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Near-field rotations excited by the microblast-method excavations

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In spring-summer 2018, science had unique opportunity to study seismic waves in near-field conditions and with precisely known sources locations, albeit with complicated source mechanisms – these were the microblasts used in excavations of two vertical shafts. Below the castle of Książ (south-western Poland) large corridors and cellars have been dug during II World War. To these subterrestrial corridors, two new entrances were built in order to facilitate the growing tourist traffic, fuelled by some legends. The main works – the digging with microblast series method – took place from 14.03.2019 to 28.06.2019. Almost every event consisted of a series of several small explosions (from 4 up to 29, around 15-20 in most cases), fired in very close vicinity and in the special pattern and order. This was needed to minimize dispersion of energy outside, maximizing the inside-directed action for crushing rocks.

The Książ castle's undergrounds house diverse scientific instrumentation including classic and rotational seismometers. The second category comprises of:

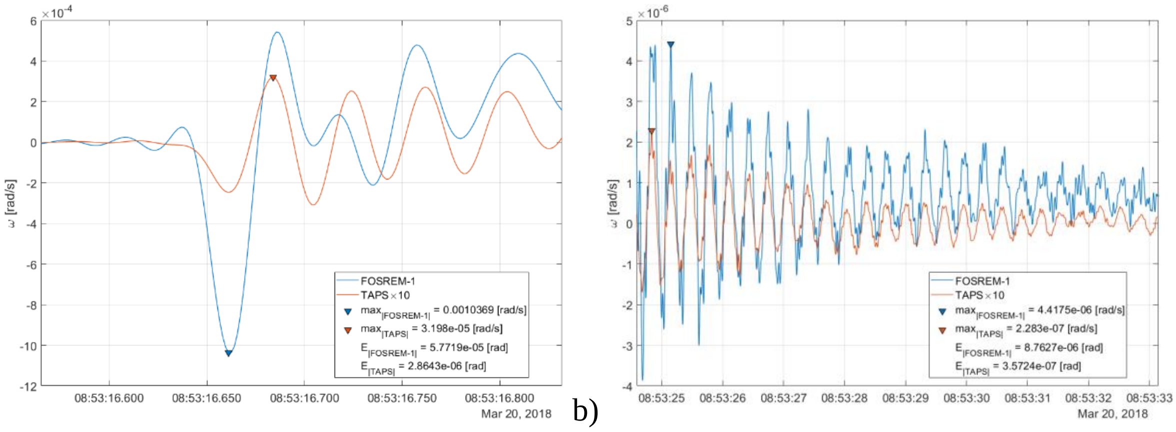
- two FOSREMs – that is Sagnac interferometers developed by the Military University of Technology, Warsaw;
- a set of two double pendulum rotational seismometers (TAPSes) from the Institute of Geophysics, Polish Academy of Sciences, working together as a micro-array;
- and two prototypical rotational seismometers made by the Geophysical Institute, Czech Academy of Sciences.

From the latter ones, one device has such low sensitivity that even in those special conditions it appeared useless in most cases, while the other confirmed its usability even if its sensitivity was too low for typical far-field work. All of sensors measured the rotation rate, while based on data from the micro-array also the rate of shear, that is shape strain, can be obtained. All these devices are located close to each other and record motions in the horizontal plane.

The mining works enabled scientists to conduct measurements of the rock mass response at close distances. Due to short available time to arrange this monitoring, only small additional temporary array of seismometers was established for time of the works. The broadband seismometer remained shut down in this time period, for its safety. Fortunately, the mentioned rotational sensors worked continuously. Distance from the rotational sensors to each of the shafts was about 80 m. Individual events were fired at various heights above the main corridor, but because the height difference did not exceed 10 m, vertical parameter of sources was not taken into account in the present study. Preliminary analysis of the obtained recordings of 73 explosions leads to the following initial observations:

- In most cases, both FOSREMs recorded the event, but signals differed between the two devices. In several occasions, one or both devices gave strongly distorted signals – starting not from zero level and oriented either only to positive or negative side, or not worked at all.
- The signals obtained from the micro-array were around one order of magnitude lower than those from FOSREM, while the signals from Czech seismometer was around two orders of magnitude lower.
- All of the systems have registered most of the excavation events similarly, although the signals differed in details.

As an example of the obtained results we present in Fig. 1. the comparison of rotations recorded from the same event with FOSREM and TAPSes.



a) b)

Fig. 1. Example of rotations recorded with FOSREM and TAPSes: a) beginning of the signal, b) later part of the same signal; TAPSes signal was 10 times magnified

The Pearson correlation coefficient obtained for the two rotations in the range presented in Fig. 1a. was $k_{12} \approx 0.65$ while in the range presented in Fig. 1b. it was $k_{12} \approx 0.87$. Clearly it can be seen that the later part of both signals were more similar. From the beginning of the signal we confirmed that sequence of shots caused a distortion of the waveform and therefore the correlation coefficient is lower than for the rest of the signals.

The rotations observed at the beginning of the seismological events are still very exciting phenomena and need further studies. The rotation results obtained from FOSREM, TAPSes and Czech seismometer were comparable, which proves the usability of those systems in real life measurements – especially in engineering applications, such as excavations, demolitions or constructions.