Seismic signature of mudflow tremor resulted from Brumadinho (Brazil) tailings dam failure

http://dx.doi.org/10.1590/0370-44672019730040

Yawar Hussain[1,8]
https://orcid.org/0000-0002-4155-6764
Omar Hamza[2,9]
https://orcid.org/0000-0002-5048-0423
Xinghui Huang[3,10]
https://orcid.org/0000-0002-0493-1350
André Carlos Silva[4,11]
https://orcid.org/0000-0002-9760-0728
Cristobal Condori[5,12]
https://orcid.org/0000-0003-2657-147X
Rogério Uagoda[6,13]
https://orcid.org/0000-0002-9448-1313
André Luís Brasil Cavalcante[7,14]
https://orcid.org/0000-0003-4980-1450

[1]Environmental Engineering and Earth Science Department, 445 Bracket Hall, Clemson University, Clemson, SC, 29634, United States.

[2]University of Derby - College of Engineering and Technology, Derby - Derby DE22 3AW, United Kingdom of Great Britain and Northern Ireland.

[3]China Earthquake Networks Center, Beijing – Beijing, 100045 China.

[4]Universidade Federal de Goiás - UFG, Faculdade de Engenharia, Catalão – Goiás - Brasil.

[5]Universidad Nacional de San Agustín de Arequipa, Departamento Académico de Geología y Geofísica, Arequipa – Arequipa – Perú.

[6]Universidade de Brasília - UnB, Departamento de Geografia, Brasília - Distrito Federal - Brasil.

[7]Universidade de Brasília - UnB, Departamento de Engenharia Civil e Ambiental, Brasília - Distrito Federal - Brasil.

E-mails: [8]yawar.pgn@gmail.com, [9]O.Hamza@derby.ac.uk, [10]huangxh19850216@gmail.com, [11]ancarsil@ufg.br, [12]ccondoriquis@unsa.edu.pe, [13]rogeriouagoda@unb.br, [14]albrasilc@gmail.com

Abstract

Mudflow is often associated with seismic activities. The present study applied a seismic based detection of the surface waves generated by the mudflow of Brumadinho dam collapse using records of Brazilian Seismographic Network. The signal envelope and time-frequency spectrograms of the mudflow signals were used in the analysis. As a result, the mudflow signals were successfully detected from the data recorded at a nearby seismic station. The findings of this study provide a good basis for future research to develop a flood early warning system based on cost-effective, remote and contentious seismic monitoring approaches.

Keywords: envelope; spectrogram; flood early warning system.

1. Introduction

The more frequent rainfall due to climate change is a worldwide problem as it may cause floods, debris and mudflow, which have disastrous impacts on the lives and property of downstream residents. In general, sediment transportation associated with floods is an important driving force in channel morphology and therefore has a wide range of applications in the field of landscape evolution, ecology, water quality, land use management, and civil and river engineerings, such as dams and recreational reservoir silting (Stall *et al*., 1958). The remote seismic detection of these events may help in the development of early flood warning systems and possible quantification of the sediments.

