Seismological and geotechnical long-term monitoring of an abandoned potash mine

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Abstract

The active application of geophysical and geotechnical methods in any kind of mining turned out to become more and more important over the last years. During the phase of exploitation as well as in the after treatment phase of mines - combination of geophysical data with classical geotechnical measurements can significant improve the quality and reliability of investigations. One example is described to demonstrate the potentials of geophysical methods such as seismic and geotechnical monitoring and its preparation with respect to stability issues of mine workings, limiting conditions (e.g. explosion protection) and especially the demands after closing of the mine. Technical ways for engineering are shown at an example of a former potash mine in the South Harz Mountains.

Introduction

As monitoring with geophysical and geotechnical methods in recent years became on significance in Germany with respect to stability issues and the after treatment of many mines special adapted methods had to be found to realize monitoring after leaving the mines. A combination of geophysical and geotechnical monitoring improved the reliability of the methods. They offer the possibility to acquire a high data density concerning the stability of mines, dams or buildings and the development of these conditions to detect early potentially dangerous conditions what is very important.

The capital sources of danger in an exploitation of mines as well as in the after treatment phase or secondary use of the chambers after potash and rock salt mining result especially from: the destabilization of mining fields or parts of mining fields and the resulting inadmissible dynamic stress and strain at the surface. These lead to a possible reduction of safety at work or reduction of safety for the population and environment.

A case example is described to demonstrate the application of geophysical and geotechnical monitoring for the assessment of the condition of a former potash mine in the South Harz Mountains which is in the process of leaving, closing and flooding.

Monitoring of a former potash mine

The mine considered in this case example was in operation between 1903 and 1993. Currently 3 shafts are left and open now. The chambers are situated in a depth of approximately 700 m underground. The mine has many specialties. Some areas have already been proofed by dams and flooded in the 1930-ies. Furthermore it is endangered by gas (CH_4). Many tectonic faults above and below the mining horizon were traversed or are situated on the edges of the mining field. Already shortly after the suspend of mining an increasing seismic activity started with magnitudes of 2-3. In several mining fields, which are tectonic highly subjected, a large number of seismic events with a high energy release appeared. This trend attenuated during the extensive backfilling and flooding for stabilization. But still an active seismicity is being measured. Without stabilization, a rock burst of Magnitude 3-4 was expected. This would have caused severe damage to the infrastructure and buildings.

After stop of production and begin of backfilling and stabilization in 1994 already from 1996 some mining fields have been masterminded flooded by degrees with brine. Salt heap brine (NaCl supported) and $MgCl_2$-supported brine from a mine-own conditioning have been used. Furthermore extensive backfilling with rock salt from neighboring mining fields lead to the stabilization and prevent water to penetrate the geological barrier. This backfilling hindered the pillars in their lateral expansion.

All works were guided by a group of experts and responsible persons from the mine and were accompanied by a large number of monitoring methods like underground and surface deformation measurements, in situ stress measurements and the seismological monitoring of the mining field. These combined data series enabled the identification of especially weakened zones, which then were put on top of the priority list. Seismic monitoring proved itself in areas which were no longer accessible.

The monitoring showed that the deformation processes in the mining field were slowed down, resulting in a significant reduction of the energy release from seismic events. Because of the moistening and loosening some new factors for the development of seismicity were created – that’s why the reduction process was so slow. The development of the seismicity of the mining field is presented in figure 1. There, the epicenters of the seismic events are plotted for each year with respect to the layout of the mining field. The event magnitude is characterized by the size of the dots. The reduction in process of time is visible. But a more or less active seismicity is still observable.

