TEMPORARY SEISMOLOGICAL MEASUREMENTS IN THE POSTOJNA CAVE SYSTEM

OBČASNE SEIZMIČNE MERITVE V POSTOJNSKEM JAMSKEM SISTEMU

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Abstract

Karst caves are suitable places for seismological measurements because they are situated underground and often have lower seismic noise than locations on the surface. The idea to establish the first underground seismological station in Slovenia has led us to make preliminary seismic noise measurements in Črna Jama (part of the Postojna Cave System) in 2007. In search for further suitable stable places within the cave, we next performed seismic noise measurements, followed by a temporary accelerometer installation, near the highest point of the Velika Gora chamber in the first half of 2010. Since 7 May 2010, the seismic station is located inside the 9 m long artificial tunnel that was built for geophysical measurement purposes in Tartarus passage in 1931. From 27 January to 12 February 2010, the seismological station Velika Gora in Postojna Cave System (VGPJ) recorded 79 earthquakes with epicenters near Postojna. Records were especially important to determine the seismological characteristics of the \( M_{LV} = 3.7 \) Postojna earthquake (15 January 2010) aftershocks. The station in the Tartarus tunnel (TTPJ) operated from 7 May 2010 till 21 December 2010 and recorded more than hundred earthquakes of the sequence near Ilirska Bistrica that started on 15 September 2010, with two \( M_{LV} = 3.5 \) earthquakes and lasted till the end of the year 2010. The aim of this study is the installation of a permanent seismic station inside the Postojna Cave System and future real-time integration of the related seismological data within the Slovenian and Italian seismological networks.

Keywords: temporary seismological measurements, seismic noise, accelerometer, Postojna Cave System, Slovenia.

Izvleček

Krške jame so primerne mesta za seizmološke meritve, saj se nahajajo pod površjem in imajo običajno nižji seizmični nemir kot mesta na površju. V želji, da bi postavili prvo podzemeljsko seizmološko postajo v Sloveniji, smo leta 2007 opravili podzemna seizmološka meritev v Črni jami (del Postojnskega jamskega sistema). Pri iskanju naslednjih ustreznih mest v jami smo v nadaljevanju v prvi polovici leta 2010 opravili meritev seizmičnega nemira ter začasno namestili pospeškometer v bližini najvišje točke podorne dvorane Velike Gore. Od 7. maja 2010 je potresna opazovalnica nameščena v 9 m dolgem ume-tnem tunelu, ki je bil zgrajen za geofizikalne meritve leta 1931 v Tartarusu. Od 27. januarja do 12. februarja 2010, je seizmološka postaja na Veliki Gori v Postojnskem jamskem sistemu (VGPJ) zabeležila 79 potresov z nadžarišči pri Postojni. Records were especially important to determine the seimologiške characteristics of the \( M_{LV} = 3.7 \) Postojna earthquake (15 January 2010) aftershocks. The station in the Tartarus tunnel (TTPJ) operated from 7 May 2010 till 21 December 2010 and recorded more than hundred earthquakes of the sequence near Ilirska Bistrica that started on 15 September 2010, with two \( M_{LV} = 3.5 \) earthquakes and lasted till the end of the year 2010. The aim of this study is the installation of a permanent seismic station inside the Postojna Cave System and future real-time integration of the related seismological data within the Slovenian and Italian seismological networks.

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Within the framework of the agreement on scientific cooperation between Agencija RS za okolje (Urad za seizmologijo in geologijo) from Ljubljana, Slovenia (ARSO), the ZRC SAZU (Inštitut za raziskovanje krasa) from Postojna, Slovenia (IZRK ZRC SAZU) and the Dipartimento di Matematica e Geoscienze Università degli Studi di Trieste, Italy (DMG), the Italian partner proposed to install an accelerometric station in the Postojna Cave System. In Northern Italy there are already two underground seismic stations in continuous operation (station TRI in Grotta Gigante and station VINO in Grotta di Villanova). Karst caves are good places for such measurements due to the fact that seismic noise is lower underground than on the surface.

The aim of the study is to find a suitable place for installation of the permanent seismic station inside the Postojna Cave System.
Postojna Cave System and to connect the instrument in the cave with GPS and GSM antennas outside the cave for accurate timing and for on-line flow of seismological data to the data centers of the Slovenian and Italian seismic networks.