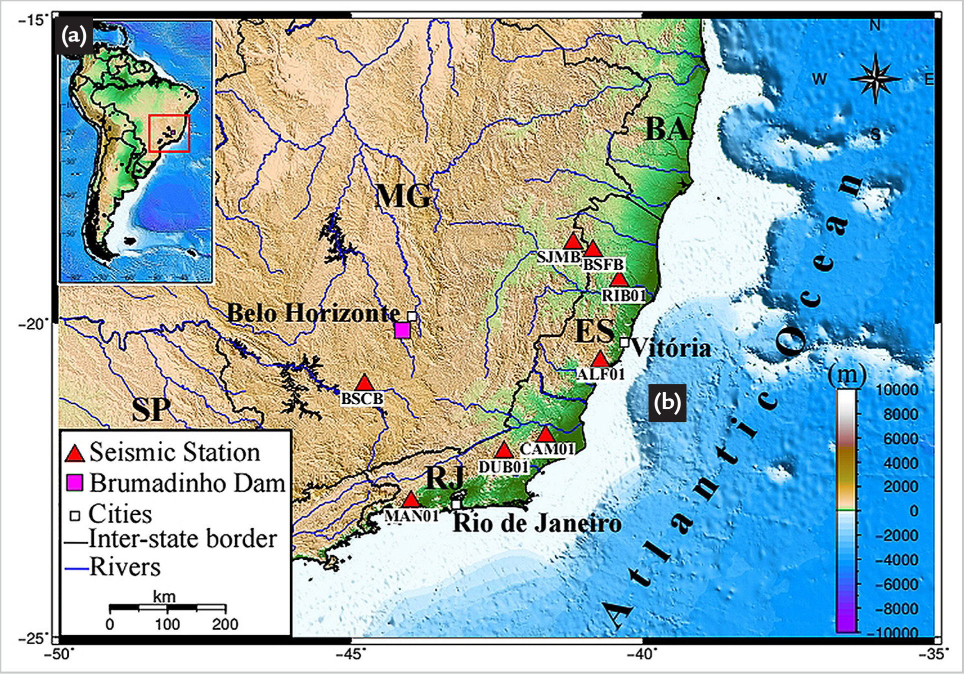

Figure 1 - Location map: (a) shows location within South America, the State of Minas Gerais enclosed in red rectangle. (b) Map shows the locations of dam site and seismometers used in the analysis.

Different attempts have been taken in the field of fluvial seismology for the detection and quantification of seismic signals generated by the fluvial processes (e.g., Burtin *et al*., 2011; Hsu *et al*., 2011; Schmandt *et al*., 2013; Barrière *et al*., 2015; Chao *et al*., 2015; Roth *et al*., 2016; Vázquez *et al*., 2016; Anthony *et al*., 2018; Goodling *et al*., 2018). These findings support the use of seismic emission for the high-resolution monitoring of river bedload and other flow attributes. In the previous studies, the attempts were also made for the seismic characterization of the signals generated by the massive mudflow, including frequency distribution modeling and Doppler effect estimation (Huang *et al*., 2019).

The present study applied analysis on the mudflow signals generated by the recent dam collapse of Brumadinho, based on the methodology adopted by Augurto-Detze *et al*. (2016). On 25 January 2019, around 12:28:20 P.M. local time (UTC-14:28:20), a tailings dam in the Córrego do Feijão Mine, in Brumadinho, state of Minas Gerais, Brazil (Figure 1), collapsed releasing more than 13 million cubic meters of water and mine waste, which led to about 300 fatalities (Petley, 2019). The surface waves generated by the mudflow at a known time (video recording) and space were used as a priori information in checking the reliability of the detections of these events at the regional seismic network. The causes of the dam collapse are out of the scope of the present study.

2. Methodology

The mudflow envelope was generated in software Seismic Analysis Code (SAC) using the processing steps adopted by Augurto-Detzel *et al*. (2016). The calculated envelope indicated the average absolute amplitude of the vibrations. Spectrograms for the records during the event were calculated using the S-transform (Stockwell *et al*., 1996; Stockwell, 2007). The data were recorded with Trillium 120p seismometers and Taurus datalogger of Nanometrics Inc (Bianchi *et al*., 2018). Details can be found at http://www.rsbr.gov.br.

3. Results and Discussions

The seismic signals generated by the mudflow are used for the analysis of the records at the nearby seismometers at the time of the collapse. These mudflow signals lasted for about 2 minutes, as evident from the envelope of the signal calculated at the nearest station BSCB (Figure 2). Different ascending and descending peaks can be seen, which may be related to different factors including effects of the topography of the region, the collapse of a railway bridge and other structural collapses. The signals finally diminish as the flooding speed decreases while flowing through the river. As the calculated seismic amplitude has a direct relationship with the discharge of the debris flow (Huang *et al*., 2008; Goodling *et al*., 2018, Anthony *et al*., 2018). There are other small unknown events which may be created by mining blasts or small magnitude regional earthquakes.

