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SEISMIC MONITORING FOR POTENTIAL LOCAL LANDSLIDE: A CASE STUDY OF THE BABAOLIAO SITE IN TAIWAN

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Abstract

Landslide is a major natural hazard on unstable steep slopes. We deploy three low-cost seismic sensors, Raspberry Shake (RS) seismometer, in an experiment site at Babaoliao in Chiayi, Taiwan and investigate the performance of the low-cost seismic sensor for monitoring the vibrations producing by outside sources (e.g., earthquakes and rainfall) and possible internal sources (e.g., tremor and precursor signal of a landslide). Potential size of a landslide in the experiment site approximates to 10 ha, which was estimated from satellite and unmanned aerial vehicle (UAV) images. We have developed a hydraulic and hydrogeological survey to monitor potential precursor factors of pre-sliding in the experiment site for two years. Other than the survey above, seismic monitoring may provide a different view for studying sliding by monitoring vibrations. The sensor we deployed for detecting vibrations is the RS-3D including three-component, short-period geophones with the natural frequency of 4.5 Hz. The sampling rate of the records is 100 points per second. We transmit the data to the cloud storage system through a mobile 4G network and backup them in local storage. The power supply is provided by solar panels. An automatic recording and transmitting system is implemented to collect and archive continuous data. Preliminary analyses show that we have the capability to identify seismic signals caused by rainfalls and earthquakes from the continuous records. We also catch other unknown events that may be related to sliding at the site showing at three stations simultaneously. Our final goal is to understand the characteristics of vibrations and evaluate possible relations between vibrations and other hydraulic and hydrogeological factors within the area of potential landslides.

Keywords: Seismic monitoring, Raspberry Shake, Landslide

1. Introduction

A proximately 70% of land in Taiwan is covered by mountains, therefore, the potential threat of landslides becomes inevitable. Traditionally, geotechnical surveys were done for the mechanical behavior of landslides. Geotechnical monitoring technology is available to investigate mechanisms of break processes, deformation process, delimiting boundaries, and potential slip surfaces for various types of landslides. Hydrological, climatic, geomorphological, and geophysical parameters are usually seen to be the key monitoring factors to evaluate the potential risk [1] [2]. The final goal is to develop appropriate approaches for the prevention and mitigation of the slope disaster. Investigation of landslide signals using seismometers started from the early 20th Century. Spectral analysis can be employed to detect and characterized landsides [3]. Through spectral analysis of specific waveform patterns, several studies depict a frequency content of 1-30 Hz for rockfalls and landslides [4] [5] [6]. Additionally, precursory patterns of landslides have also been observed by the seismic analysis [7] [8], suggests that the applicability of seismic monitoring to determining variations from potential sliding events should be an alternative tool for the mitigation of landslide hazards.

Furthermore, geophysical surveys with both invasive and noninvasive methods were previously conducted to preliminarily understand the hydrogeological characteristics of a landslide area and locate potential failure surfaces to strengthen slope failure prevention. Poorly cemented marlstone causes potential surface rupture surface [9]. Thus, heavy rainfall would cause slope instability increasing, then, induce sliding events.

In the present study, we focus on a potential landslide area in Babaoliao in Chiayi County in Taiwan. The potential sliding region distributes in the altitude ranging from 404 to 550 m. Potential size of the landslide in the experiment site approximates to 10 ha determined by the unmanned aerial vehicle (UAV). The current seismic network with 3 stations has been deployed on the boundary of the potential sliding area for detecting vibration signals since June 2019 (Fig. 1). The background is a UAV image. In this study, we investigate the performance of the low-cost seismic instrument and analyze the records to detect the potential signals from local landslides. In addition, our preliminary aim is to contribute to a comprehensive database of classified signals for this specific site. The final goal is to understand the characteristics of vibrations and evaluate possible relations between vibrations and other hydraulic and hydrogeological factors within the area of potential landslides.