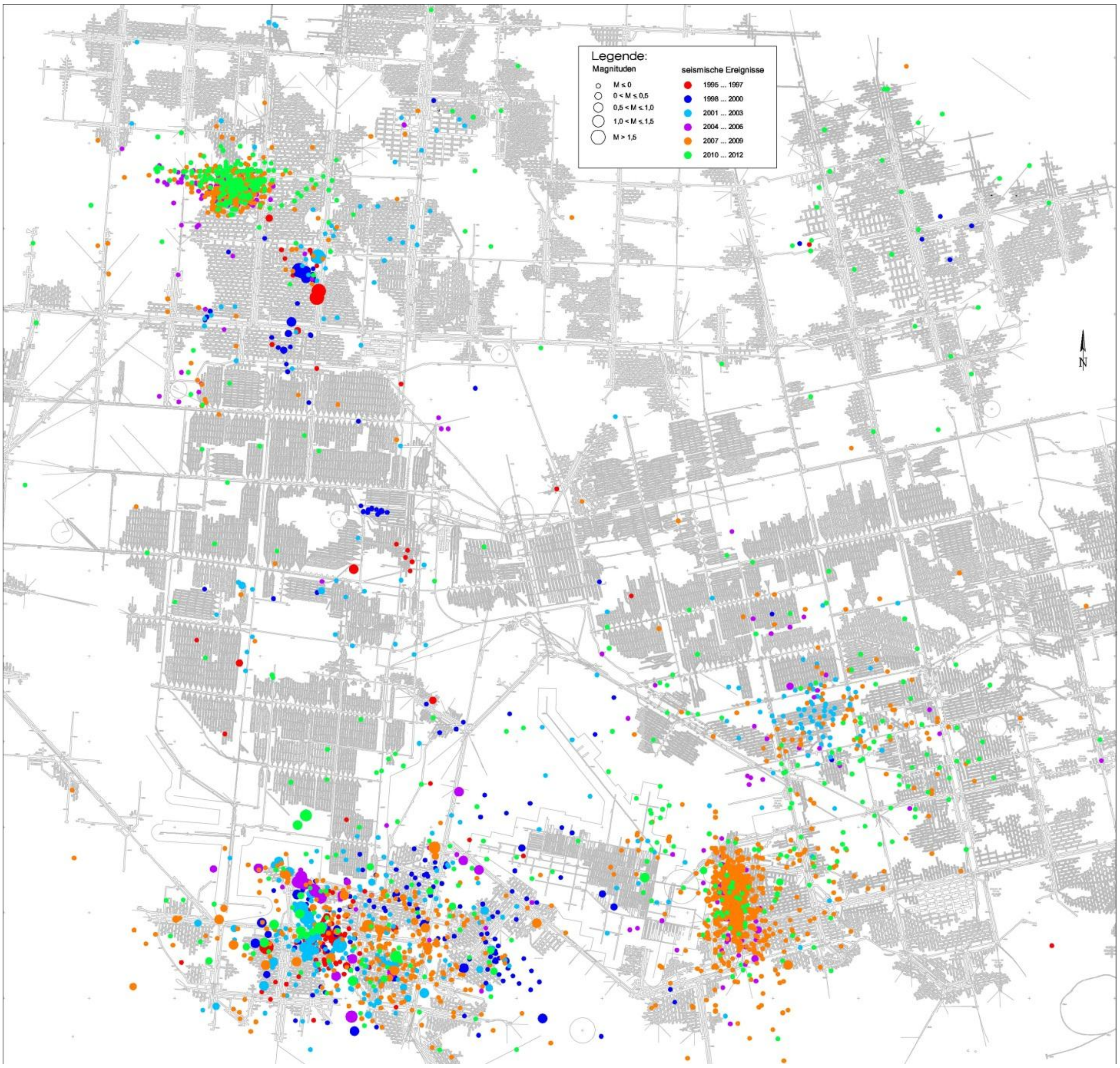


Figure 1: epicenters of seismic events in the potash mine; development 1994-2013

Additional to the alignment and grouping of the seismic epicenters the calculated focal parameters such as stress drop, dislocation, size of fault plane and released seismic energy can be directly used for further geomechanical assessments. Another way of characterizing the development of the field's condition over time by means of observed seismicity is shown in figure 2. There, the cumulative released seismic energy or respectively the square root of the energy, which is directly proportional to the stress release, is plotted over time (Benioff, 1951). Moreover, the shape of the curve gives qualitative indications of how the stress is released. A high number of small events will result in a rather smooth curve while a small number of strong events would give a blocky shape. A change in the mean slope of the curve indicates a change in the characteristics of the deformation processes.

Some periods of activity can be distinguished in figure 2 which shows the Benioff-curve for the mining field. The sudden onset of seismic activity (Period A) is represented by a rather steep slope and a blocky shape due to the series of strong seismic events until 1998. This period was followed by a more or less constant energy release (Period B) at a still high level, but lower than in period A. From 2001 on an increase in the energy release could be observed (Period C). Afterwards a constant energy release at a lower level took place (Period D). Here the number of events was rather high, but the magnitudes were on a mean level. 2006 in a single mining field a number of events with large magnitudes occurred. That dominated that phase. Since then the seismic activity is kept on a more or less constant high level since then, although the characteristic of the deformation processes seems to point more towards the accumulation of energy and the stress release by stronger seismic events at greater intervals.

