Using these projected angles, the source direction relative to the receiver location can be estimated. As an example. this is shown for the event of the 9th of September 2017.

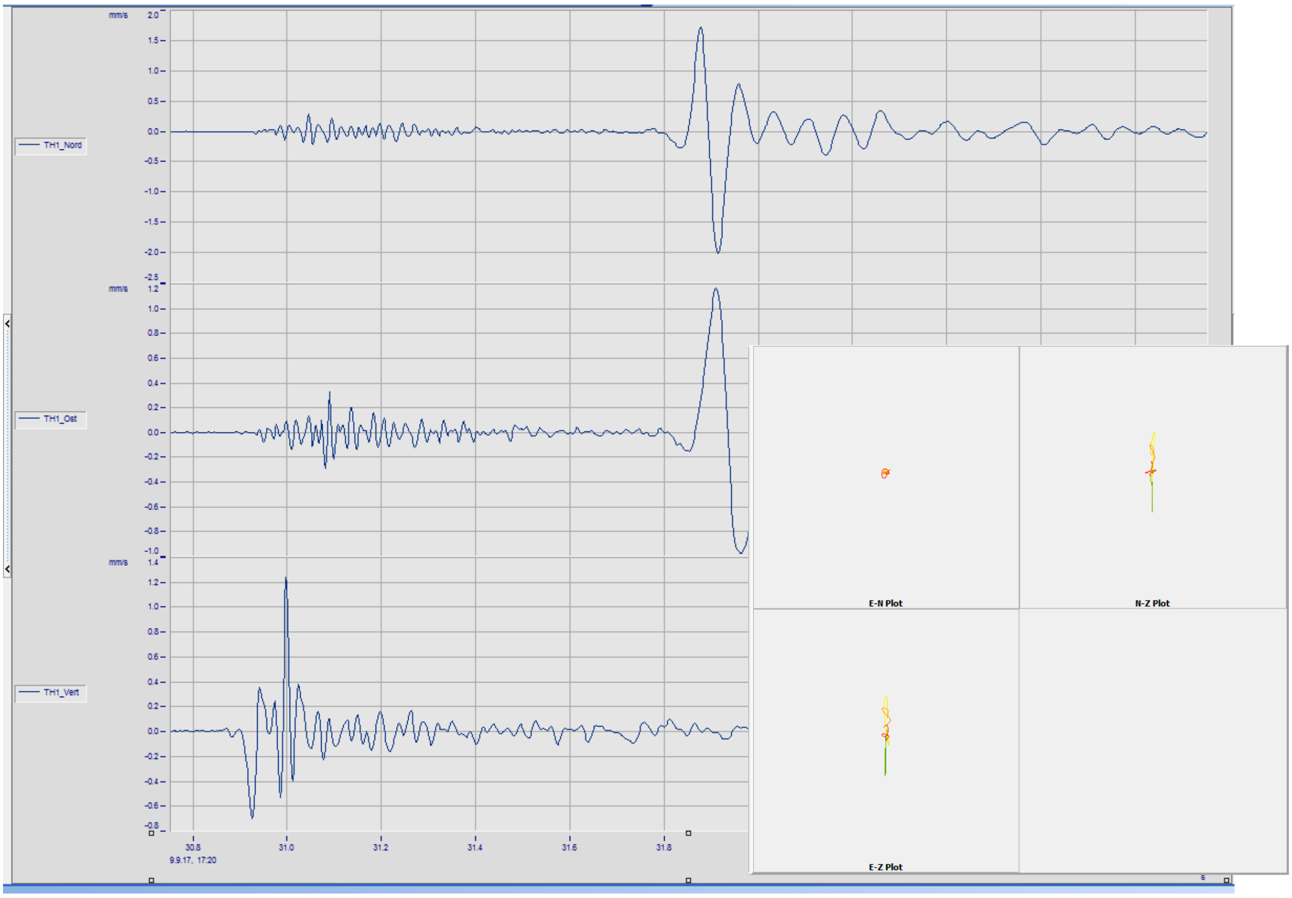

Figure 8: Seismic event of 9th of September with the particle motion analysis to estimate the angle of incidence.