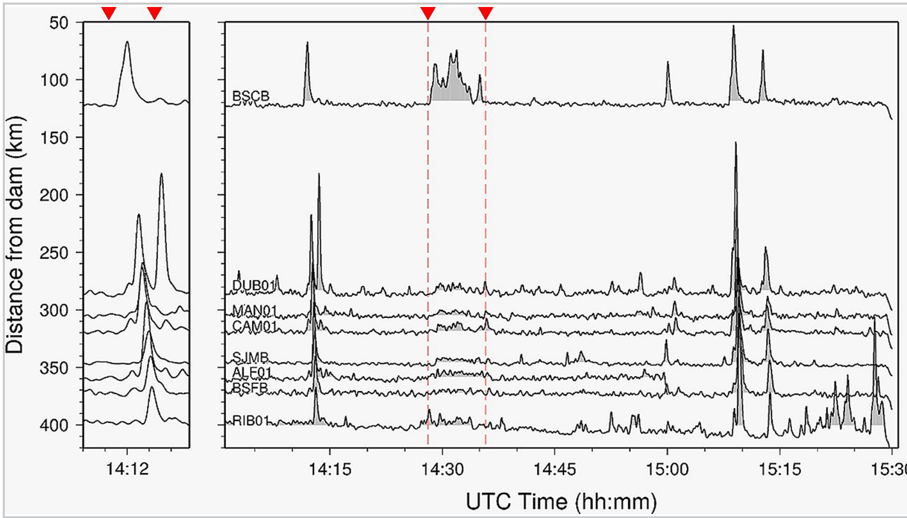

Figure 2 - Seismic envelope of the signal produced by the mudflow. The envelope of events (the events' time indicated by red triangles). The red triangles on left indicate an unknown zoomed event around 14:12h.

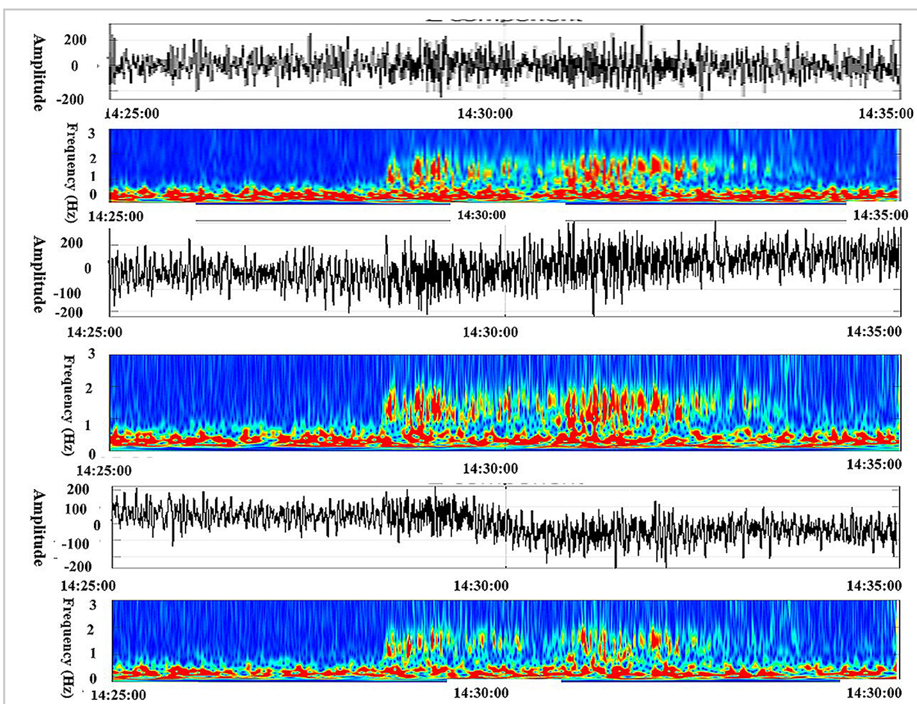

Figure 3 - From top to bottom: Z-component, N-component and E-component spectrograms of station BSCB generated during the mudflow event.

