ACOUSTIC SIGNALS AND GEOPHONE RESPONSE INDUCED BY STONY-TYPE DEBRIS FLOWS
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ABSTRACT

In this study, we examine the infrasounds and geophone response induced by a stony-type debris flow which occurred in Houyenshan, Taiwan due to a heavy rainfall event on June 10, 2006. Infrasound propagates to long distance in the atmosphere at the speed of sound for the low adsorption in the air and the high reflectivity of the ground. The infrasonic signals induced by debris flows are related to the magnitude and composition of the failure zone as well as the slope areas. The stony debris flows occurred in Houyenshan with the peak acoustic frequencies within 15-40 Hz for most surges, and the corresponding geophone responses exhibit peak frequencies within 15-50 Hz. The range of peak frequency for the stony-type debris flows is higher than that of viscous debris flows occurred in Jiangjia Gully, Yunnan, China. Non-stationary acoustic signals of the debris flows are analyzed by adopting the HHT approach.

Keywords: Infrasound geophone, Debris flow, Houyenshan, Hilbert-Huang Transform

INTRODUCTION

Infrasound monitoring systems (IMS) have been used to detect large natural hazards such as earthquakes (Stump et al., 2001), landslides (Bedard, 1996), Volcanic eruptions (Vergniolle et al. 1996; Johnson, 2001) and nuclear explosions (Stump et al., 2001). Infrasound is inaudible with its acoustic frequencies band below 20 Hz. Infrasound can travel a longer distance than audible sounds (Johnson, 2001). It means infrasound has fewer adsorption loss than audible sound. Recently, an infrasound debris flow warning system (DFW-I Model) with analog lowpass filter was developed to detect the occurrence of debris torrents in Jiangjia Gullies, Yunnan, China (Zhang et al., 2004). Over sixty debris flow surges were detected with verification by using the DFW-I Model. The warning time is about 10-30 minutes prior to the arrival of the debris flows (Zhang et al., 2004). Such information is vital for downstream communities. Infrasound is generated by the violent surge front and the collisions (or abrasion) between debris flow and the ground. However, the dominant frequencies for the debris flows were closely related to the soil properties, the magnitude of debris flow surges and the types of debris flows.

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In this study, the infrasound characteristics of debris flows are examined by the field data collected in Houyenshan, Sanyi, Taiwan. Under different geological settings and torrent magnitudes, the distinction of the infrasound characteristic is analyzed.

**STUDY SITES AND MONITORING SYSTEM**

**Geographical settings**

As shown in Fig. 1, Houyenshan in Taiwan is a gravel-formation badland with active head-cutting gullies, stony debris fans and aboriginal habitats. Houyenshan is the deposition of Houyenshan Facies, which consists of conglomerate with thin sand layers, makes the upper Toukoshan Formation, and is about 0.5-0.9 Ma old (Chi and Huang, 1981). The drainage area of Houyenshan is 2.2 km² and debris flows often occur and run through the ravines in gullies 1-5 in intensive rainfall events. At present, Gully 1 (Fig.2) is an incised channel with the longitudinal slope of about 8° and a stony fan at the downstream with a slope of about 6°. The elevation of channel bed can vary up to 3-6 m in a large scale of debris flow due to either deposition or scouring process (Figs. 3a, b).

![Fig. 1 Drainage basins of Houyenshan, Sanyi, Taiwan(There are five Gullies counted from right side, red circle indicates the location of the equipment box)](image1)

![Fig. 2 The incised channel of Gully 1 after Typhoon Morakot (August 6-10, 2009)](image2)

![Fig. 3a Pre-event configuration (June 7,2006) (dashed line : equipment box)](image3a)

![Fig. 3b Post-event configuration (June 19, 2006)](image3b)
Particle size distribution of bed material in both Houyenshan and Jiangjia gully are shown in Fig. 4. Boulders and gravels are poor sorted, and fine particles are mostly within 0.1-1mm in Houyenshan. According to their particle size distribution, the types of debris flows in Jiangjia gully and Houyenshan can be categorized as viscous debris flow and stony debris flow, respectively (Takahashi, 1991).

**Setup of the IMS**

The IMS systems contain different infrasound sensor systems, i.e. the CHZ-Model sensor in DFW-I model (Zhang, 2002), which is compatible to the GRAS system (0.5” microphone Type 40AF with 0.5” Preamplifier Type 26AK (G.R.A.S. Sound and Vibration Inc.)). The acoustic sensor is connected with the Spartan-L data logger (Integrated Measurement & Control Inc.). The integrated IMS was installed in Gully 1 (shown in Fig. 3a). A two-story steel box container was levelly installed with the IMS and battery power inside. The data logger and sensors placed on top, while two 12-V batteries at bottom (Fig. 5). The recordable time span is about 3 days for continuous recording modes. In order to check the accuracy of the sensors, the geophone sensor (GS-1 Geospace) was also installed nearby. Both ground vibrations (through geophone sensor) and the infrasound were recorded simultaneously at the sampling rate of 500 Hz.

