MICROSEISMIC MONITORING OF AN UNSTABLE ROCK FACE: PRELIMINARY EVENT LOCATION

Z. Zhang[1], D. Arosio[2], A. Hojat[3,1], L. Zanzi[1]

[1] *Dipartimento di Ingegneria Civile e Ambientale, Politecnico di Milano, Milano, Italy*

[2] *Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Modena, Italy*

[3] *Department of Mining Engineering, Shahid Bahonar University of Kerman, Kerman, Iran*

Introduction. Microseismic monitoring has been increasingly used in rockfall studies in the last two decades. Event location is one of the basic processes in microseismic monitoring, following signal recording and signal classification. Event location is an interesting field of research that has been investigated in several studies. For instance, Spillmann *et al*. (2007) used a nonlinear probabilistic localization algorithm based on nested-grid search (Lomax *et al*., 2000) to determine the hypocenter parameters. Colombero (2017) also adopted this localization algorithm using the oct-tree importance sampling method (Lomax and Curtis, 2001). Events were routinely located by Helmstetter and Garambois (2010) within a uniform velocity model. In these rockfall-related cases, the location procedure encounters several difficulties: (1) Heterogeneous distribution of P wave velocity; (2) Inaccurate first arrival picking; (3) Undistinguishable P and S waves; (4) Proper localization algorithm. Our research aims at tackling some of the abovementioned difficulties and focuses on Mount San Martino rock cliff (northern Italy), where a microseismic monitoring system has been installed since 2013. An automatic classification scheme is now working on this system to select microseismic events related to the stability of the rock mass. In this work, we present the preliminary results on event location related to trigger tests performed before a tomographic survey and an event location exercise with a uniform velocity model.

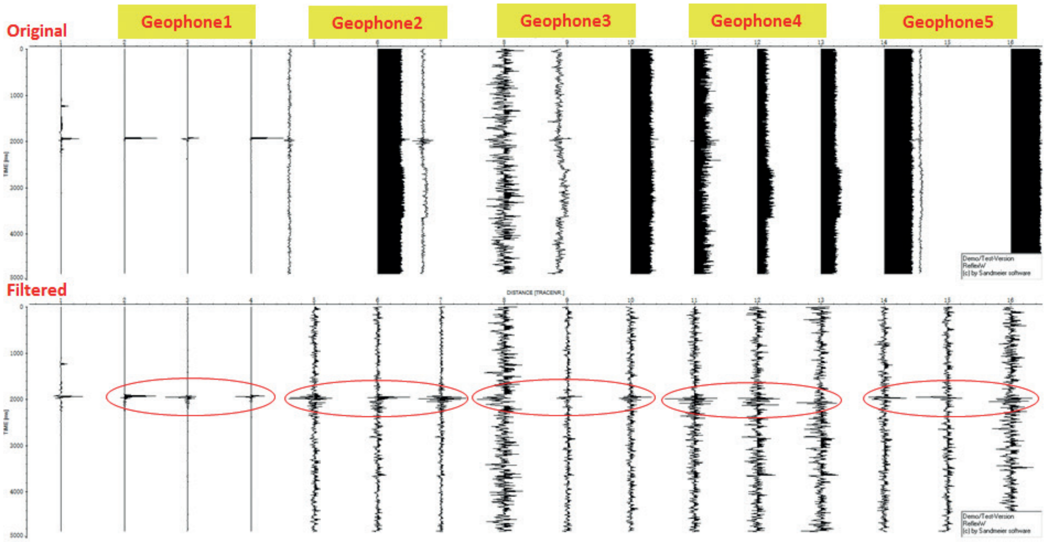

Fig. 1 - Recordings of each channel before and after filtering.

Trigger tests for the tomographic survey. Detailed velocity information is a basic requirement for reliable location of earthquakes in heterogeneous media, and seismic tomography is a helpful tool to estimate the velocity distribution. In our case-study, a well-designed tomographic survey necessitates a suitable source to be employed in order to trigger all the five three-component geophones installed on the unstable rock slope. For this reason, we planned three field tests on the top of the rock face and a hammer, firework charges and a seismic gun were selected to compare their capability to trigger the geophones. The first two tests using the hammer and firework charges have been carried out. The last test is supposed to be performed in near future. The results of the first two tests are discussed below.

In the test performed with the hammer, 16 channels (1 for triggering and 15 for recording the three component signals from the 5 geophones) were used to record the data with 1 kHz sampling frequency. The minimum duration of recording was set to 5 s, including a 2 s pre-trigger window. Five hits were performed at the same hit point located close to the hole in which geophone 1 has been installed. Collected data were filtered using Reflexw software, and the processing involved DC removal, band-pass Butterworth filtering with band 5-100 Hz and notch filtering with frequency of 25 Hz, 50 Hz, 75 Hz and 100 Hz. Fig. 1 shows the recordings before and after filtering for one hammer hit. Tab. 1 summarizes the results for different channels; 'Y' indicates that the channel has sensed the signal and 'N' indicates that the signal has not been sensed by the channel.

