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DAMPING MEASUREMENTS FROM MICROSEISMIC SIGNALS TO INFER ROCK MASS DAMAGING

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EXTENDED ABSTRACT

Le indagini di simica passiva, volte al monitoraggio di eventi microsismici, risultano essere una tecnica vastamente utilizzata in diversi campi di applicazione, che vanno dal monitoraggio strutturale, al controllo della stabilità di gallerie o miniere, sino alla stabilità dei versanti. Per quest'ultimo caso, risulta sempre più diffuso il monitoraggio microsismico finalizzato alla rilevazione dell'entità di emissioni vibrazionali di ammassi rocciosi o blocchi di roccia predisposti a fenomeni di crollo, le quali possono fornire un importante contributo nella valutazione del rischio connesso a frane in roccia. Infatti, è ormai noto come si osservi un incremento di microsismicità emessa da blocchi di roccia instabili precedente al verificarsi di eventi di frana e/o caduta di blocchi, unito alla variazione dei modi propri di oscillazione degli stessi. Un'ulteriore e più recente sfida consiste nell'investigazione dei processi di danneggiamento dell'ammasso roccioso (*rock mass damaging effect*), che precorrono fenomenologicamente gli effetti sopradescritti, portando alla formazione di nuova fratturazione o allo sviluppo di quella preesistente, e che pertanto possono essere indicatori di incipiente instabilità. Nell'ottica di contribuire alla mitigazione del rischio e di aumentare la conoscenza dei fenomeni precursori di instabilità, è in corso di sperimentazione una metodologia di analisi basata sullo studio dello smorzamento dei segnali microsismici registrati su un blocco di roccia predisposto a fenomeni di crollo, localizzato in un campo sperimentale individuato e gestito dal Centro di Ricerca per i Rischi Geologici (CERI) di Roma "Sapienza" presso una cava dismessa nel comune di Acuto (Frosinone, Italia Centrale). Il suddetto blocco di roccia, del volume di circa 12 m^3, poiché aggettante rispetto alla parete di cava e da essa parzialmente svincolato mediante una frattura principale, a partire dall'autunno 2015 è sottoposto ad un monitoraggio deformazionale mediante una rete di estensimetri e fessurimetri, ed è stato scelto quale sito per un'installazione temporanea di 6 accelerometri monoassiali finalizzati alla presente sperimentazione metodologica. Questi strumenti sono stati impiegati per un periodo di circa 3 mesi e disposti sulla faccia laterale del blocco, lungo un allineamento di circa un metro a cavallo fra l'ammasso roccioso e il blocco svincolato, con il fine di investigare possibili cambiamenti nel trend vibrazionale da poter relazionare ad effetti di danneggiamento. I dati sono stati acquisiti in continuo con una frequenza di campionamento di 2400 Hz, costituendo un *dataset* di poco meno di 1200 ore di registrazione, che è stato poi analizzato mediante apposite procedure sviluppate in Matlab e con il *software* SAC (*Seismic Analysis Code*). Gli smorzamenti dei segnali microsismici registrati sono stati analizzati per delle frequenze di interesse, mediati per ogni giorno e in seguito comparati all'interno del periodo di analisi. Poiché nel sito indagato sono presenti solo deboli sollecitazioni imputabili a rumore ambientale o a forzanti naturali di bassa intensità, quali le fluttuazioni termiche giornaliere e stagionali, non sono state osservate variazioni rilevanti nei valori di smorzamento durante il periodo di tempo analizzato. Si prospetta, tuttavia, che tale metodologia possa essere applicata su *dataset* più estesi e per lo studio di ambienti caratterizzati da sollecitazioni esterne frequenti e più intense, al fine di investigare l'esistenza o meno di una relazione fra la variazione del coefficiente di smorzamento e l'aumento dello stato di fratturazione del sistema studiato.

ABSTRACT

Geophysical monitoring performed on unstable portions of rock masses can help in defining a variation in its stability conditions, resulting as a useful indicator for landslide risk reduction. In particular, understanding geophysical markers of rock mass damaging, intended as the processes that lead to the formation or to the growth of fractures, could improve risk mitigation strategies. This work illustrates a methodology used to process a microseismic dataset acquired on a 12 m^3 rock block prone to failure, located in the Acuto quarry test site, Central Italy. The microseismic monitoring campaign lasted 3 months and was conducted by deploying 6 one-component accelerometers partially on the rock block and partly on the rock mass wall. The acquisition was set in continuous mode and with a sampling frequency of 2400 Hz, allowing to collect hundreds of microseismic events. The damping coefficient of each event has been evaluated for some frequencies of interest, then the values have been averaged and compared through the whole period analysed in order to derive possible variations in the vibrational behavior of the monitored rock block. Despite no relevant changes have been noted, this technique could be helpful for analysing bigger datasets or to study different sites in which the external stresses are more intense and recurrent.

KEYWORDS: *Microseismic monitoring, rock mass damaging, damping analysis*

INTRODUCTION

Microseismic monitoring represents an affirmed diagnostic tool to detect vibrational signals in several contexts, as structural monitoring, mining excavation (SUN *et alii*, 2012), tunnelling (TANG *et alii*, 2010), and in slope stability assessment as well (AROSIO *et alii,* 2009; COLOMBERO *et alii*, 2018).