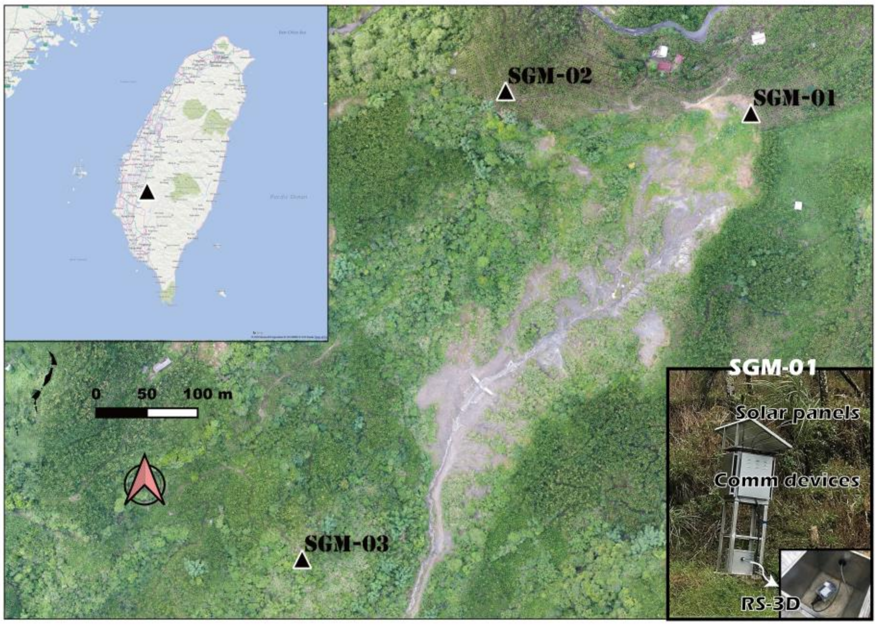

Fig. 1 – Layout of seismic stations

2. Seismic Instrument

The seismic instrument we deployed at the site is Raspberry Shake RS-3D. It includes a three-component, short-period geophone combination with the natural frequency of 4.5 Hz and a three-component microelectromechanical systems (MEMS) accelerometer set with a broader frequency bandwidth. It costs approximately USD $1000. An instrumented test of the geophone of Raspberry Shake RS-4D (the type with one vertical geophone) was done in Anthony et al.'s study to reveal the sensor performance. Comparing to the broadband sensor of Nanometrics Trillium Compact 120 s, the geophone has similar self-noise levels. However, the RS-3D MEMS accelerometer has obvious higher self-noise levels up to 0.3 gal [10]. Taruselli et al. (2019) utilized the Nanometrics Trillium Compact 20 s to assess the performance of RS-3D geophones [11]. The preliminary test showed that it is suitable to detect the fundamental frequency of unstable rock blocks, especially in a frequency band of 1 to 15 Hz. We thus only adopted the geophones to evaluate the signal characteristics.

In this study, the current seismic network comprises three RS-3Ds. The analog ground motion is digitized with a 24-bit analog-to-digitizer (ADC). The data is sent out and processed in miniSEED format. Flate frequency response from around 0.5 to 40 Hz. Time correction is done by the Network Timing Protocol (NTP) with GPS timing supported. Comprehensive information for the seismograph could be found from the speculations of Raspberry Shake 3D at the website [12]. The power supply is provided by solar panels. The sampling rate is 100 points per second. The data are transmitted to the cloud storage system through a mobile 4G network automatically and have a backup on the local site. It has operated in June 2019. The basic information of stations shows in Table 1.

Table 1 – Station information

Sta_ID	X*	Y*	RS_ID	RS_Type	Start_time	RS_Status
SGM-01	120.5300	23.3534	R351B	RS-3D	2019/06/19	on site ground
SGM-02	120.5233	23.3536	R55F8	RS-3D	2019/06/03	on site ground
SGM-03	120.5214	23.3494	RD678	RS-3D	2019/06/17	on site ground

* The coordinate system of TWD97 used in Taiwan

3. Detection and Classification of seismic events

We identify seismic events manually from the continuous seismic records. Then amplitude of each record is converted from count to a physical unit of ground motion (m/s/s) using the corresponding transfer function of the equipment. According to the shapes of waveforms, we classify the event into three groups: earthquake events, rainfall signals, and other events. The signals of other events will be achieved for future advanced classification (potential sliding events and man-made signals and so on). A procedure shows the flowchart in Fig. 2.