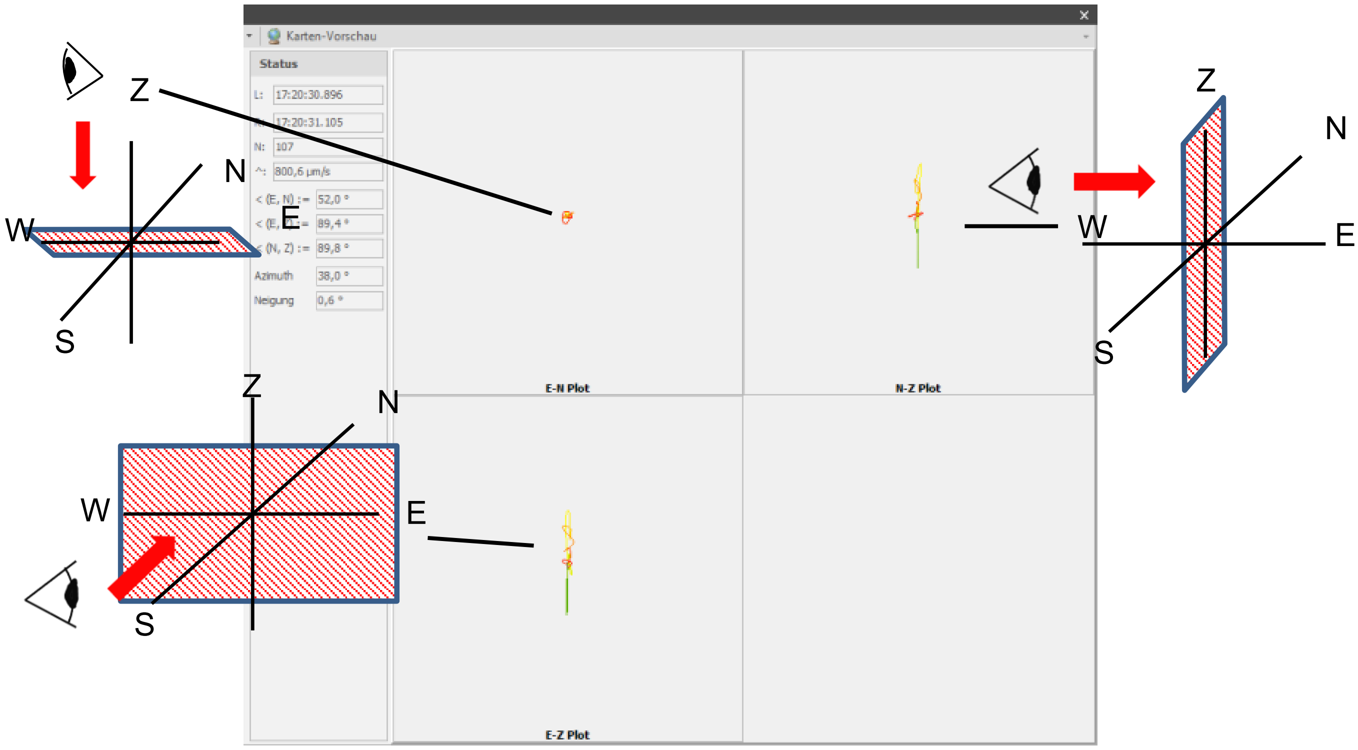

Figure 9: Projection planes and view of imaginary observer onto these planes of the particle motion evaluation.

