*Exploration Geophysics, Remote Sensing and Environment XXX.1 (2023)*

**DOI: 10.26345/EGRSE-030-23-103**

# SEISMIC STATIONS IN THE SUBTERRANEAN SPACES OF SANATORIUM EDEL LTD.: HISTORY

# SEISMICKÉ STANICE V PODZEMNÍCH PROSTORÁCH SANATORIA EDEL, S.R.O.: HISTORIE

***Zdeněk Kaláb***

**Abstract**

Caves are typical spaces for speleotherapy; however, other underground spaces are also used. Sanatorium EDEL Ltd. in Zlaté Hory (Jeseník District, Czech Republic) uses abandoned mine as subterranean spaces. To evaluate seismic loading of this area, two origins of seismic events are necessary to take into account: firstly, breaking of rock massif as consequence of former mining activities, and secondly, influence of seismic events originated in the surroundings. First seismic station in Zlaté Hory operated by the Institute of Geonics of the CAS was placed in the territory of the ore mine "Zlaté Hory - East" in 1997. Since 2003, seismic monitoring has been carried out in the inaccessible part of underground space of the sanatorium. Evaluation of long-term seismological monitoring in the subterranean spaces of sanatorium is very important part of safety studies.

**Abstrakt**

Jeskyně jsou typickým prostorem pro speleoterapii, jsou však využívány i další podzemní prostory. Sanatorium EDEL s.r.o ve Zlatých Horách (okres Jeseník, Česká republika) využívá opuštěný důl jako podzemní prostory. Pro hodnocení seismického zatížení této oblasti je třeba vzít v úvahu dva původy seismických jevů: za prvé porušování horninového masivu v důsledku dřívější těžební činnosti a za druhé vliv seismických událostí vzniklých v okolí. První seismická stanice ve Zlatých Horách provozovaná Ústavem geoniky AV ČR byla na území rudného dolu „Zlaté Hory - východ“ umístěna v roce 1997. Od roku 2003 probíhá seismický monitoring v nepřístupné části podzemních prostor sanatoria. Hodnocení dlouhodobého seismologického monitoringu v podzemních prostorách sanatoria je velmi důležitou součástí bezpečnostních studií.

**Keywords**

*Subterranean space, seismic loading, seismological monitoring*

**Klíčová slova**

*Podzemní prostory, seismické zatížení, seismologický monitoring*

# 1. Introduction

Caves are typical spaces for speleotherapy. Sanatorium EDEL Ltd. in Zlaté Hory, Jeseník District, Czech Republic, uses not a cave but an abandoned mine as subterranean spaces for speleotherapy purposes for children. Evaluation of the stability of these underground spaces is basic information that is permanently observed. The study of seismic loading of the given area and the surroundings is one part of this evaluation. Two reasons exist for seismic monitoring: detection of rock massif breaking as a consequence of mining activities and detection of natural weak earthquakes and quarry blasts in close surroundings including of influence of seismic loading that is generated by far strong events.

The studied area is located in the Jeseníky Mountains near the town of Zlaté Hory. The polymetallic deposit at Zlaté Hory was the largest ore district in Northern Moravia (Fig. 1). The whole area has a rich mining history. The first reference regarding the panning and shallow mining of gold in this locality dates back to the 13$^{th}$ century. The underground extraction of Au, Cu, Pb, and Ag has been developing since the 16$^{th}$ century. In the late 19$^{th}$ century, Fe was also extracted. Modern mining history in this nonferrous metal and gold ore site began in 1952 by drilling exploration of the copper site Zlaté Hory (ZH) – South and ZH – Mining Rocks; polymetallic site of Cu, Pb, Zn, and Ag metals was verified at the locality ZH – East and polymetallic site of Cu, Pb, Zn and Au metals were verified at the locality ZH – West. In 1965, the mining operations were initiated at the site ZH – South, in 1981 at the site ZH – Mining Rocks and in 1988 also at the polymetallic site ZH – East. By 1993 mining activities ended in all localities. Extraction of the monometallic copper sites ended 30.6.1990; extraction at the site ZH – East ended 30.6.1992. Extraction at the polymetallic site ZH – West (mainly Au, less Cu and Zn) took place between 1990 and 1993. A total of 7,184.4 kt of ore was mined, of which 6,412.8 kt from monometallic deposits, 127.9 kt from the ZH - East polymetallic deposit and 643.7 kt from the ZH - West polymetallic deposit. The opening of the deposits was ensured by 4 shafts, 14 galleries, 4 mining pits and 11 vertical tunnels (http://www.diamo.cz/en/Zlaté-hory, e.g. Kotris, 2014). During last the 2 years (since 2001), new exploratory work was started to verify the reserves of mineable ores.