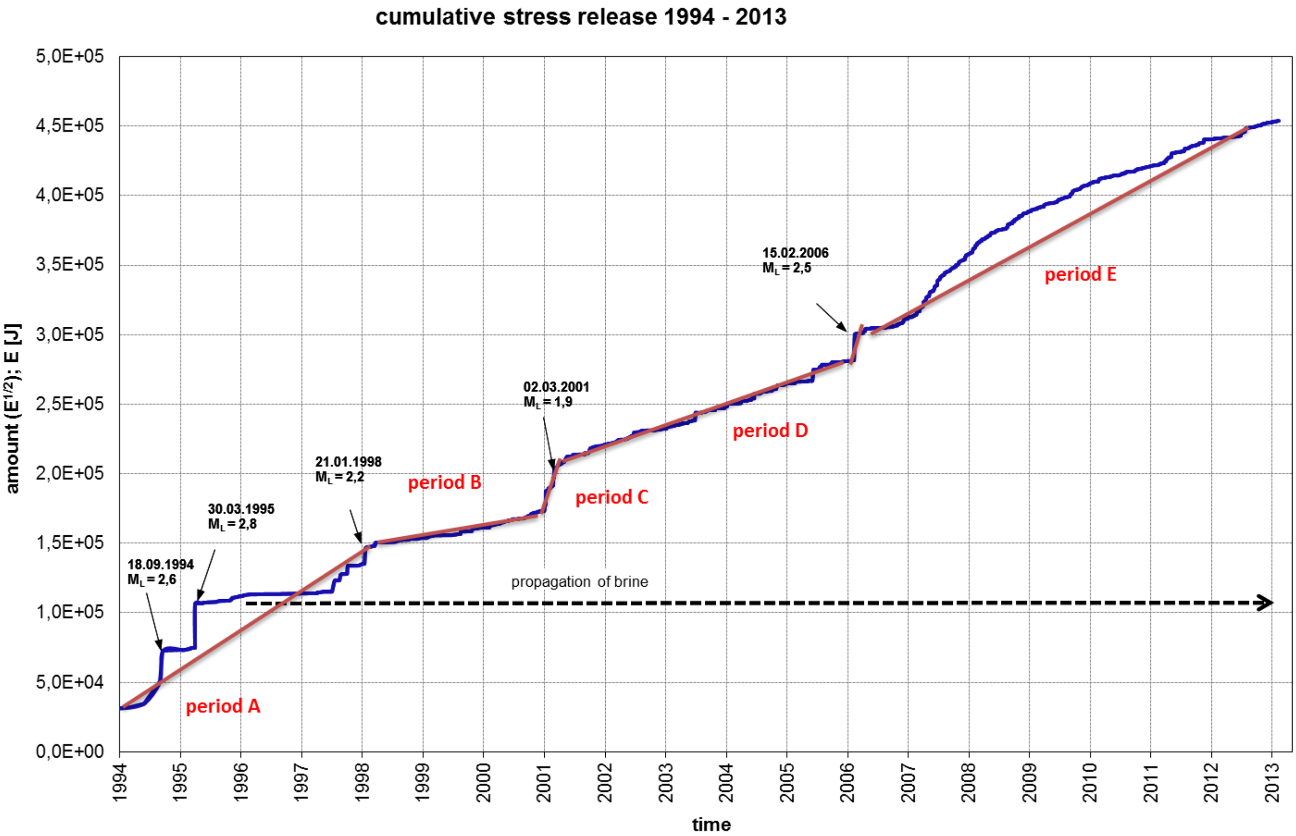


Figure 2: cumulative stress release in the mine 1994 - 2013

Technical realization of the long term monitoring

The seismic monitoring system of the mine having been operated for 15 years composed of 11 measuring points in the mine, 4 on the surface and 2 mobile vibration monitoring stations for long term detection and monitoring seismic-geomechanical-events and the process of backfilling and flooding. The mobile vibration monitoring stations record data autarchic. All measuring points on the surface record data also autarchic and send the data over an internet access to the central data acquisition place. A software collects the data of all sites and assembles them into a combined data set. Over the long period of time the system many times was adapted to the works of backfilling and the accessibility of sites. It was completed by an additional measuring point on the surface, a seismometer in a borehole, two underground sites and a mobile vibration monitoring station.