The article describes the first results of seismic noise measurements in parts of the Postojna cave system named Črna Jama (being accomplished in 2007), Velika Gora and Tartarus (measured in 2012), and of the temporary seismological recordings on Velika Gora and in the artificial tunnel in Tartarus obtained since January 2010. The first analyses have shown low seismic noise in the cave, and proved that the artificial tunnel in Tartarus is appropriate for a permanent seismological station installation.

Geophysical studies in the Postojna Cave System started already in 1932 (R. R. Grotte Demaniali di Postumia 1933). Horizontal pendulums with photographic recording were the instruments used to detect minimal variations of the vertical. They were constructed at the Astronomic Observatory in Trieste and installed in the 9 m long artificial tunnel, built in 1931, in the Tartarus section of the Postojna Cave System (Fig. 1). During May 1932 these instruments detected the lowering (0.0003 mm) of the southern part of the rock mass due to the increased level of the underground river Pivka. The studies were important for understanding earth tides, underground karst hydrology and seismology (Carnera 1933).

In autumn of 1933 the underground river Pivka was very high and pendulum instruments in Tartarus were flooded and had to be moved to another place in the cave (R. R. Grotte Demaniali di Postumia 1934). The flood of 23 to 24 September 1933 affected a huge part of Slovenian territory. The level of the water in Tartarus reached more than 519.8 m above the sea. This was the highest flood in the cave in the last 100 years (Šebela 2011). Horizontal pendulums with photographic registration were removed from the cave before World War II.

**DESCRIPTION OF THE STUDY AREA**

Slovenia is located at the northern part of the Adriatic microplate, which is presently moving northward with a counter-clockwise rotation. A northward-oriented maximum principal stress direction has been also obtained from fault plane solutions. These reflect mostly strike-slip mechanisms along Dinaric (NW-SE) or cross-Dinaric (NE-SW) oriented faults (Poljak et al. 2010).

Slovenia is considered to have a moderate seismicity (Poljak et al. 2000). The last strong earthquakes occurred in 1998 ($M_s = 5.6$) and in 2004 ($M_s = 5.2$) in Krn Mountains in NW Slovenia (Živčič et al. 1999; Bajc et al. 2001; Pahor et al. 2006). In January 1926 (Ribarič 1982) the so-called Cerknica earthquake ($M_s = 5.6$) was well felt also in the Postojna Cave (Šebela 2010). The last strong earthquake ($M_{LV} = 3.7$) in Postojna was felt with intensity V (EMS-98) on 15 January 2010 (Jesenko et al. 2011).

The Postojna Cave System is located some 100 m north of the Predjama Fault zone and about 4–5 km southwest of the Idrija Fault. Both faults have a Dinaric orientation (NW-SE) and the Idrija Fault is presumably responsible for the strongest known earthquake in the area that happened on 26 March 1511 (Fitzko et al. 2005; Živčič et al. 2011a).

Being 20.570 m long and 115 m deep the Postojna Cave System is the second longest in Slovenia. The part of the cave open for visitors has electricity and other infrastructure facilities that are important and can be used for the installation of an underground seismological station.

**STATION SITINGS (AND RELATED NOISE MEASUREMENTS)**

The Earth is in a state of permanent shaking. Although such vibrations, called seismic noise, are imperceptible to human senses, they severely limit the sensitivity of seismic instruments and hamper their ability to record weak seismic signals. Since high-noise levels obscure weak seismic signals that we wish to record, the level of seismic noise is one of the main criteria when assessing the quality of a certain location to be used for seismological measurements. Seismic noise is present at all frequencies of interest for seismology and is caused by natural and human activity. Among the strongest natural generators of seismic noise are oceanic waves, fluctuations in barometric press-
sure, and wind (Bormann 2002), and their effects cannot be avoided. On the other hand noise due to human activity contains higher frequencies and propagates to shorter distances compared to long-period oceanic waves (Webb 2002), but is high close to large urban agglomerations with lots of industrial facilities and traffic.

The first idea was to install the subterranean seismic station close to one of the cave entrances. Thus, the Črna Jama section of the Postojna Cave System (Fig. 1) was selected for the first seismic noise measurements (Fig. 2). In order to find the best site for the seismic station installation, ARSO, IZRK ZRC SAZU and DST (now DMG), organized one-day-long seismic noise measurements in the Črna Jama cave in October 2007. Three sites have been selected, in advance, by IZRK ZRC SAZU colleagues. These sites are far enough from the part of the cave open for tourists, are near to an electric power connection, and are not far away from another cave entrance (not used for tourist visits) in order to have the possibility to install the GPS and GSM antennas necessary to synchronize the absolute time and to transmit the data to the data centers in Ljubljana and Trieste. The measurements were made on 18 October 2007 at several sites located 10 to 50 meters from the cave entrance. The place with the lowest noise level has been selected for the sensor installation. The measurements were done using Guralp CMG-40T, Lennartz LE-3D/5s and Mark IV 1s seismometers.