With the particle motion analysis inclination and azimuth of the event can be determined. Together with the information about the local geological setting to obtain an estimate for seismic propagation velocities, the epicentre of the seismic event can be determined with an adequate error. For the calculation the following simple equations can be used:

Calculation with apparent velocity difference of the p-s phases (v_{ps}):

$$z = v_{PS} * t * \cos(\alpha)$$

$$r = z * \tan(\alpha)$$

using:

v_{ps}...apparent velocity difference of the p-s phases

z… depth of seismic event

t…travel time difference between the p and s wave

α…inclination angle to the vertical axis

r… radial distance

With these equations and the parameters of the seismic velocities and the information of the particle motion analysis the epicentre of the Bavarian Earthquake Services could be confirmed in the assumed error range of 500 m.

4.2 seismic event Dürrnhaar 29/Apr/18

The second example shows a distant event with its source located near Dürrnhaar (south of Munich, Germany), which was recorded by the Poing seismic monitoring system. The travel time differences of the recorded p- and s-waves (Figure 11) give a first hint of the distance to the epicentre.

Additionally, the performed particle motion analysis of the single seismic stations (Figure 12) showed slightly different incident directions for the respective registrations. As a result of the local geological setting the radiated seismic waves are refracted on different geological boundaries, resulting in slightly different angles of incident at different receiver locations (c.f. Figure 13). The angle of refraction follows Snell's law and is controlled by the seismic velocities of both geologic formations that form the boundary.

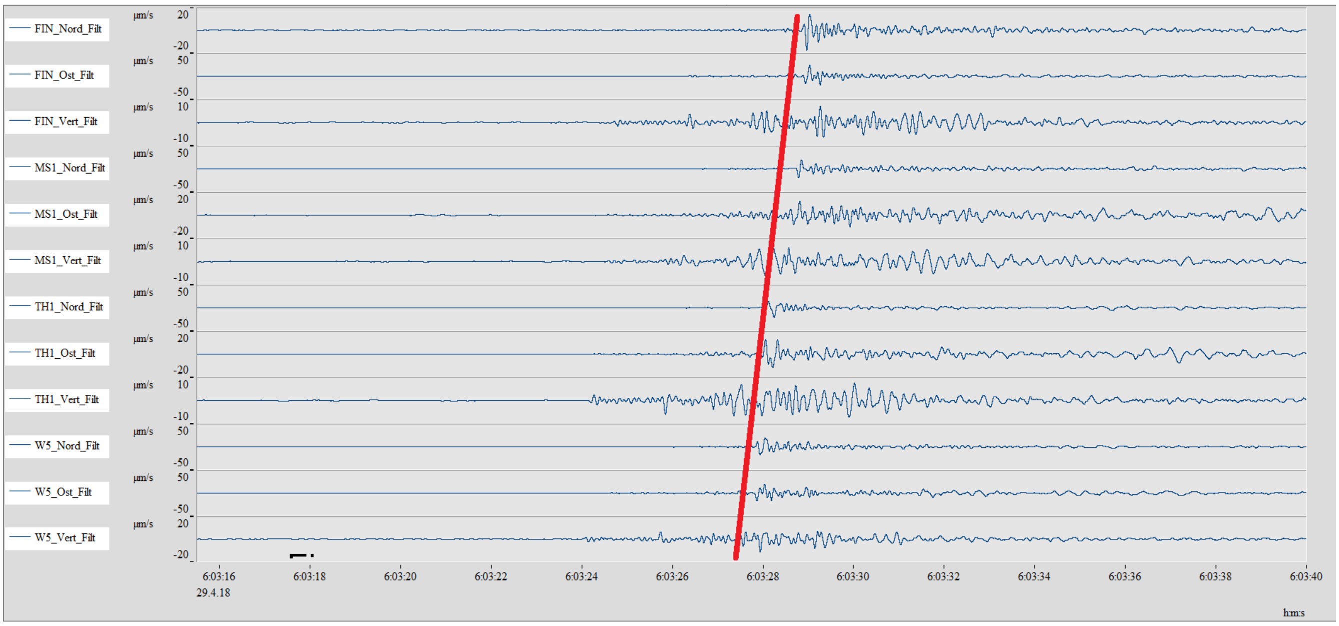

Figure 10: Seismic registration at the Poing seismic network from the seismic event Dürrnhaar.