Taiwan Rapid Earthquake Information Release System developed by the Central Weather Bureau (CWB) has been operated since 1996. Local and regional earthquakes with magnitude larger than 4.0 have been located and announced. We pick up earthquake events by comparing the catalog released by CWB and our own catalog by the event detection. Furthermore, rainfall data from a rain gauge station deployed near the study area was applied. A signal related to a rainfall event can be easily identified. Other events include all signals we cannot correlate with any known events. We may find the potential signals for the landslides and rockfalls in this group.

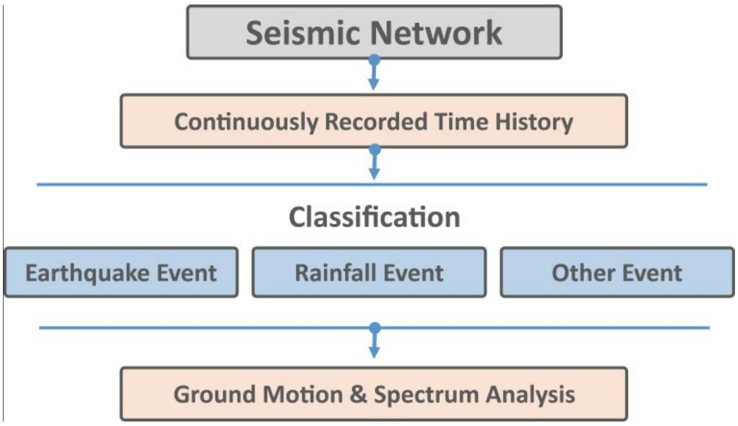

Fig. 2 – Scheme of event signal detection and classification

4. Observation Results

The classified results are represented in the following. We choose cases with signals induced by an earthquake, a rainfall event, and other events. Time history and spectrum reveal the different characters among them in frequency and time domain.

4.1 Earthquakes event

The CWB announces a report by the Earthquake Rapid Reporting System after the occurrence of earthquakes in the Taiwan region. The location, time and magnitude offer in the report. According to the occurrence time and epicenter distance between the earthquake location and our site, we estimate the arrival time and dig out the corresponded trace. Then, we calculate the peak ground acceleration (PGA) of three stations from the time history of each earthquake and represent the PGA with time as Fig. 3. We can see almost all earthquake report from CWB can be detected by our network, even an earthquake with magnitude of 3.0 and < 100 km. The performance of RS-3D is good enough to detect local earthquakes. However, sometimes regional earthquakes can not be detected when the magnitude is too small.

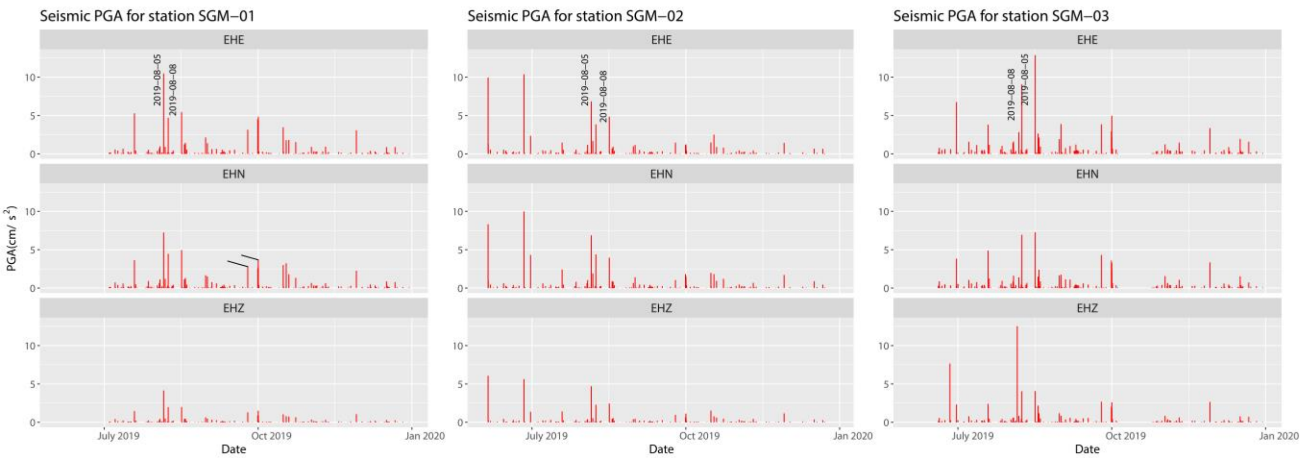

Fig. 3 – Peak Ground Acceleration of each earthquake with the period from June 3 to December 31, 2019