The energy bursts can also be observed in amplitude power spectrograms of three-component records from a nearby station (BSCB) which show that the maximum mudflow amplitude content in the frequency domain is observed up to 2 Hz (Figures 3). These results are consistent with the findings of a previous case study on dam collapse in the area (Augurto-Detzel *et al*., 2016). In the spectrogram, the onset time, as well as frequency content, is quite clear. The signal energy is more prominent on the vertical and north components, while its amplitude is low at the east component. Because the recording was done at a distinct seismometer, the spectrogram shows a very narrow frequency range as frequencies are attenuated with distance from the source (Figure 3), and this was also found in a previous study by Burtin *et al*. (2009).

4. Conclusions and Recommendations

The possible seismic signals generated by the turbulent mudflow of the recent collapse of Brumadinho dam were analyzed by the seismic signal envelope and time-frequency spectrogram. By using this methodology, the onset and frequency contents of mudflow were detected from the remote seismometer data. The mudflow was well detected on the envelope and was found more prominent on the nearby station (BSCB) which installed almost ~120 km away from the dam.

The following findings and conclusions can be obtained from the study: (i) Spectrogram of the event recorded at the nearby station showed that its frequency was below 2 Hz. (ii) The results of the present study are consistent with the previous similar study on tailings dam failure in the area (Augurto-Detzel et al., 2016).

The regional seismic network (used in the present study) can detect events of strongest energies. However, for the monitoring of small energy events, dense temporarily seismic networks of short-period arrays can fill the gap of missed seismicity. The higher frequencies are attenuated because of the long distance between sources and receivers. Under these conditions, it is not possible to determine the frequency distribution model of the event, which explained the force applied by the mudflow generated signals. This analysis is recommended for future studies where sensors should be placed near the dam site.

Acknowledgments

The authors would like to thank Dr. Marcelo Bianchi (University of São Paulo) for sharing the codes used for the calculation of signal envelope. This study was financed in part by the Coordination for the Improvement of Higher Education Personnel – Brasil (CAPES) – Finance Code 001. The authors also acknowledge the support of the National Council for Scientific and Technological Development (CNPq Grant 304721/2017-4), and the University of Brasília.

References

ANTHONY, R. E.; ASTER, R. C.; RYAN, S.; RATHBURN, S.; BAKER, M. G. Measuring mountain river discharge using seismographs emplaced within the hyporheic zone. ***Journal of Geophysical Research: Earth Surface,*** v. 123, n. 2, p. 210-228, 2018.

AUGURTO-DETZEL, H.; BIANCHI, M.; ASSUMPÇÃO, M.; SCHIMMEL, M.; COLLAÇO, B.; CIARDELLI, C.; CALHAU, J. The tailings dam failure of 5 November 2015 in SE Brazil and its preceding seismic sequence. ***Geophysical Research Letters,*** v. 43, n. 10, p. 4929-4936, 2016.

BARRIÈRE, J.; OTH, A.; HOSTACHE, R.; KREIN, A. Bed load transport monitoring using seismic observations in a low gradient rural gravel bed stream. ***Geophysical Research Letters,*** v.42, n.7, p. 2294-2301, 2015.

BIANCHI, M. B.; ASSUMPÇÃO, M.; ROCHA, M. P.; CARVALHO, J. M.; AZEVEDO, P. A.; FONTES, S. L.; DIAS, F. L.; FERREIRA, J. M.; NASCIMENTO, A. F.; FERREIRA, M. V.; COSTA, I. S. L. The Brazilian Seismographic Network (RSBR): improving seismic monitoring in Brazil. ***Seismol. Research Letters,*** v.89, p.452–457, 2018.