As mentioned above, the part of abandoned mine workings in the locality of Zlaté Hory – East is used for speleotherapy purposes for children. Seismic stations that are located in underground spaces of the sanatorium enable seismic loading evaluation of these spaces, among other studies. A brief overview of historical seismic activity is also mentioned.

*Fig. 1 The surroundings of the Zlaté Hory mine in 1999 (currently the mine towers have been removed) – photos: Kaláb*

## 2. Historical seismic activity of the Czech Republic and area under study (according to Kaláb et al., 2017)

The Czech Republic (below CR) is one of the areas with low seismicity. This is due to the absence of significant tectonic faults on the territory; therefore it has been spared from catastrophic earthquakes. Six seismic areas were defined in which the vibration effect reaches at least a macro-seismic intensity of 6°; it means that some effects of earthquakes can be seen on buildings. To determine seismic hazards and risks from historical data, the seismic web http://www.seismicportal.eu/ is possible to use. This website was performed under the project: "Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation" (2010 – 2014). Current data are completed under the project CzechGeo/EPOS – "Distributed System of Permanent Observatory Measurements and Temporary Monitoring of Geophysical Fields in the Czech Republic – Development and Operation of the National Node of the Pan-European EPOS Project".

The most intensive ("extra large") historical earthquakes documented in the wider surroundings of CR are the events of January 25, 1348, which is localized in the Carinzia region (Italy). Its intensity is given at Io = 9° - 10°, magnitude at Mw = 6.99 ± 0.30. The most intensive earthquake with vibration effect on the territory of the CR described in the historical period occurred on 15 September 1590 in the Niederroesterreich region (Austria); its reported intensity is Io = 8° - 9° (Mw = 6.06 ± 0.47).

An overview of the localization of earthquakes during 1900 - 1990 is shown in Fig. 2. It is evident from the figure that on the territory of the Czech Republic, only a very small number of earthquakes were recorded, and very weak ones at that. The most intensive earthquake was recorded in the area of the town of Náchod on January 10, 1901 (02:30 a.m.) with a magnitude of Mw = 5.1. For this earthquake, (Kárník, 1996) indicates the local magnitude of 4.9 and the maximum observed intensity of Io = 6°. The magnitude of all other earthquakes on the territory of the Czech Republic was below the value 5.

