FRACTURED ROCK MASS RESPONSE TO INDUCED VIBRATIONS: PRELIMINARY RESULTS FROM TWO TEST SITES

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Introduction. Rockslides and rockfalls represent one of the most hazardous natural events because of the short time available for taking actions in case of exposed infrastructures due to their rapid evolution as well as their hardly detectable precursors. A recent approach devoted to risk prevention consists in performing ambient vibration studies on potentially unstable fractured rock masses, in order to capture permanent changes in their vibrational response that can be related to a microcracking process or to a variation in the pre-existing fracture net (Got et al., 2010; Levy et al., 2010; Bottelin et al., 2013). As some rock masses are subjected to the action of external vibrations, for instance those located in proximity of railway lines and highways, their behaviour can change through time also because of anthropic reasons beyond the natural ones linked to variations of environmental parameters.
Through a microseismic monitoring in continuous acquisition mode, it is possible to disaggregate and analyse the records in order to distinguish contribution in different frequency ranges, allowing the identification of the natural (low frequency) or anthropic (high frequency) vibration sources. Moreover, the observation of permanent changes in the vibrational behaviour of the monitored rock mass can be related to a rock damage process and, hence, interpreted as precursor of its failure.

In this paper, we present preliminary results of spectral and time-frequency analyses, performed by Geopsy software (www.geopsy.org), obtained in two test sites set for studying variations in the vibrational response of rock masses to induced vibrations. The first site is located in an abandoned quarry (Acuto, Frosinone), where the rock mass was shaken by a vibrodyne for monitoring a protruding and potentially unstable rock block; the second site is located along the Terni-Giuncano railway line (Terni), where a rock wall, exposed to a hourly transit of trains, was monitored.

**Acuto test site.** The abandoned quarry is located NE of the village of Acuto (Frosinone), in the carbonatic Monti Ernici ridge. This quarry was chosen on Autumn 2015 as test site for the installation of a multi-sensor monitoring system on a rock block prone to failure, to investigate long-term rock mass deformations due to temperature, wind and rainfalls. The multi-sensor monitoring system consists in: one thermometer for the rock mass temperature; six strain-gauges installed on micro-fractures of the rock mass; four extensimeter installed on open fractures; one optical device for the detection of rock fall events on a railway track posed to reproduce hazard scenarios and two weather stations, installed at foot and top of the slope wall, equipped with air-thermometer, hygrometer, pluviometer and anemometer for wind speed and direction. The sub-vertical quarry wall has a height ranging from 15 m up to 50 m and is composed of Mesozoic wackestone with rudists (Accordi *et al.*, 1986). A geomechanical characterisation of the rock mass led to the identification of four joint sets, here indicated according to dip direction/dip convention: $\alpha_0$ (130/13) corresponding to the limestone strata, $\alpha_1$ (270/74), $\alpha_2$ (355/62) and $\alpha_3$ (190/64) (Fantini *et al.*, 2016). The monitored sector is located in the NW portion of the 500-m-long quarry front and is characterised by the presence of a 64 m$^3$ densely cracked protruding block, separated from the back quarry wall by a main fracture.

**Field activities.** Experimental activities took place on July 2016 and consisted in shaking the rock mass with a vibrodyne, an electro-mechanical device able to produce vibrations at fixed frequencies and amplitudes that induce stress-strain effects under controlled conditions. During such experiments, the monitoring system was implemented with the installation of six 1-component Kinematics FBA11 accelerometers connected to a Kinematics K2 datalogger that was provided with an internal 3-component accelerometer and set to record data in continuous mode with a sampling frequency of 250 Hz. The accelerometers were installed partly on the quarry wall and partly on the prominent block, in particular: two on the rock wall, two on the block lateral side, and two on the block front side (Fig. 1). Subsequently, six shaking sequences were generated by the vibrodyne at different frequencies (5 Hz, 10 Hz, 15 Hz, two at 20 Hz and 25 Hz) and time durations (40, 25, 17, 13, 26, 6 minutes respectively). After each shaking sequence the experiment was interrupted for at least one hour, to restore undisturbed vibrational conditions on the rock wall.