Fig. 4 shows three-component seismograms of local and regional earthquakes recorded at three stations. The corresponding spectra are given in an amplitude scale of dB. We can identify P- and S-wave phases in an earthquake record, and their amplitudes are different in both vertical and horizontal components. Signals of local earthquakes conduct higher frequency and shorter duration. On the contrary, the ones of regional earthquakes perform lower frequency and longer duration.

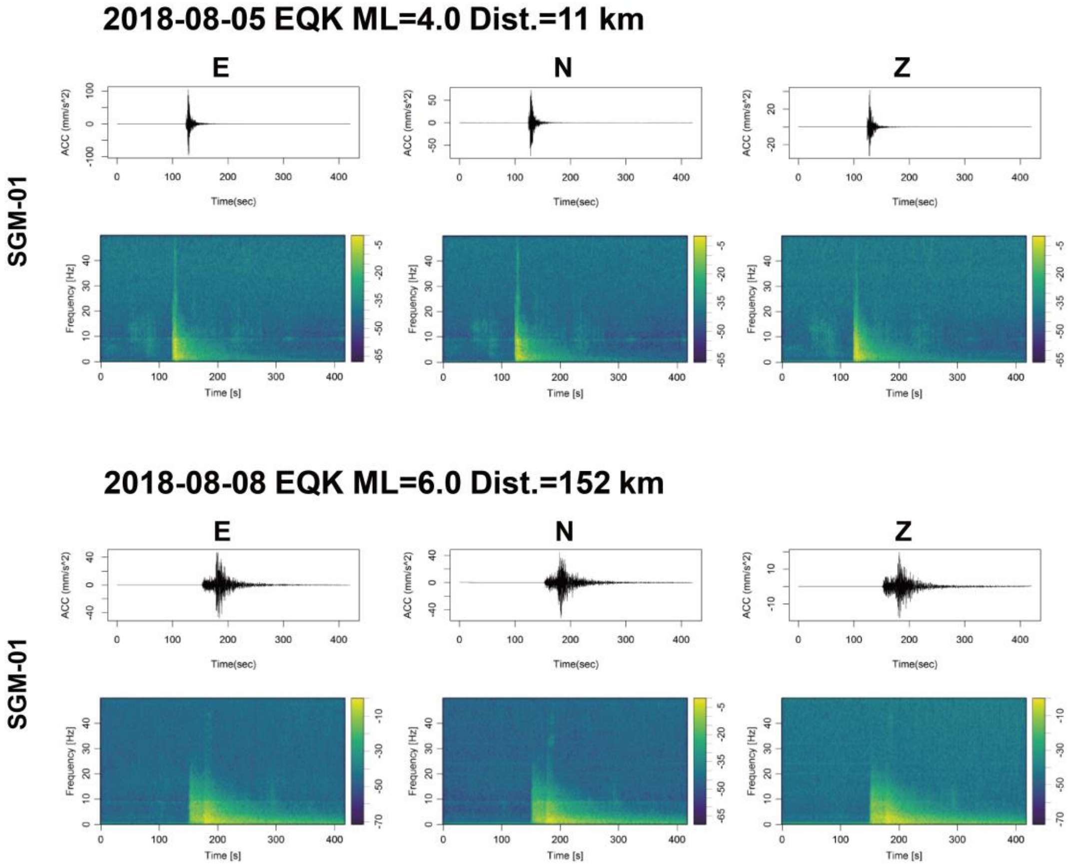

Fig. 4 – Time history and spectrum of SGM-01 station of near- and far-field earthquake events

4.2 Rainfall event

A rainfall gauge station deployed in the site to measure precipitation with a 10-min interval. A rainfall event can be easy to capture by the data from the rainfall gauge. We recognize that a time history of PGA standard deviation (SD) in three components seems to have a high correlation to rainfall data and can assist to determine signals related to rainfall events. For instance, a heavy rainfall event occurred on July 24, 2019, correlates to the SD of PGA and time history very well (Fig. 5).