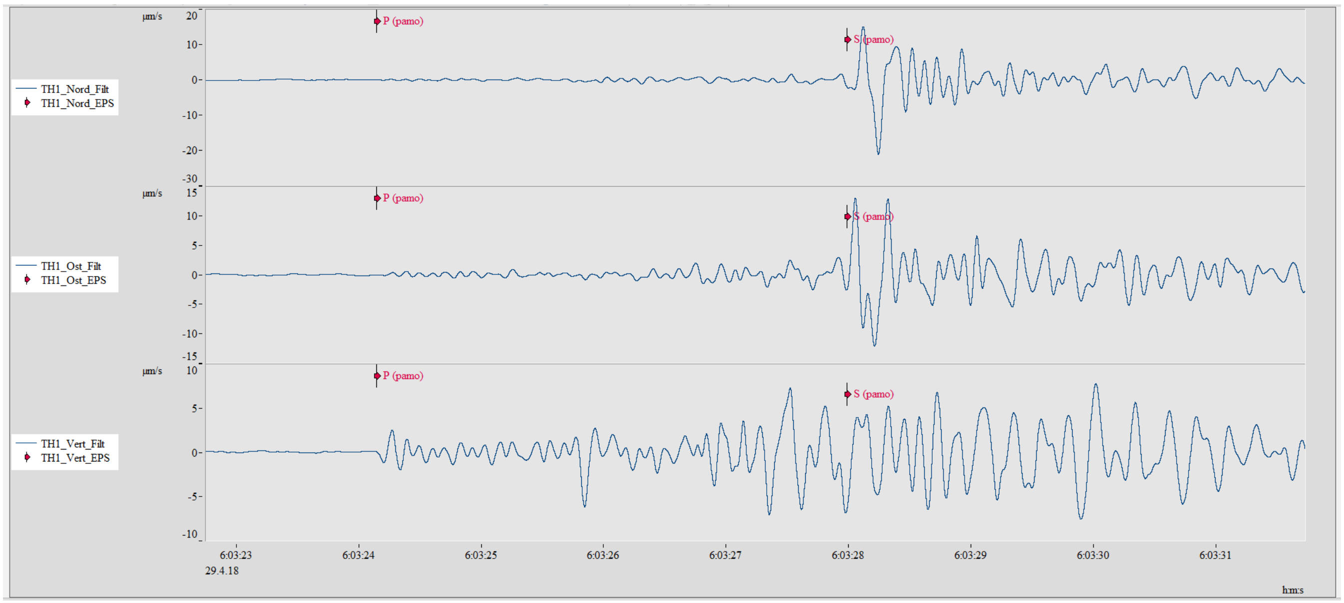

Figure 11: p-wave/s-wave arrival time difference

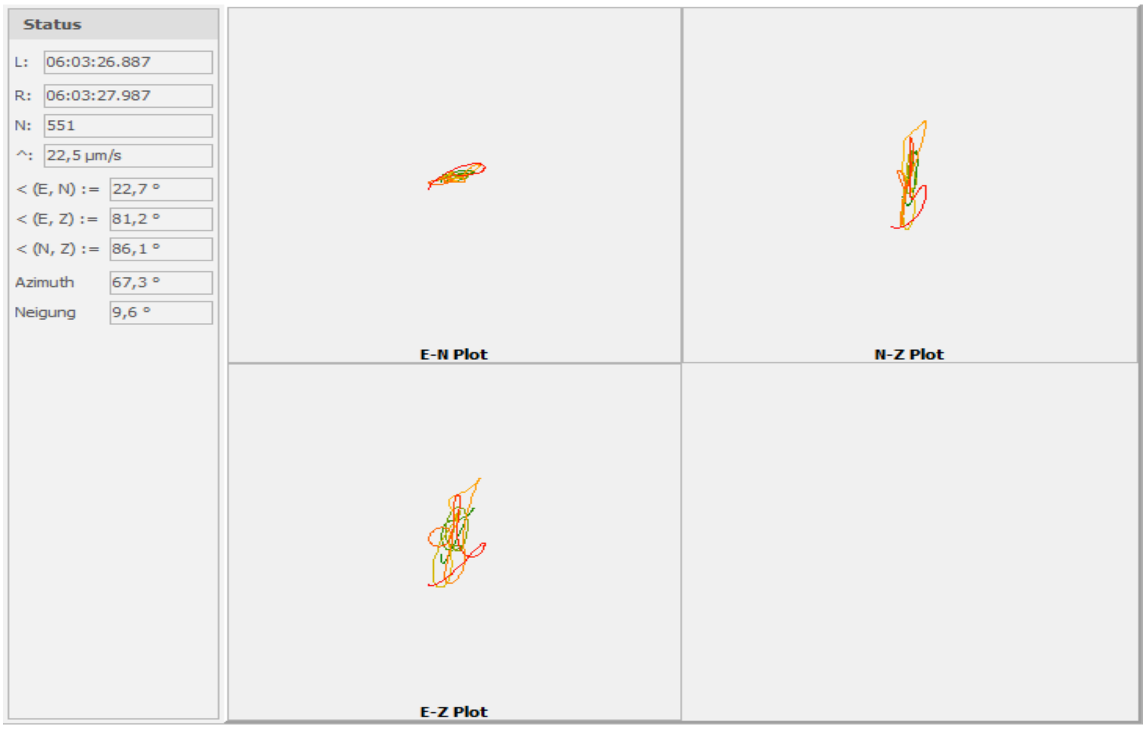

Figure 12: Particle motion results of the station TH1

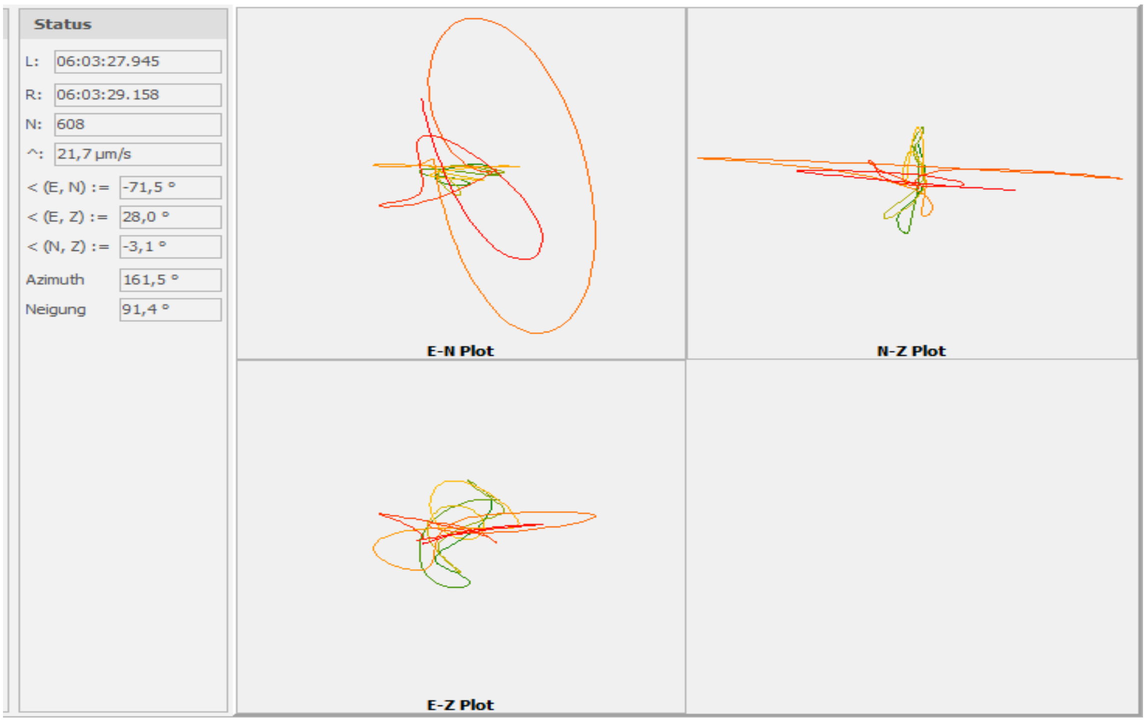

Figure 13: Particle motion results of the station MS1 of the Dürrnhaar seismic event