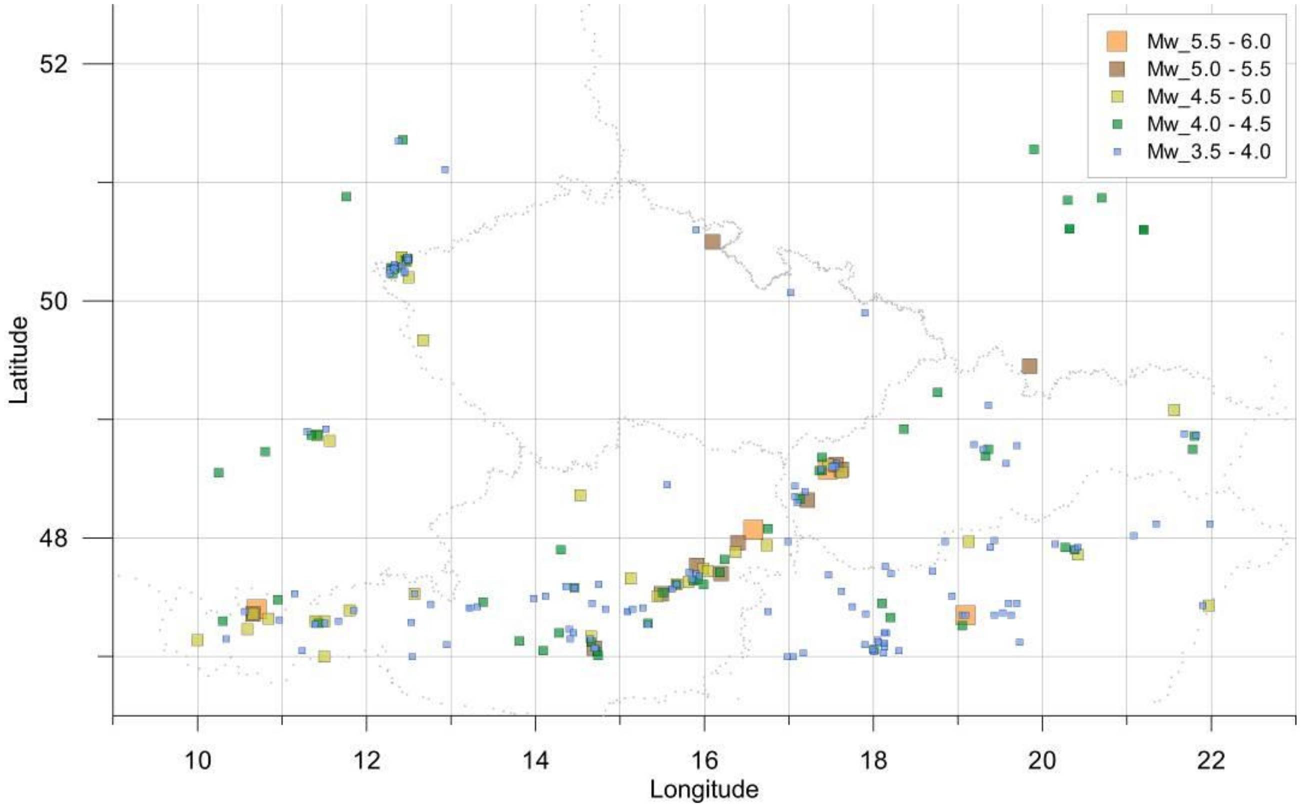


***Fig. 2 Map of earthquake epicentres presented magnitude values Mw during 1900 - 1990 ([http://www.seismicportal.eu/](http://www.seismicportal.eu/))***

Several areas of increased seismic activity can be defined in the provinces of Lugicum and Moravo-Silesicum (approximately the boundary between CR and Poland). It is possible to summarize: In the northern part of the Moravo-Silesian region, the area of Těšín (1786, Io = 7.5° MSK scale), the surroundings of Opava (1931, series of 48 shocks with the maximum Io = 6.5° MSK; 1934, 1993 series of 24 shocks with the maximum Io = 5° MSK) and the Hrubý Jeseník Mts. (1883, Io = 5° MSK; 1935, Io = 5.5° MSK; 1986, series of 18 shocks with the maximum Io = 5.5° MSK; 2012, shocks with the maximum up to Io = 3° - 4° EMS98) belong to the most important focal zones (e.g., Kárník et al., 1958, 1984, Schenková et al., 1993, Kárník, 1996, Pazdírková et al., 2013). Most of earthquakes are documented by macroseismic observations of 3° - 7.5° MSK.

## 3. First position of seismic station

The first seismic station in Zlaté Hory operated by the Institute of Geonics CAS was placed in the territory of the ore mine "Zlaté Hory - East" in 1997 (Kaláb, Knejzlík, 1999). The seismometers of the SM-3 type were placed underground in the gallery of abandoned mine shaft (the 3-rd level) at a depth of about 300 m deep (50°13′23.40′′N, 17°24′22.68′′E). Seismic apparatus PCM3-A (Knejzlík, Kaláb, 2002) was located in the engine room on the surface (Fig. 3). Mine telephone network was used for the transmission of data from the seismometers to the recording apparatus.