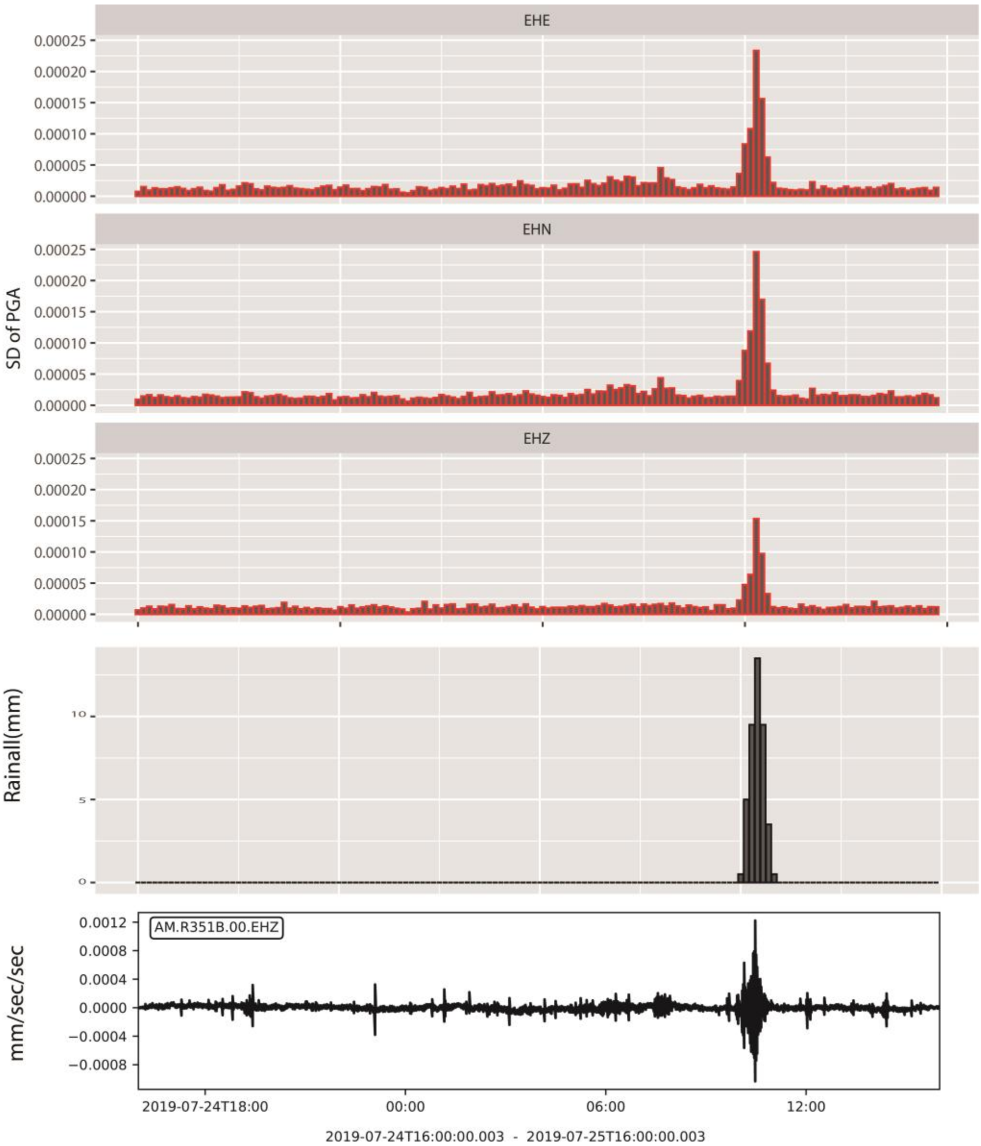

Fig. 5 – Comparison of a rainfall event and its vibration of time history

4.3 Other event

We identify a number of signals which do not correlate to earthquake and rainfall events. Although some signals are not shown in an earthquake report, we can still discriminate them as earthquake signals by P- and S-wave phases. We expect they are local earthquakes that cannot trigger the CWB seismic network. Those local earthquake events could be compiled for understanding the background pattern of nearby seismic seismicity. Some of the events were only recorded at one station and amplitudes are small (< 0.1 gal), suggesting that the source is close to the station. They are probably related to local noises (e.g., wildlife and human activities). We thus focus on the signals that were recorded at three stations simultaneously. Case01 and Case02 of other events are shown in Fig. 6 and Fig. 7. Arrival times of signals are different at the three stations for the Case01. We can see that the signal arrives at the SGM-02 firstly. The duration is about 5 s. The frequency content of the event is from 10 to 40 Hz. However, the lower frequency content of 2 to 30 Hz occurs at the SGM-03.