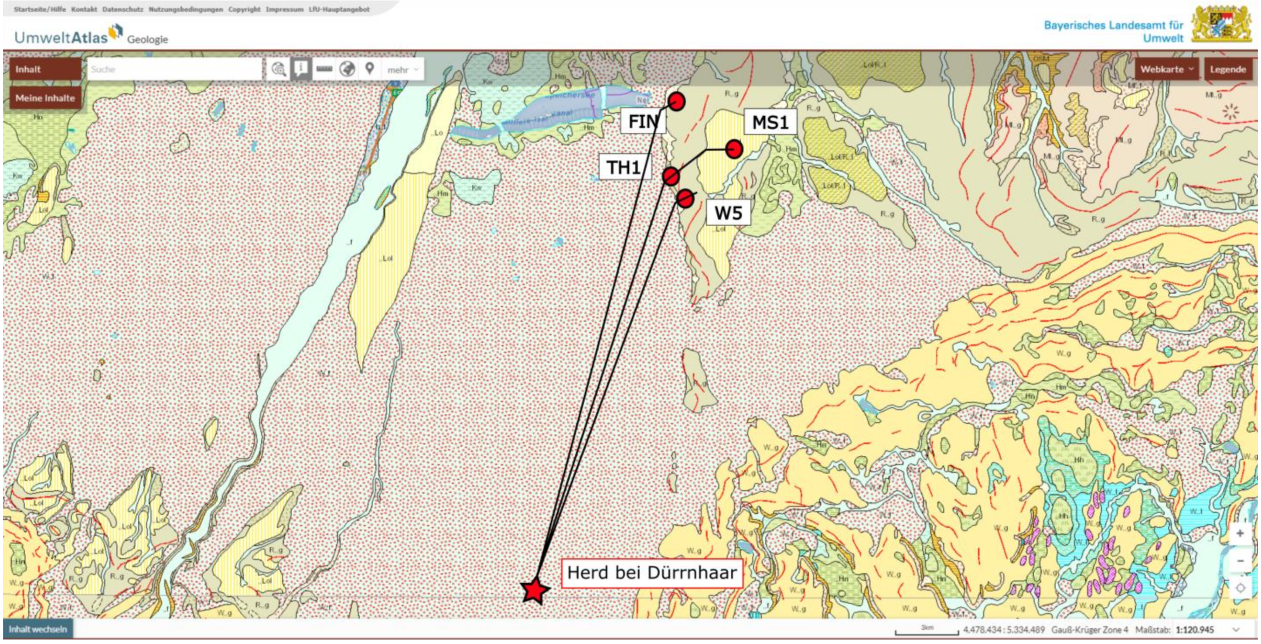

Figure 14: Calculated travel paths of the seismic first arrivals of the seismic event Dürrnhaar. (iv)

The seismic wave travel time, the calculated travel path and the angles of incidence all explain the recorded data and match with the observed geological setting of this region.

4.3 vibration impact analysis of the seismic events in Poing

One additional task of the seismic network of Poing is the evaluation of vibration impact on buildings according to the German DIN regulation 4150 Part 3.

Both recorded seismic events from December 2016 and September 2017 complied with the thresholds of maximum vibration velocity of 5 mm/s.