***Fig. 3 Seismic apparatus PCM3-EPC located in the engine room on the surface (left) and three seismometers SM-3 located on the third level of the mine (right) – photos: Kaláb***

Three SM3 seismometers, oriented in the directions of geographic coordinates (Z, NS, and EW), were bolted to the concrete pillar in the underground gallery. The seismometers are tuned on the 2 s natural period; the damping value is 0.7. The PCM3-A apparatus is designed as an AD converter, connected to the trigger circuit and input of the digital delay of the signal. From the output of the digital delay line, the signal is recorded as digital data through an interface to a PC and/or converted to an analog form on the chart recorder (Knejzlík, Skotnica, 1996). The frequency response of signal amplifiers is determined by the 6-pole Bessel type low-pass filter combined with the 50 Hz active notch filter. The resulting frequency range of the seismic channel is 0.5-30 Hz (-3 dB). Amplified analog seismic signals from individual channels are converted to a digital form in the time multiplex of 4 channels (3 channels of the digital seismic signal, I empty channel as a frame synchronization of PCM). The sampling frequency is set to 100 Hz, the dynamic range is 90 dB (MSB/LSB). The record of data starts if the signal amplitude exceeds n-times ($l < n < 15$) the selected triggering level in the 1 s time window. It is possible to record up to 10 s the signal history before triggering and up to 10 s the signal duration after last detecting the trigger. The length of the data record is limited only by the free capacity of the recording media (HDD, FDD). The density of the data record is 0.8 kB/s, the HDD capacity of the notebook PC is 80 MB, and the total capacity of recorded signal duration is 26 hours. Therefore, it is possible to choose acceptable time intervals for station services, typically one visit per month.

Time information added to the data file is derived from the PC system time synchronized by the DCF 77.5 kHz radio time signal. General accuracy is 55 ms. It is possible to improve during data processing up to +/- 10 ms using the front edges of the DCF impulses. According to the results of the experimental operation, the top of the recorded velocity amplitude range was set to 0.25 mm.s$^{-1}$, i.e., the

***Fig. 4 Entrance to the Subterranean Spaces of Sanatorium EDEL Ltd. in 2003 (left) and seismic pillar with a case with seismometers and remote telemetric transmitter (photo: Kaláb)***

conversion constant is $7.66*10^{-9}$ mm.s$^{-1}$/LSB. The Miller code was used for data transfer. To ensure the reliable operation of instrumentation, it was necessary to use a battery DC power supply because of the possible fail-rate of mains. A detailed description of this instrumentation is published by Kaláb, Knejzlík (1999).

The data acquisition program works under two main regimes:

- if the trigger is not detected, PC clocks are synchronized by the DCF 77.5 kHz radio time signal,
- if a trigger is detected, data is recorded to the chosen media (HDD or FDD).

This monitoring was realized in 1997 – 1998 only due to the complete termination of the mine operation. A total of approx. 300 useful records were interpreted.

## 4. Second position of seismic station

Non-accessible underground spaces used for the speleotherapy were selected for the second position of the seismic station (Fig. 4). This position has almost the same coordinates; the seismometers are anchored on seismic pillar at a depth of about 90 m, recording apparatus is placed in a service building near the entrance into speleotherapy. Full operation started in this position in September 2003. The recording station was similar to that at the first position. The main difference was in the distance between the seismometers and the recording station – about 1 km. Therefore, a remote telemetric transmitter PCM3/Rx was developed, and seismometers SM-3 and recording apparatus PCM3-A were also modified (Kaláb, Knejzlík, 1999). This configuration was used until the year 2017. The parameters of records remained the same: trigger regime, frequency range 0.5 – 30 Hz, sampling frequency 100 Hz, dynamic range 90 dB. The seismometers and the remote telemetric transmitter were covered by a waterproof case (partial protection from moisture and falling drops of water and small pieces of rocks falling from the ceiling) – Fig. 5.

*Fig. 5 Modified seismometers SM-3 together with PCM3/Rx digital telemetric transmitter in a waterproof case in the underground gallery (photo: Lednická)*

About approx. 500 useful records were interpreted per year. The majority of these useful records consist of vibrations caused by mining induced events from the Lubin copper mines (Poland), and then mining induced events from the Upper Silesian Basin, blasting of explosives in the surrounding quarries and less heavy traffic on the road above the mine. Records interpreted as rock massif breaking in the mine were very few - the first units per year. The registration overview can be found at https://ugn.cas.cz/?l=en&p=bulletin.