BURTIN, A.; BOLLINGER, L.; CATTIN, R.; VERGNE, J. Spatiotemporal sequence of Himalayan debris flow from analysis of high-frequency seismic noise. ***Journal of Geophysical Research: Earth Surface,*** v. 114, n. F4, 2009.

BURTIN, A.; CATTIN, R.; BOLLINGER, L.; VERGNE, J.; STEER, P.; ROBERT, A.; TIBERI, C. Towards the hydrologic and bed load monitoring from high-frequency seismic noise in a braided river: The "torrent de St Pierre", French Alps. ***Journal of hydrology,*** v. 408, n. 1-2, p. 43-53, 2011.

CHAO, W. A.; WU, Y. M.; ZHAO, L.; TSAI, V. C.; CHEN, C. H. Seismologically determined bedload flux during the typhoon season. ***Scientific reports,*** v.5, n. 8261, 2015.

GOODLING, P. J.; LEKIC, V.; PRESTEGAARD, K. Seismic signature of turbulence during the 2017 Oroville Dam spillway erosion crisis. ***Earth Surface Dynamics,*** v. 6, n. 2, 2018.

HSU, L.; FINNEGAN, N. J.; BRODSKY, E. E. A seismic signature of river bedload transport during storm events. ***Geophysical Research Letters,*** v. 38, n. 13, 2011.

HUANG, C.-J.; YEH, C.-H.; CHEN, C.-Y.; CHANG, S.-T. Ground vibrations and airborne sounds generated by motion of rock in a river bed. ***Natural Hazards and Earth System Sciences,*** v. 8, n. 5, p. 1139–1147, 2008.

HUANG, X.; LI, Z.; FAN, J.; YU, D.; XU, Q. Frequency Characteristics and Numerical Computation of Seismic Records Generated by a Giant Debris Flow in Zhouqu, Western China. ***Pure and Applied Geophysics,*** v. 177, n. 1, p.347, 2020.

OLIVIER, G.; BRENGUIER, F.; DE WIT, T.; LYNCH, R. Monitoring the stability of tailings dam walls with ambient seismic noise. ***The Leading Edge,*** v.36, n.4, p. 350a1-350a6, 2017.

ROTH, D. L.; BRODSKY, E. E.; FINNEGAN, N. J.; RICKENMANNI, D.; TUROWSKI, J.; BADOUX, A. Bed load sediment transport inferred from seismic signals near a river. ***Journal of Geophysical Research,*** v. 121, n. 4, p. 725-747, 2016.

SCHMANDT, B.; ASTER, R. C.; SCHERLER, D.; TSAI, V. C.; KARLSTROM, K. Multiple fluvial processes detected by riverside seismic and infrasound monitoring of a controlled flood in the Grand Canyon. ***Geophysical Research Letters,*** v. 40, n.18, p. 4858-4863, 2013.

STOCKWELL, R. G. A basis for efficient representation of the S-transform. ***Digital Signal Processing,*** v. 17, n. 1, p. 371-393, 2007.

STOCKWELL, R. G.; MANSINHA, L.; LOWE, R. Localization of the complex spectrum: the S transform. ***IEEE Transaction on Signal Processing,*** v. 44, n. 4, p. 998-1001, 1996.

VÁZQUEZ, R.; SURIÑACH, E.; CAPRA, L.; ARÁMBULA-MENDOZA, R.; REYES-DÁVILA, G. Seismic characterisation of lahars at Volcán de Colima, Mexico. ***Bulletin of Volcanology,*** v. 78, n. 2, 2016.

Received: 20 November 2019 - Accepted: 2 April 2020.

CC BY All content of the journal, except where identified, is licensed under a Creative Commons attribution-type BY.