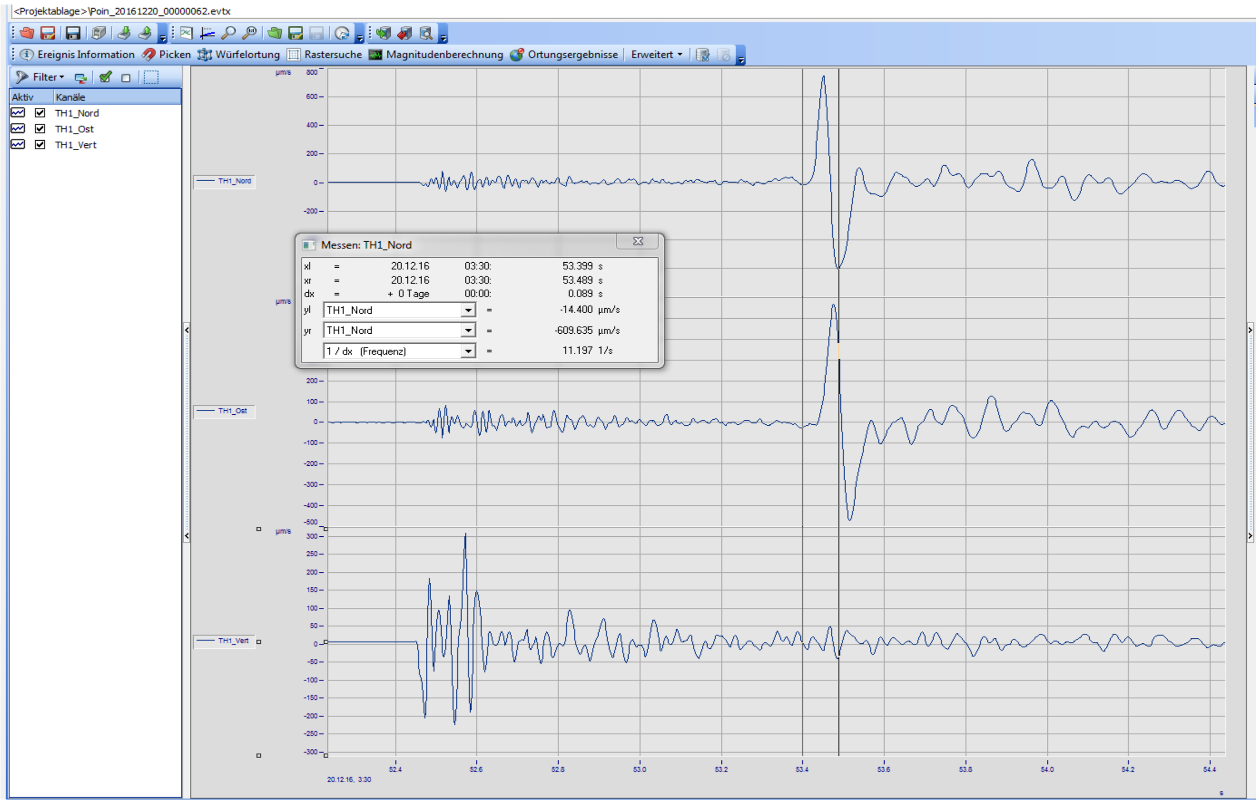

Figure 15: Vibration impact analysis example 20th of December 2016 with a Magnitude of M=1.8; maximum vibration velocity at nearest measuring point v = 0.75 mm/s (on north component at a frequency of 11.2 Hz).