Tab. 1 - Performance of each channel to sense the signal for different hits performed with the hammer.

Trace no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Channel	Trig	1X	1Y	1Z	2X	2Y	2Z	3X	3Y	3Z	4X	4Y	4Z	5X	5Y	5Z
Hammer1	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	N	N
Hammer2	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N
Hammer3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hammer4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hammer5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

The test using firework charges was also performed on the top of the rock face using the same channels and the same sampling frequency, but the shots were triggered in 8 different positions near geophone 1 and geophone 2. Charges were fired in natural surface cavities or fractures. Filtering was applied as in the previous test, except for the notch filter, since no harmonic noise was disturbing these records. Tab. 2 summarizes the results for all the employed channels.

Comparing the results of the two tests, it is obvious that the hammer has a better performance than firework charges. Using the hammer, except a few channels for Hammer 1 and Hammer 2 hits, all the 5 geophones record the vibrating signals, while for the trigger test with firework charges, all the 5 geophones could record the signals only in Explosion 3. Therefore, by now hammer is the preferred source for the tomographic survey.

Tab. 2 -Performance of each channel to sense the signal for different shots performed with firework charges.

Trace no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Channel	Trig	1X	1Y	1Z	2X	2Y	2Z	3X	3Y	3Z	4X	4Y	4Z	5X	5Y	5Z
Explosion1	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Explosion2	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Explosion3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	N
Explosion4	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	N	N	N
Explosion5	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N
Explosion6	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N
Explosion7	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Explosion8	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N

Event location with a uniform velocity model. The seismic source localization algorithms have been reviewed by considering the most common earthquake location techniques. The probabilistic, non-linear, global-search earthquake location method, implemented in the NonLinLoc software (Lomax *et al*., 2009), was used in this work. Since no velocity information was available, event location was performed to preliminarily test the accuracy of this method, and the data from the trigger test with the hammer were used.

For the Probabilistic Density Function (PDF), the Equal Differential Time (EDT) likelihood function was used to estimate the event location. The standard deviation of the uncertainties for observed arrival time and calculated travel time at each observation was assumed to be 4.5 ms. We manually picked the P-wave first arrival to obtain the observed arrival time, while travel time calculation was based on the assumption that the ray path between the source and the receiver is a straight line, instead of considering the Eikonal finite-difference scheme. The simple grid search method was used for travel time calculation. The 3D grid model was derived from the Digital Terrain Model (DTM) of the rock face, having size 200×200×200 m and 100 nodes in each direction. A constant velocity is assigned to the geometric model. According to the typical values of P-wave and S-wave velocities (Hardy and Reginald, 2005), we assumed P-wave velocity in limestone to be 3200 m/s, and we set the velocity in the air to 331 m/s to take into account the area of the model above the DTM surface.

The estimated source position was determined by the grid node having the maximum value of the PDF. The result of event location is shown in Fig. 2. The five hammer hits are located next to the real hit point and detailed location information can be found in Tab. 3. The coordinates of the 5 analyzed events are the same along the X- and Y-axis and show a minor variation along the Z direction of just 2 m, i.e. one grid spacing. In terms of the average error in each direction, Y direction has the minimum error value and Z direction shows the largest error, but all the 1D average error values are within one grid spacing. For the 3D error, the average value is only