The construction of the seismological station in Črna Jama was delayed for some time during which the manager of the Postojnska jama d.d. company that manages the cave installed an internet infrastructure within most parts of the cave accessible to tourists. This opened new possibilities in the search for sites suitable for a station installation since the internet infrastructure can be used to carry a GPS signal to the station deep inside the cave, where seismic noise is expected to be even lower, and also to connect the stations with the seismic data.
RESULTS

For each series of noise measurements, a site having a good sensor-to-ground coupling has been chosen. All the measurements have lasted for at least half an hour long, in order to stabilize the sensors and to have a long enough time series for the analysis. From the computed power spectral densities (Fig. 6), it is possible to see that the seismic noise in Postojna Cave is very low, as expected for rock sites in a cave located far away from urban areas. This holds for all the investigated sites, which show a very similar PSD in the frequency range investigated.

Fig. 6 shows comparison of seismic noise measured on three locations in the Postojna Cave. The measurements were made with the same sensor but not at the same time. Signal samples of 10 minutes are compared.

Comparison of the spectra of the seismic noise measured in Tartarus tunnel in Postojna Cave and the spectra of the noise on two nearby stations situated in the caves Trieste (TRI) station located in the Grotta Gigante Cave and Villanova (VINO) station located in the Villanova Cave is presented on Fig. 7. The measurements have been made at the same time. However, the seismometers were different: STS-1 at TRI, STS-2 at VINO and LE-3D/5s at TTPJ.

During the measurement at Site 1 in Črna Jama, an explosion occurred nearby at 09:00:01 and was well recorded. The records have been compared with the records of JAVS seismological station (ARSO network), located not far from the cave (Fig. 8). Site 1 looks less noisy...
than JAVS station, although it is the noisiest site of the three considered.

During noise measurements at Velika Gora and Tartarus tunnel sites we also recorded the signal caused by the passage of the tourist train. The duration of the signal is about two minutes. The preliminary analyses show a low level of seismic noise in the cave and the artificial tunnel in Tartarus as appropriate site for permanent seismological station.

From January 27 to February 12, 2010, the seismological station VGPJ recorded 79 earthquakes with epicenters beneath Postojna (Fig. 9). The data was very useful to determine the seismological characteristics of the \( M_{L} = 3.7 \) Postojna earthquake (15 January 2010) swarm sequence. The distribution of the differences in arrival times of transversal (S) and longitudinal (P) waves at the VGPJ station is presented in Figure 10. The majority (95%) of earthquakes had a \( T_s - T_p \) difference in the range of 0.07s (between 1.84 and 1.91s), which helped us to constrain the size of the activated volume to about 500 meters, which is in agreement with the source size determined from the corner frequency of the P-wave spectrum assuming Brune’s circular source model (Brune 1970, 1971).
CONCLUSIONS

The noise measurements performed and the temporary installations of seismic stations at various sites have shown that the location in the Tartarus artificial tunnel is appropriate and particularly suitable for the installation of a permanent seismic station. Although the site is sensitive to the high-frequency (above 20 Hz) noise caused by the train passage the noise in the rest of the frequency band is sufficiently low to provide good conditions for recording local seismicity. Also, this site is close to the internet installation in the cave and with electric power already at hand. The existing concrete pier built in 1931 can be used for the sensor placement. There is also enough space in the tunnel for the supporting equipment.

For these reasons ARSO and DMG propose the Tartarus tunnel as the best possible location for the installation of the permanent seismic station in the Postojna Cave System.

The TTPJ station in the Tartarus tunnel recorded more than hundred earthquakes of the sequence near Ilirska Bistrica, that started on 15 September 2010 with two $M_{LV} = 3.5$ earthquakes (Čarman et al. 2011) and lasted till the end of 2010.

Fig. 9: Number of earthquakes with hypocenters in the vicinity of Postojna recorded on the temporary station VGPJ located in the Velika Gora chamber. On 15 January 2010 an earthquake of magnitude $M_{LV} = 3.7$ followed by numerous aftershocks happened essentially underneath Postojna.

Fig. 10: Distribution of the differences in arrival times of transversal (S) and longitudinal (P) waves at station VGPJ in the Velika Gora chamber.
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REFERENCES