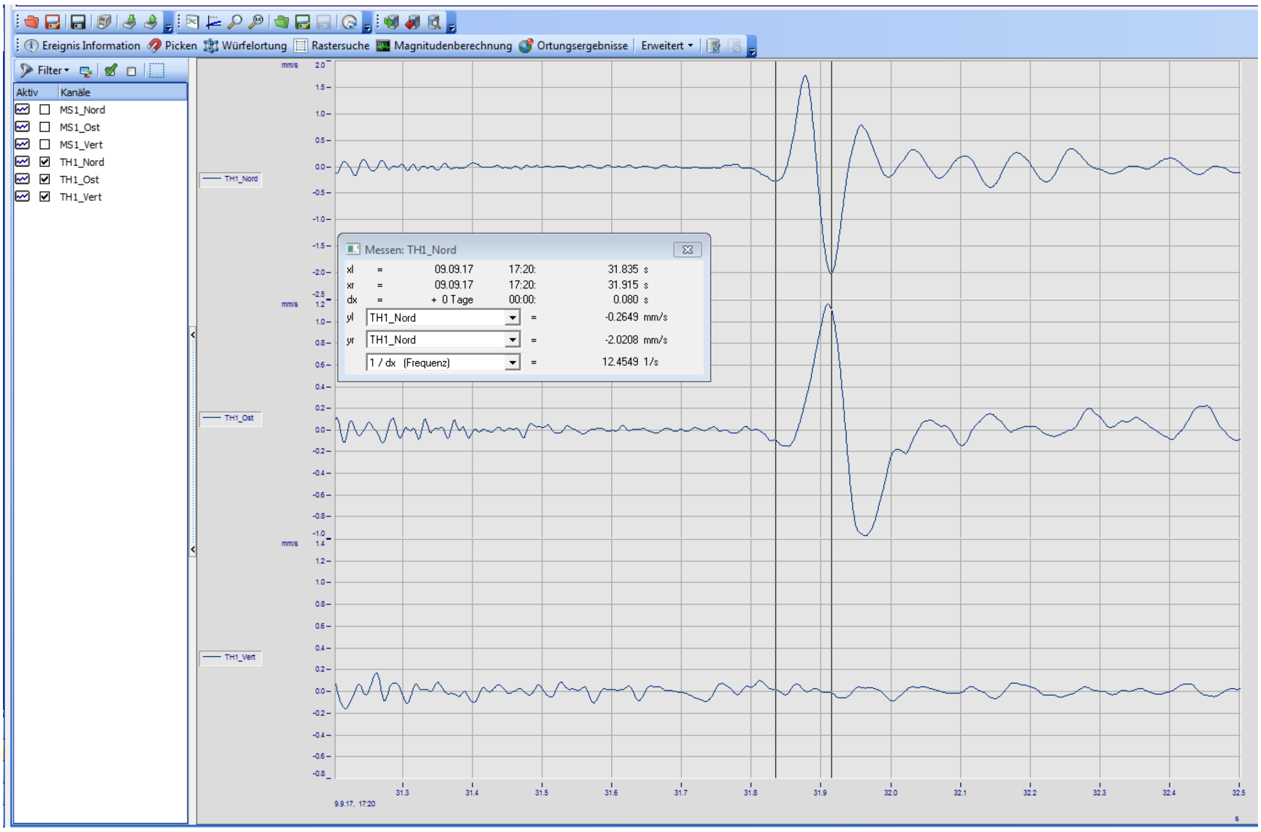

Figure 16: Vibration impact analysis example 9th of September 2017 with a Magnitude of M=2.1; maximum vibration velocity at nearest measuring point v = 2.02 mm/s (on north component at a frequency of 12.5 Hz)

4. CONCLUSIONS

The local seismic network at Poing went into operation mid-December 2016. Since that time, two local seismic events have been recorded and evaluated. Additionally, a few "remote events" have been registered. It could be shown, that near and far events are easily distinguishable based on their respective frequency content as well as p- and s-wave arrival time differences. With the seismic network the local seismicity can be accurately assessed.

Examples have shown that a seismic event with only a few or only one measuring station can be localized and evaluated under known conditions.

The DIN evaluation showed that even from the few events there was no danger for local residents or buildings.

5. BIBLIOGRAPHY

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