A qualitative change in the recording of seismic events occurred in 2017. The existing seismometers and recording instrumentation were dismantled and a seismic recorder with continuous data recording was put into operation. It is a BRS-32 apparatus (Brož et al., 2014) to which a three-component short-period system Lennartz Le-3D lite ($T_0$ = 1 s) seismometer is attached. Frequencies range and dynamic range depend on the installation, in our case, it is frequency a range of 1 – 80 Hz in dynamics up to 120 dB, sampling frequency f = 250 Hz. The apparatus after switching on automatically connects to the signal GPS, which will ensure time synchronization of data with high accuracy (depending on the choice of sample rate) and also save the measurement coordinates. Data gathering is realized approximately once per two months.

The type of seismic data is practically the same. Seismic events are possible to divide into three basic groups (e.g. Holub et al., 2009; Kaláb, Knejzlík, 2003):

- Local seismic events – local earthquakes, quarry blasts in the surrounding of the stations, so far unidentified local seismic events that could belong to local earthquakes,
- Mining induced seismic events occurred in the Karviná part and the Polish part of the Upper Silesian Coal Basin and in the copper mine in the Lubin area,
- Unidentified parts of teleseismic events (far strong earthquakes).

Long-term seismological observations on the territory of northern Moravia and Silesia proved the existence of natural seismic events (microearthquakes) in this region. However, the overall level of seismic activity can be estimated as low, especially for their number, but also regarding their intensity classification according to the magnitude scale. Data from the seismic station ZLHC is processed and added to the regional bulletin with a certain delay.

## 5. Conclusion

Data on recent earthquake activity are known from seismological observation performed by the Institute of Geophysics, CAS, Prague, the Institute of Physics of the Earth, Masaryk University Brno, and the Institute of Geonics, CAS, Ostrava – see https://www.czechgeo.cz/en/data-and-services/seismological-data. Institute of Geonics operates, among others, a seismic station located in Zlaté Hory. The main aim is the evaluation of underground spaces used for speleotherapy and the detection of weak natural seismic activity. Experimental seismological measurements in this locality were also performed, e.g. measurement during the detonation of the winding tower in the area of the former company "Rudné doly – Zlaté Hory" (Kaláb, Lednická, 2014), mapping the resonant frequencies of upper geological layers (Lednická et al., 2015) and, seismological monitoring of rockfalls as a tool to study weathering processes at the Geoheritage Site Žebračka Mine (Lednická and Kukutsch, 2021).

Observing of seismological situation in this place is useful also for the evaluation of underground space stability, i.e. safety of all people inside. Seismic loading of buildings and structures is performed using Czech Technical Standard CSN 73 0040 for technical seismicity (for example quarry blasts, vibrations generated by traffic, mining induced seismic events) and Eurocode 8 (CSN 73 0036) for natural seismicity (natural earthquakes). Underground spaces that are used for the speleotherapy of children are stable construction, especially in parts that are used for therapy. Evaluation of the maximum seismic velocity of recorded events at the given point shows that current seismic loading is low. Mining induced seismic events from Lubin area are usually the most intensive manifestations. However, these vibrations are not possible to detect by people.

**Acknowledgement**

This research is partly sponsored by Research Program of Academy of Sciences of the Czech Republic, OZ30860518, and project CzechGeo/EPOS - Distributed System of Permanent Observatory Measurements and Temporary Monitoring of Geophysical Fields.

**References**

BROŽ, M., ŠTRUNC, J., MÁLEK, J., LINDA, M. Seismický záznamník nové generace BRS32-USB (28bit & GPS) a jeho využití při měření indukované seismicity. *International Journal of Exploration Geophysics, Remote Sensing and Environment (EGRSE),* XXI.1, 2014, p. 35 – 47.