In fact, since rock slides and rock falls represent high-hazardous events due to their rapidity, recurrence and the few precursory phenomena associated, passive geophysical monitoring of rock masses, favoured by the increasing resolution and sensitivity of modern seismic devices, can allow the recording of very weak signals with a broad frequency resolution, thus helping in defining the overall stability conditions. Among the various and widespread applications of microseismic monitoring aimed at rock fall and rockslide risk prevention (SPILLMANN *et alii*, 2007; WALTER *et alii*, 2012), several studies have been also focused on the investigation of ambient noise characteristics showed by rock block prone to failure prior of their collapse (BOTTELIN *et alii*, 2013; VALENTIN *et alii*, 2016). Indeed, geophysical investigations can help in understanding the processes occurring within the structure of the rock masses, seeing as how the signals recorded by microseismic monitoring systems can be related to the ongoing damaging of the rock mass, i.e. formation of new fractures, thus indicating a worsening of its stability conditions, that can lead to rock failures (LOEW *et alii*, 2016). By considering a microseismic dataset collected in an experimental test site, this study proposes an analysis of microseismic events focused on investigating damping coefficients from recorded signals, since damping could be regarded as a possible indicator of variations in the rock mass micro-fractures network.

MICROSEISMIC MONITORING AT ACUTO TEST SITE

On Autumn 2015, an abandoned quarry located NE of the village of Acuto (Frosinone, Central Italy) has been individuated as test site for the installation of a multi-sensor monitoring system, to investigate the long-term rock mass deformations due to temperature, wind and rainfalls. The quarry front is 500 m long and is characterised by subvertical walls that reach heights up to 50 meters, and that are made up of Mesozoic wackestone with rudists belonging to the carbonatic succession of the Monti Ernici (ACCORDI *et alii*, 1986).

In the western portion of the quarry, a protruding and prone to failure rock block of about 12 m^3, which is partially separated by a main open fracture from the back quarry wall, has been chosen for the installation of the multi-sensor monitoring system consisting in: 1 thermometer for the rock mass temperature; 6 strain-gauges installed on fractures of the rock mass; 4 extensimeters installed on open fractures and 2 weather stations, installed at foot and top of the slope wall both equipped with air-thermometer, hygrometer, pluviometer and anemometer for wind speed and direction (FANTINI *et alii*, 2016). For previous experimental activities was also installed 1 optical device for the detection of rock fall events on a railway track specifically posed to reproduce hazard scenarios (FANTINI *et alii.,* 2017). Indeed, several experimental activities have been carried out so far, in order to analyse the influence of thermal and dynamic stresses acting on the rock block monitored, aiming at understanding the processes responsible for the accumulation of inelastic strain within the rock matrix and thus of the microfracturing processes (FIORUCCI *et alii*, 2018).

To pursue these studies, on February 23th 2018, a microseismic monitoring system was installed in order to investigate the vibrational behaviour of the protruding rock block and of the quarry rock wall. In particular, 6 one-component micro-accelerometers Brüel & Kjær type 8344 have been deployed along an horizontal alignment with a spacing of about 15 cm: in this configuration 3 sensors are placed on the rock block (ID: 1, 2, 3), 2 are located on the rock mass wall (ID: 5, 6) and the last one is positioned at the passage between the rock block and the rock mass wall (ID: 4) (Fig. 1). The sensors were connected to a datalogger SomatXR CX23-R of HBM, powered by a supply system constituted of a solar panel and a