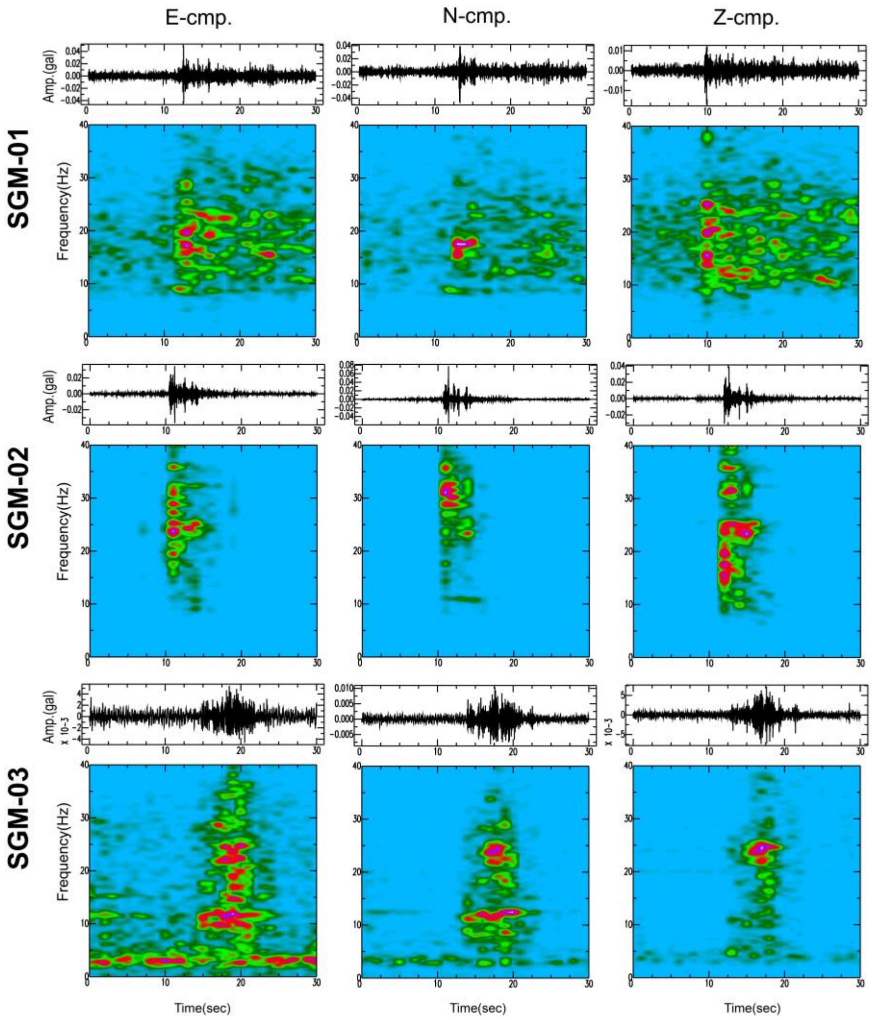

Fig. 6 – Time history and spectrum for the Case01 of other events

The arrival time is almost the same for the Case02. It means that the source is far away from the main sliding region or in the middle of the network. This event contains the wave with a frequency band < 10 Hz. The duration of the event in the horizontal and vertical components is about 25 s and 5 s, respectively. The Case02 is similar to the definition of ‘quakes’ and ‘rockfalls/debris flows’ in the papers of Helmstetter and Garambois (2010) which are associated with the dynamics of landslides [5]. Tonnellier et al, (2013) represented the dominant frequency band for those seismograms of 2 to 30 Hz [13]. In the meanwhile, we determine the likely origin of an unknown seismic trigger by visual inspection. Due to the lack of camera images, human-activity reports, and physical evidence, these time history data for unknown events will be extracted and archived.