The geomechanical measuring program contained for many years measurements e.g. convergence, pillar-strain- and hydraulic fracturing-measurements. Deformation and distortion of the pillar structures as well as the convergences and the stress and strain of the horizons above the mining horizon can be evaluated and rated. Hydraulic fracturing measurements provide data about the local strain situation and the time-dependent deformation behavior of pillars and local mining fields. Additionally levellings are surveyed on the surface in certain cycles. The pillar-strain-measurements use distributed boreholes in the mine. In several depths wires are installed. Differential measurements are carried out to the case at the mouth of the borehole. So the deformation in this area of the mine can be determined. Convergence measuring sites are composed of marked points on the bottom and the roof of a chamber or a way. The distance is regularly determined. Hydraulic fracturing measurements are carried out with a special probe in boreholes. Silence and rupture pressures are determined in several depths of the borehole and afterwards the current state of the pillar and the mining field can be determined.

Test field

During the flooding of the first mixed salt mining fields with a $MgCl_2$ saturated protection fluid a mining area was chosen for tests for the complex monitoring in the after treatment phase. The seismic and geomechanical monitoring networks were completed by rock mechanical sensors. These should deliver data about the brine surface, the brine density and the seismicity under the use of lost sensors. The aim was to record the development of the masterminded flooding and seismic-geomechanical events (with magnitudes above $M_L = 0$) over a long period of time during and after flooding after closing the shafts. The test results were used to compile a concept for monitoring under the condition of the later non-accessibility of the mine.

After closing of the shafts the access to the mining field is only possible with a borehole. This borehole is developed with 3 reinforced plastics. One is for flooding the mine, the other two for the cables belonging to the monitoring system. The specialties of the potash mine are that it is endangered by gas (CH_4) and the danger of falling boulders from roof or face a well as the masterminded flooding. So the conditions concerning technical parameters, responsibility and robustness of the sensors and cables were very ambitious. The system has to be operating over a long period of time. In the test field all used sensors were tested in terms of function and robustness. A wide reach test was carried out over cable ways up to 8 km to check the capacity and efficiency of the cable.

After the tests a concept for a long time monitoring was created. Its components were installed between 2010 and 2012.

Area wide monitoring of the mine

A monitoring network was designed. The existing and planned monitoring network was searched for skips to provide redundancies where measuring points can compensate each other. Only at sites where at the defect of a sensor an inadequate or no result can be achieved, additional sensors were planned. An estimation of the localization accuracy was made to detect deficits.

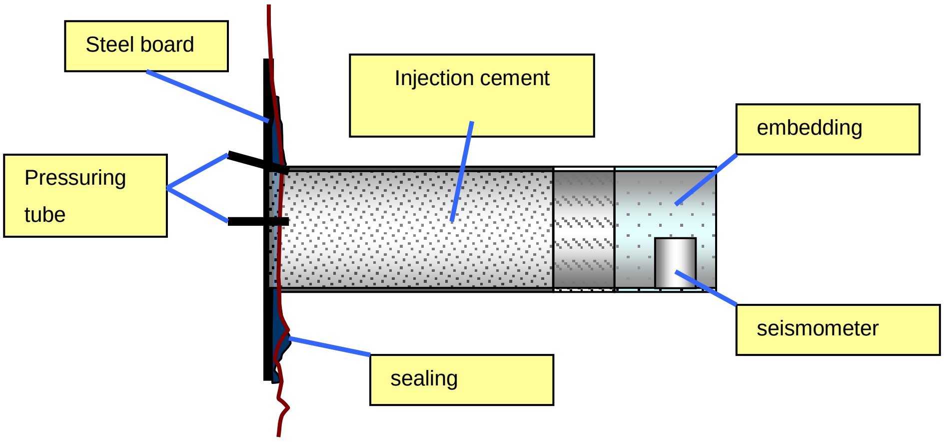
For the geotechnical monitoring ultrasonic level sensors with an ATEX permission were used (figure 3). They are protected against mechanical effects by a steel cylinder. They measure the fluid level in the cavity filled with air/gas.

In the fluid-filled areas dip probes are used. They have ATEX permission as well. To protect the pressure sensors from the direct contact with the aggressive brine they are mounted in an plastic case with an oil submittal. They were hung up from the roof. The pressure probes allow the determination of different densely brines over measured hydrostatic differences. It is then possible to control the alignment of the flooding and the unexpected inflow of water or brine.