The methodologies adopted for data analysis include the fast Fourier Transform (FFT) and the Hilbert-Huang Transform (HHT). Historically, Fourier spectral analysis has provided a general method to analyze the wave data in frequency domain for examining its global energy-frequency distributions. Unfortunately, the requirement of system linearity, periodicity and stationarity is necessary for Fourier spectral analysis; otherwise, some spurious harmonic components will be induced to simulate the deformed wave profiles that cause energy spreading and mislead the energy-frequency distribution for nonlinear and non-stationary data.

For analyzing nonlinear and non-stationary data, an Empirical Mode Decomposition (EMD) method, based on the adaptive characteristic time scale of the data, was
proposed by Huang et al. (1996). With which a data set $X(t)$ can be decomposed into several Intrinsic Mode Functions (IMF) $C_1 \sim C_n$, and a residue $r$, which can be neglected due to the trend. The EMD provides a symmetrical data to zero line to be fitly applied in Hilbert Transform. An energy-frequency-time 3D contour view shows the instant frequencies depend on time.

The Fourier expansion is based on the properties of the function over the whole time span through integration. On the other hand, IMF represents a more generalized Fourier expansion. It improves the efficiency of the expansion, and enables us to solve the problem of non-stationary effect in the field data.

**INFRASOUND SIGNALS GENERATED BY DEBRIS FLOWS**

**Debris flows in Houyenshan**

The IMS were set up in Gully 1 on June 6, 2006 once the rainfall forecast was announced by the Central Weather Bureau. The original surface elevation of the IMS equipment box aggregated up to 3m (see Figs. 3a and 3b) after the intensive rainfall, which confirmed the occurrence of debris flows. Fig. 6 shows the signals of Grass microphone (a), geophone (b) and rainfall data (curves c and d), respectively. There is a strong correlation among those data in the early morning of June 10, 2006. Two large surges of debris flows are expected to occur during that period.

![Signals from IMS, (a) microphone (b) geophone, and (c) accumulative rainfall (d) rainfall intensity with 1 minute interval at Sanyi station (C0E530) during June 7-10, 2006](image)

Big debris flow events occurred in the morning on June 10, 2006. IMS was buried by the large debris flow, and responses of two signals showed that the box was hit and rotated. Beside the debris flow events, there are background noises in the infrasound signals when compared to the geophone response under the same rainfall condition. On the other hand, the
geophone sensor was taken away by the debris flow on June 10 while the IMS system was buried and dig out later on June 19 (Fig. 3b). Both the acoustic and geophone signals before being buried provide the information of debris flows and will be analyzed in the next section.

RESULTS AND DISCUSSIONS

Acoustic characteristics of debris flows in Houyenshan

There are nine possible debris flow events around two large surges in Figs. 7 and 8. After second large surge, the geophone was taken away by debris surge. The IMS system was hit, rotated and buried by the debris flows, so the events with obvious signals between two surges are possible candidates for debris flow events. The FFT show the spectrum of each event. However the spectrum characteristics of events presented by HHT exhibit better revolution than that of FFT.

Fig. 7  Acoustic signal during June10, 2006  3:00~7:00 (each piece per hour) with 9 debris flow events(circles)
Especially, Event 2 shows that both microphone and geophone share most the same frequency peak than others (see Figs. 9,10). In order to highlight the non-stationary process of acoustic signals caused by the debris flows, Event 2 is analyzed by employing the HHT approach. The spectra histogram for the acoustic signals and geophone generated by HHT are shown in Figs. 11 to 12, respectively. Spectrum of the Geophone data shows the typical peak frequencies between 15-40Hz, which is similar to the debris flows recorded in Aiyuzih Creek, Nantou, Taiwan on July 2, 2004 (Huang et al., 2007). So it may be concluded that the stony debris flows will intensify the infrasound energy with the frequencies between 8-20 Hz during the surges. The peak frequency thus is higher than that of viscous debris flows.
Fig. 10 The FFT of geophone signals seven possible debris flow events (count from top, Events 8 and 9 are neglected due to the missing geophone since then)

Fig. 11 The HHT of the acoustic signal and sound data of Event 2
SUMMARY AND CONCLUSIONS

Infrasounds produced by debris flows are explored in this study by examining the field data in Houyenshan, Taiwan. The stony debris flows occur in Houyenshan with the peak frequencies between 5-15 Hz during the surges. However, it is hard to guide how to provide the infrasound. In our guess, the overload forces to the ground or move style of surges were two possible ways to generate the infrasounds.

Non-stationary process of the debris flow acoustic signals are demonstrated by using the HHT approach. The energy level of spectrum are enhanced around 8 Hz to 20 Hz, for microphone and geophone signals in Gully 1, Houyenshan during hard rainfall event.

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REFERENCES