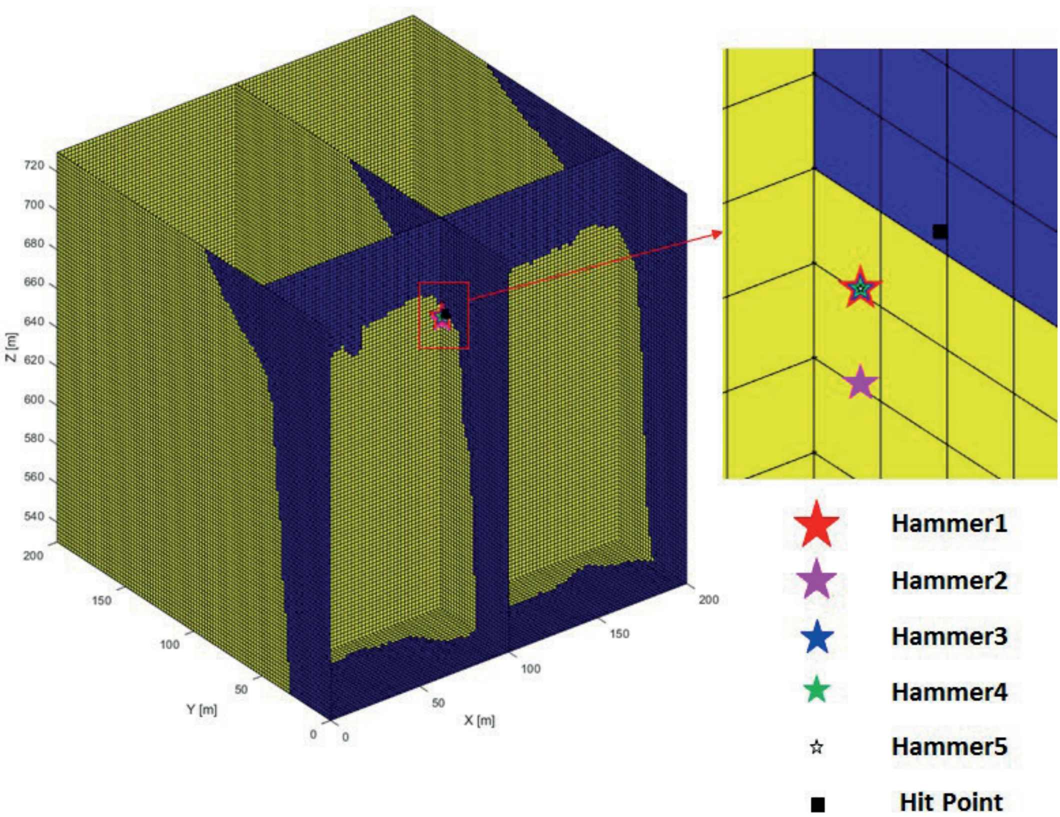

Fig. 2 - Location of events from five hammer hits with the uniform velocity model. Stars in different colors named "Hammer n" indicate the estimated source positions for the hammer hits, while the black square is the real hit position, apparently in the air due to the 2m discretization of the model, actually on the rock surface

2.29 m within one grid spacing in 3D. Therefore, although the grid spacing affects the precision of location, the error of the location is acceptable and limited to one grid spacing. This shows the accuracy of the applied location algorithm.

Tab. 3 - Summary of the location results for the hammer hits.

	X [m]	Y [m]	Z [m]	3D error [m]
Hit position	99.079	44.991	683.2864	-
Hammer1	98	46	682	1.96
Hammer2	98	46	680	3.60
Hammer3	98	46	682	1.96
Hammer4	98	46	682	1.96
Hammer5	98	46	682	1.96
Average error	1.079	-1.009	1.6864	2.29

Conclusions. We have performed a preliminary study on microseismic event location considering a monitoring system deployed on a rock cliff in northern Italy. With the aim of exploring the most suitable source for a planned tomographic survey, we performed some trigger tests using a hammer and firework charges. The results showed that the hammer performs better than the firework charges as more geophones can record the source signal. Proper design of selective filters is absolutely necessary to detect the events since high frequency noise (above 100Hz), and in some instances harmonic noise, strongly disturb the records. Since there is no velocity model available for the studied rock cliff, the event location exercise was carried out using a constant velocity model. Although the grid spacing affects the accuracy of location, the result is still satisfactory and the error is limited to one grid spacing. However, the results cannot be considered as a prediction of the expected accuracy since the position of the source was very close to one of the geophones, but, to some extent, the test shows that the location algorithm is robust. The research is still in progress and a triggering test with a modified seismic gun is planned in the near future to take a final decision on the source to be used for the tomographic survey. During tomographic survey, 24 to 48 additional 1C geophones will be deployed on the top of the rock cliff and the source point will be moved to several different positions to explore the unstable rock mass from different directions in order to constrain as much as possible the reconstruction of the 3D velocity model.

References

Colombero C.; 2017: *Microseismic strategies for characterization and monitoring of an unstable rock mass*, PhD Thesis.

Hardy Jr, Reginald H.; 2005: *Acoustic emission/microseismic activity: volume 1: principles, techniques and geotechnical applications*. Vol. 1. CRC Press.

Helmstetter A., and Garambois S.; 2010: *Seismic monitoring of Séchilienne rockslide (French Alps): Analysis of seismic signals and their correlation with rainfalls*, J. Geophys. Res. Earth Surf., 115(F3), F03016.

Lomax A., Virieux J., Volant P. and Berge C.; 2000: *Probabilistic earthquake location in 3D and layered models: Introduction of a Metropolis-Gibbs method and comparison with linear locations, in Advances in Seismic Event Location*, edited by C. H. Thurber and N. Rabinowitz, Kluwer, Amsterdam, 101-134.

Lomax A. and Curtis A.; 2001: *Fast, probabilistic earthquake location in 3D models using oct-tree importance sampling*. Geophys Res Abstr 3:955.

Lomax A., Michelini A., Curtis A.; 2009: *Earthquake Location, Direct, Global-Search Methods, in Complexity In Encyclopedia of Complexity and System Science*, Part 5, Springer, New York, 2449-2473, doi:10.1007/978-0-387-30440-3.

Spillmann T., Maurer H., Green A. G., Heincke B., Willenberg H. and Husen S.; 2007: *Microseismic investigation of an unstable mountain slope in the Swiss Alps*, J. Geophys. Res., 112(B7), B07301.