For compensation of the atmospheric pressure an air pressure sensor was installed on the surface. The level- and pressure sensors were distributed over the whole mining field at places which are expressive for the development of the masterminded flooding for observation.

Figure 3: ultrasonic- and pressure sensors in the mine

The lost seismometers (figure 4) own an sensitivity of 1.109 mV/(m/s²) in a frequency range of 0,15 to 1.000 Hz. These are piezoelectric sensors and were installed by the following scheme in figure 4. At least 15 sensors were mounted. They have ATEX permission. With a specially by K-UTEC developed operation the seismometers were installed in the pillars.



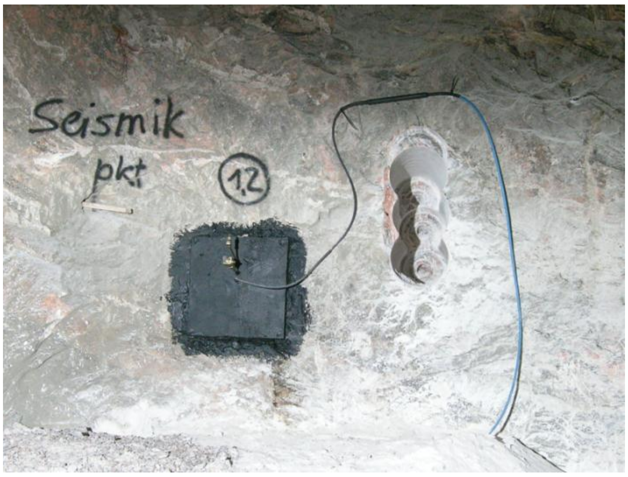


Figure 4: scheme of installation of the seismometer in a pillar and after installation cable and cable ways

The cable and the cable ways with a total length von about 80 km had to be planned and installed by a method that offers protection against mechanical effects like fall of boulders from roof and face. The type of the used cable is G-2YY(Z)Y with a high mechanical strength (additional carrier) and the ATEX permission. The cables were placed in a undercut near the face and were covered with rock salt (figure 5, 6)

Figure 5: signal cable with salt cover

Figure 6: signal cable with salt cover after (natural) fall of salt on the cover

The electric connection with signal cable between the seismic and geotechnical sensors in the mining field and the borehole to the surface was realized in a terminal box. The box filled with potting compound and protected by a salt cover.

Figure 7: end of borehole in the mining field

At the combined borehole for flooding and data transmission (figure 7) the self-supporting signal cables were collected. They were installed in the fiber reinforced plastic liners and brought to the surface. The liners function as an additional mechanical protection of the cable.