**Preliminary results.** A Standard Spectral Ratios (SSR) analysis (Borcherdt, 1970, 1994) was carried out by taking in account the spectra obtained on the prominent block and on the rock wall, the latter considered as reference. Such an analysis points out an amplification on the block at 25 Hz in case of both 15 and 20 Hz inputs. Spectrograms of the recorded signals show that at the lowest generated frequencies (5 and 10 Hz) no energy was received by the rock block and, consequently, no significant induced vibration was detected. On the contrary, starting from the 15 Hz signal, a very low energy response was detected at the rock block. The 25 Hz and 40-50 Hz frequencies are unfortunately also induced by the generator necessary to energize the vibrodyne, so the data derived from the 25 Hz shaking test are of difficult interpretation.
Moreover, the three-dimensional mobility of the rock block was investigated in order to define the amount of displacement, the vibrational polarisation in azimuthal direction and the tilt degree induced by each shaking test. At this aim, the accelerometric records were integrated twice to obtain displacement records and processed by a customised software in order to obtain the three-dimensional displacement. The results show a displacement in the order of tenths of micrometer of the rock block and a different polarisation respect to the rock wall for signals recorded when the vibrodyne is turned on, while these values return to the initial condition when the solicitation is switched off. Therefore, this behaviour points out elastic displacements not permanently affecting the rock mass and testifies that the block is cinematically separated by the behind rock wall.

**Terni test site.** On March 2017, a portion of a rock mass in proximity of a tunnel along the Terni-Giuncano railway line was chosen as test site for monitoring the vibrations induced by recurrent transit of trains. The railway line runs along the Serra valley, a narrow valley deeply incised by the homonymous river, in the southern sector of the Martani Mounts, NE of the Terni basin. This area is characterised by folded and fractured rock masses deformed by several thrusts and faults (for instance Monte Torricella thrust and Battiferro fault) related to the Apennine structuration (Calamita and Pierantoni, 1994; Bruni et al., 1996); in particular, Scaglia Rossa formation crops out in the investigated sector and a geomechanical characterization of the rock mass provided $J_v: 7-10$ and $I_s: 0.3-0.5$.

**Field activities.** A seismic monitoring of the rock mass was performed from April 20 to June 15 2017. As shown in Fig. 2, the monitored sub-vertical rock wall is 4.4 m distant from the railway and its slope face (oriented 260/80 in dip direction/dip convention) is parallel to the railway track, which runs along N-S direction. Four 1-component FBA11 accelerometers were fixed on the rock wall, in particular two at its base (0.5 m from ground) and two at 1.5 m from ground, both couples measuring vibrations along N-S and vertical direction. In addition, two 3-component velocimeters Lennartz LE-3Dlite MkIII were installed at the rock mass base, as
near as possible to the railway track, in order to evaluate the soil attenuation and the amount of vibrations reaching the rock mass. The accelerometers were connected to a Kinemetrics K2 datalogger, while the velocimeters were connected to Trimble REF TEK 130S-01 dataloggers set to record with a sampling frequency of 250 Hz, with K2 in trigger mode and REF TEK in continuous mode.

Data processing. Because of limited storage capacity, the accelerometric records are discontinuous and do not include all the trains transited during the experimentation period. Anyway, the collected data are adequate to perform preliminary analyses and to test the methodology of record disaggregation in different frequency ranges. The accelerometric records were filtered from 4 to 60 Hz, and then integrated to obtain velocity records in order to be comparable with those acquired by Lennartz velocimeters. Fast Fourier Transform (FFT) and spectrograms computed for the transit of different train typologies (i.e. freight trains, passenger trains) show a peak around 50 Hz, with a FFT amplitude that is similar for the accelerometers 5-6-12 and about an order of magnitude smaller for sensor 8. Mean ambient noise levels were obtained in three frequency ranges (low: 0.1-30 Hz; medium: 30-50 Hz; high: 50-60 Hz) to measure the amount of vibration that reaches the rock mass in each frequency range. The preliminary results evidence that the rock mass vibrational behaviour is mainly influenced in medium and high frequency ranges. In order to obtain a better estimation, further analyses will include more frequency ranges.

Conclusions. The two here-presented test sites can be considered as natural scale laboratories for investigating the effects of induced vibrations on fractured rock masses. In Acuto test site it was possible to observe the vibrational response of a rock block and its independent mobility respect to the behind rock wall, evidenced by SSR analysis and spectrogram results as well as by the three-dimensional micrometric displacement obtained during shaking tests. In Terni test site it was possible to record numerous events of induced vibrations, which will be processed in order to establish the influence of environmental parameters as well as of train typology on variations of the mean ambient noise trend.

Further data analyses will be performed to understand whether the dynamic inputs of the
vibrodyne as well as the recurrent transit of trains can induce irreversible deformations, able to produce microcracking and reduce both stiffness and strength of the jointed rock mass. In this regard, the recorded accelerometric signals will be processed to compare their physical features before, during and after the arrival of vibrations.

Acknowledgments The Authors wish to thank the Municipality of Acuto for the authorization provided to the experimental activities carried out at the abandoned quarry; RFI (Rete Ferroviaria Italiana) to allow the in situ test along the Terni-Giuncano railway line as well as for providing data on train transits; the DTP (Direzione Territoriale Produzione) of Foligno for the logistic support to device installation and maintenance.

References