HOLUB, K., KALÁB, Z., KNEJZLÍK, J., RUŠAJOVÁ, J. Contribution of the Institute of Geonics of the ASCR Ostrava to Seismolological Monitoring in Silesia and Northern Moravia. *Acta Geodyn. et Geomater.*, Vol. 6, No. 3(155), 2009, p. 391-398.

KALÁB, Z., LEDNICKÁ, M. Profile Seismological Measurement during Winding Tower Demolition. *14$^{th}$ International Multidisciplinary Scientific Geoconference SGEM 2014*, Albena, Bulgaria, Conference proceedings, Vol. 1, 2014, p. 565-572. DOI: 10.5593/sgem2014B11

KALÁB, Z., KNEJZLÍK, J. Instrumentation of the Local Seismic Stations HRMC and ZLHC (Northern Moravia). *Publ. Inst. Geoph. Pol. Acad. of Sci*., M-22(310), 1999, p. 153-157.

KALÁB, Z., KNEJZLÍK, J. Seismicity of the East Sudeten as Recorded by Solitary Triggered Stations of UGN. *Acta Montana IRSM AS CR*, Ser. A, No. 24(131), 2003, p. 73-79.

KALÁB, Z., KNEJZLÍK, J. Seismological Measurement in the Moravo-Silesian Region in 2003. *Acta Geodyn. Geomater*., Vol. 1, No.3(135), 2004, p. 145-153.

KALÁB, Z., ŠÍLENÝ, J., LEDNICKÁ, M. Seismic stability of the survey areas of potential sites for the deep geological repository of the spent nuclear fuel. *Open Phys*., 15, 2017, p. 486–493. DOI 10.1515/phys-2017-0055.

KÁRNÍK, V. *Seismicity of Europe and the Mediterranean*. ČSAV, 1996, Prague.

KÁRNÍK, V., MICHAL, E. AND MOLNÁR, A. Erdbebenkatalog der Tschechoslowakei. *Geofyzikální sborník*, 69, 1958, p. 411-598.

KÁRNÍK, V., PROCHÁZKOVÁ, D. AND BOUČEK, I. Catalogue of Earthquakes for the Teritorium of Czechoslovakia for the period 1957 - 1980. *Travaux Géophysiques*, 29, 574, 1984, p. 155-186.

KNEJZLÍK, J., KALÁB, Z. Seismic Recording Apparatus PCM3-EPC. *Publs. Inst. Geophys. Pol. Acad. Sc*., M-24(340), 2002, p.187-194.

KOTRIS, J. Security of "Poštovní štola" Gallery in Zlaté Hory Region and its Accessing to Public, In: *HPVT Proceedings,* Příbram, Czech Rep., 2014, CD, 7 pp., (in Czech).

LEDNICKÁ, M., KALÁB, Z., GYŐRI, E. Mapping the Resonant Frequencies of Upper Geological Layers in the Vicinity of Abandoned Mining Pit at the Zlaté Hory Locality, Northern Moravia. *Acta Geodyn. Geomater*., No. 2(178), 2015, p. 157–167. DOI: 10.13168/AGG.2015.0013

LEDNICKÁ, M., KUKUTSCH, R. Seismological Monitoring of Rockfalls as a Tool to Study Weathering Processes at the Geoheritage Site Žebračka Mine in Mining District of Zlaté Hory (Czech Republic). *Geoheritage* 13(2), 2021. DOI:10.1007/s12371-021-00563-x

PAZDÍRKOVÁ, J., ZEDNÍK, J., ŠPAČEK, P., PECINA, V., SÝKOROVÁ, Z. Earthquake in the Hrubý Jeseník Mts. on 14.6.2012. *Geol. Výzk. Mor. Slez*., Brno, 2013, p. 205-209. (in Czech)

SCHENKOVÁ Z., SCHENK V., KOTTNAUER P. Earthquake Catalogue of the Czech Republic and Adjacent Area, 1993, unpublished.

---

**Author:**

prof. RNDr. Zdeněk Kaláb, CSc. – Ústav geoniky AV ČR, v. v. i., Studentská 1768, 708 00, Ostrava-Poruba, kalab@ugn.cas.cz