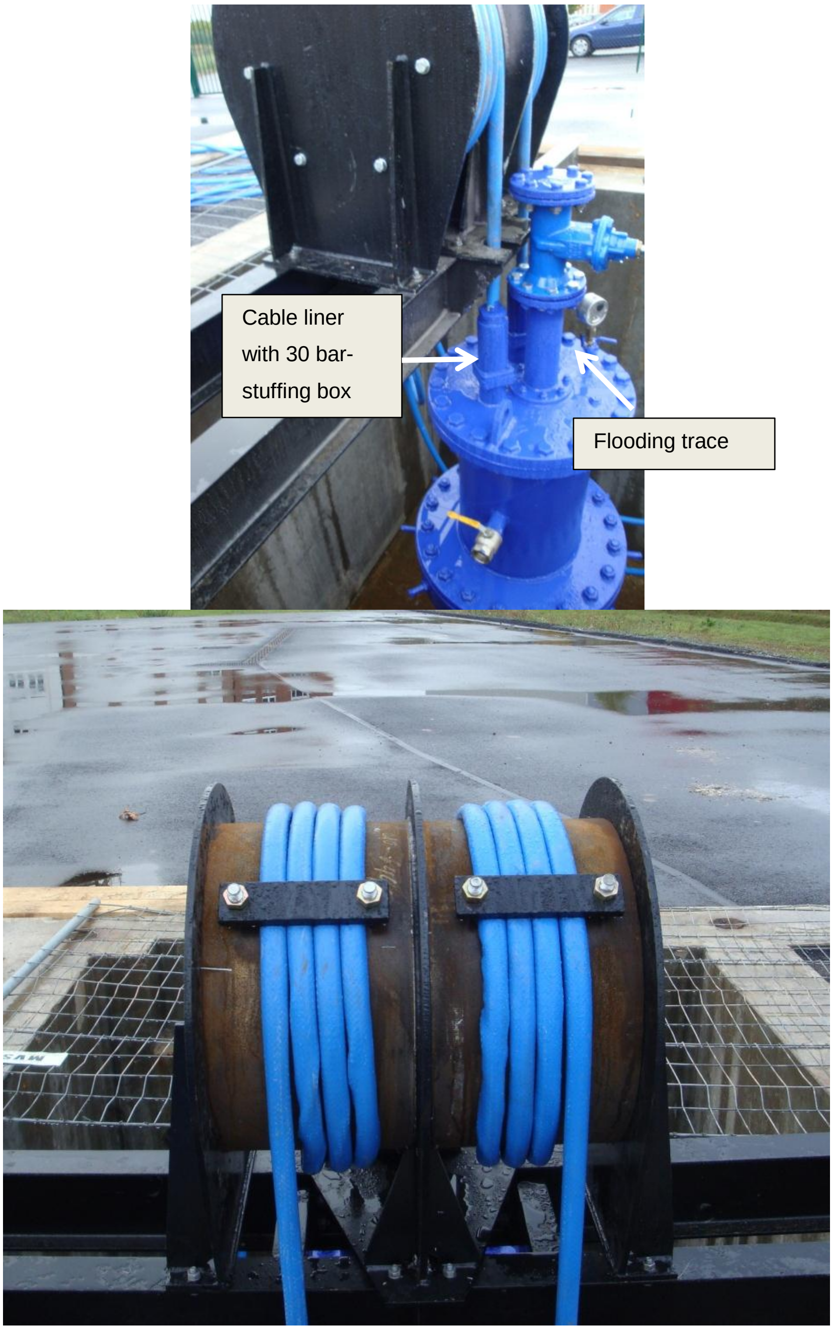


Figure 8: wellhead with stuffing box and flooding trace, socket

At the wellhead (figure 8) the cable are lead through a stuffing box which is up to 30 bar gas proof. The weight of the signal cable is contained by a special socket.

Central data acquisition unit

The central data acquisition unit (figure 9) is situated in an administration building of the mine on the surface. The galvanic separation of the electric connections is carried out because of belongings from the explosion protection. For a safe galvanic separation of all sensors in the mine isolator switches and barriers were installed. They are used as separating barriers and enable the error-free transfer of all analogue signals as well as a HART remote diagnosis. The barriers and isolator switches were installed in a terminal box near the central data acquisition unit.

All instruments like modules for acquisition, storage, graphic representation, transient recorder (data logger), industry-PC for system control, GPS-clock, electric current sources for the seismometers and voltage supply for short power failures are installed in a switch control box.

Figure 9: central data acquisition unit

The electric current sources provide electric power for the seismometers with a voltage of + 24 V DC and a current of 24 mA and offer an adjustment of the pre-amplification from the surface. The data of the sensors are recorded by a transient recorder which stores up to 32 analogue input channels. The data record is simultaneously made triggered and continuously. The time synchronization is realized by a GPS-clock. The data of one measuring point at the surface are transmitted with the PFM-method. This is a very robust analogue data transmission method. That is why the demodulation unit for this site is integrated in the switch control box. The industry-PC is used for configuration of the monitoring system and its components. A software realizes the data collection from all sensors in the mine and on the surface and combines the single data sets in one whole triggered data set. It fulfills a first assessment of the seismic signals and releases an alert (as email or text message) when an predefined magnitude is exceeded. The system can be telecontrolled by every internet connected PC. One carrier contains modules for power supply, its protection, a relay for restart of the system. In the upper part of the switch control box a module for data acquisition, storage and graphic representation of the level sensors is situated. Furthermore a sensor for recording the air pressure is installed for the correction of the data from the mine.

Conclusions

The possibilities were shown for monitoring of an abandoned mine with geophysical and geotechnical methods. It became clear that seismic monitoring offers important information about geomechanical risks of mines. The mastermind of stabilization, backfilling and flooding can be carried out for many years after closing of the shafts and under complex conditions (explosion protection) with appropriate methods. So a monitoring and preservation of evidence for the public can be carried out. The safety for the public is highly increased. The combination of geophysical and geotechnical methods, which use different physical properties, lead to a reliable predication about the geomechanical state of a mine – also after closing.

References

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