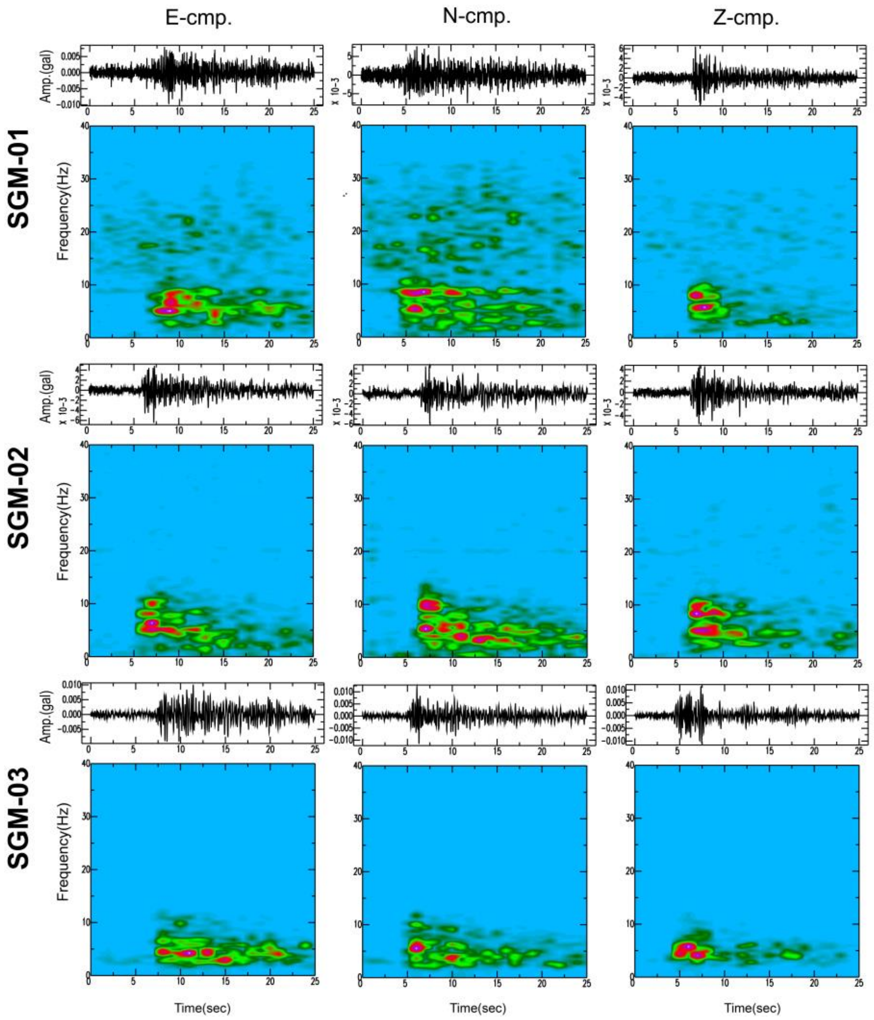

Fig. 7 – Time history and spectrum for the Case02 of other events

5. Summary

We deploy three RS-3D seismometers, in an experiment site at Babaoliao in Chiayi, Taiwan and investigate the performance of monitoring the vibrations producing by earthquakes, rainfall, and possible internal sources. The signals from earthquake and rainfall events can be well-identified. Other events can be related to the critical signals for the advanced analysis of landslide characteristics. A comprehensive data compilation is able to be prepared from this study for advanced analyses or applications. Next, the improvement for the application of monitoring landside would be focused on the long-period operation and extended dense network. The temporal and spatial resolution of data may help us to observe the detail changes with time, such as repeating events and subsurface velocity. The low-cost system can be anticipated to increase the availability and application of seismic monitoring for the landside. we provided a preliminary experience report to support a qualitative result using three RS-3D sensors. We think that RS-3D is available to monitor the local and regional vibration and further provide a hazard warning once the potential sliding signal can be well-identified. Through this pilot project with three RS seismometers deployed since summer 2019, we reveal a suitable performance level of the low-cost sensors and their potential capabilities in landslide seismology investigations.

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