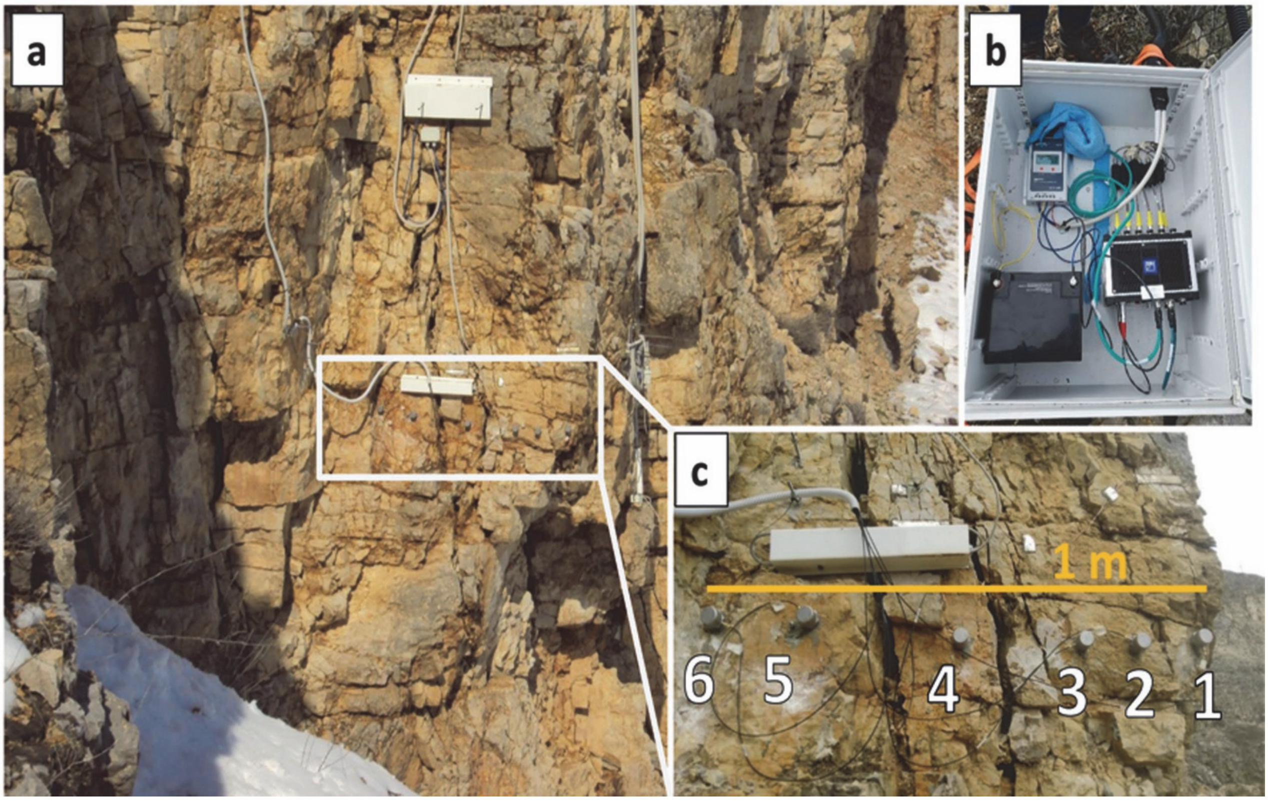

Fig. 1: Acuto quarry test site. The monitored sector of the quarry wall and the 12 m^3 protruding rock block is shown in a); the squared area is zoomed in c), where positioning and ID of the accelerometers is reported; datalogger and power supply system (b).

backup battery. The acquisition was set in continuous mode with a sampling frequency of 2400 Hz; data were periodically downloaded on site until the end of May 2018, when the microseismic monitoring was stopped.

MICROSEISMIC SIGNALS ANALYSIS

The microseismic dataset collected were analysed by means of the software SAC (Seismic Analysis Code, GOLDESTEIN *et alii*, 2003; GOLDESTEIN & SNOKE, 2005) and with customised scripts implemented in Matlab. At first, the three-month seismic records were high-pass filtered above 5 Hz and then analysed in order to extract microseismic events, chosen with a criterion of threshold exceedance set at 0.001 g. This procedure resulted in a very variable number of detected events per each day monitored, passing from very few or no event, to several hundreds, with a concentration in rainy days. In general, a typical microseismic event is characterised by a very short duration in time, spanning from 0.05 to 0.2 s, and a frequency content mostly ranging from 80 to 500 Hz.

With the aim of investigating the variability of dynamic parameters associated to incoming vibrations on the monitored rock mass during time, the following step consisted in deriving damping coefficient associated to each event for some frequencies of interest (30, 50, 100, 200, 500, 1000 Hz). At this aim, the microseismic signals were filtered within a narrow frequency range, in order to obtain a mono frequential waveform, on which is possible to observe the attenuation of the signals over time (i.e. the damping), characterised by an exponential decrease of the oscillation amplitude defined as the logarithmic decrement. Consequently, each filtered signal was normalized in respect to its maximum value to allow the evaluation of the damping coefficient, essentially depending by the frequency considered and by the angular coefficient of the straight line derived by the interpolation of the data values constituting the logarithmic decrement. Successively, the values obtained for the considered frequencies were averaged for each day in order to be compared throughout the whole three-month period. On a long-time period, such an assessment resulted in no remarkable changes in the damping values and this is probably because at the Acuto quarry there are only weak external actions mainly referable to temperature ranges and wind intensity that does not facilitate the detection of variations in damping values. A further consideration is that since the external disturbances affecting this specific test site is very low, is required a longer monitoring period to observe accumulation of inelastic strain, and thus changes in the vibrational properties of the medium. Hence, even if no relevant fluctuations have been observed in the analysed dataset, it is deemed that the analysis performed can be applied in other sites characterised by vibrations more frequent and intense.

CONCLUSIONS AND FUTURE PERSPECTIVES

A three-month microseismic dataset collected on a rock block prone to failure, located in the Acuto test site was analysed in order to observe possible variation in its vibrational behaviour to be related to ongoing microfracturing processes. The preliminary application of the here-presented methodology, focused on the evaluation and comparison of damping values of the microseismic signals over time, did not showed notable results for the test site monitored. On the other hand, the application of such a technique for microseismic datasets acquired on rock masses subjected to recurrent and intense external vibrations, as those located in proximity of the infrastructures, is promising for deepening knowledge in the evaluation of changes related to the dynamical behaviour of the monitored rock mass system.

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