Acoustics • Shock • Vibration • Signal Processing **November 2002 Newsletter**

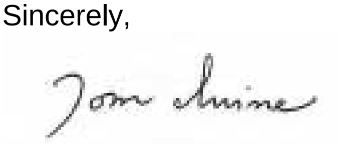
Talofa

Volcano debris flows consist of volcanic ash, rock debris, mud, and water. These destructive flows may cause loss of life. Fortunately, seismologists can detect these flows by monitoring seismic vibration on a volcano's slope over the 30 Hz to 100 Hz frequency domain. Warnings can be issued accordingly. People in nearby towns can be evacuated. Many lives were thus saved after Mount Pinatubo's eruption on June 15, 1991. The lead article in this month's newsletter gives further information about this seismic monitoring technique.

The second article deals with motion sickness, which may result from vibration exposure in the 0.1 Hz to 0.5 Hz domain.

If you enjoy these newsletters, please subscribe to Vibrationdata Software and Tutorials. The tutorials present practical methods for shock and vibration analysis. The software includes programs for digital filtering, Fourier transforms, shock response spectra, and other signal processing functions.

Sincerely,



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Feature Articles

Seismic Monitoring of Volcano Debris Flows Page 3

Motion Sickness Page 8

Welcome to Vibrationdata Consulting Services

Vibrationdata specializes in acoustics, shock, vibration, signal processing, and modal testing. The following services are offered within these specialties:

1. Dynamic data acquisition
2. Data analysis and report writing
3. Custom software development and training
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Vibrationdata also performs finite element analysis.

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Seismic Monitoring of Volcano Debris Flows By Tom Irvine

Introduction

A composite volcano is constructed from alternating layers of pyroclastics and rock solidified from lava flows.

Pyroclastics are fragments of rock formed by volcanic explosions.

Composite volcanoes have thick, viscous lava. The thick lava can form plugs at the top of the volcano. The plugs allow gas pressures to build up to high levels. Thus, these volcanoes often suffer explosive eruptions.

A composite volcano is also called a stratovolcano. Examples of composite volcanoes are Mount Rainier, Mount St. Helens, and Pinatubo.

Lahars

A volcanic debris flow is a mixture of volcanic ash, rock debris, mud, and water. These flows are also called lahars.

A debris flow originates on the steep slopes of the volcano. It may be triggered during or after a volcanic eruption. Heavy rainfall increases the likelihood of lahars. Furthermore, rapidly melting snow from lava flows may amplify the lahar.

Lahars have enormous energy. They rush down the slopes of a volcano at speeds as great as 40 miles per hour (65 kilometers per hour) and can travel more than 50 miles (80 kilometers).

Lahars can destroy people and property. Their deposits can cover roads and railways, smother crops, and fill stream channels, thereby reducing their flood-carrying capacity and navigability.

Geophones

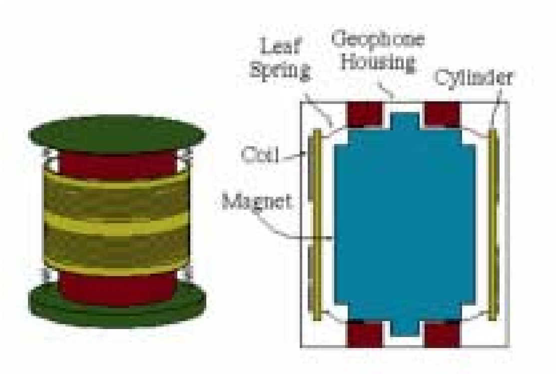

Figure 1. Geophone

Geophones are used to measure seismic vibration generated by earthquakes, volcanoes, and explosions.

A geophone is a sensor that consists of a magnet and a coil, as shown in Figure 1. The geophone is mounted to the ground. Ground vibration causes a relative motion between the magnet and coil. Specifically, the coil moves with the housing while the magnet mass tends to remain stationary, in response to the seismic vibration. Note that the magnet mass is isolated by springs from the ground motion.

Some geophones have the opposite design. The coil is designed to remain stationary while the magnet moves with the ground vibration.

Regardless, the resulting current is proportional to the ground velocity.

Acoustic Flow Meter

An acoustic-flow monitor (AFM) is a geophone sensitive to ground vibration with higher frequencies than those

Figure 1. Acoustic Flow Meter Installation

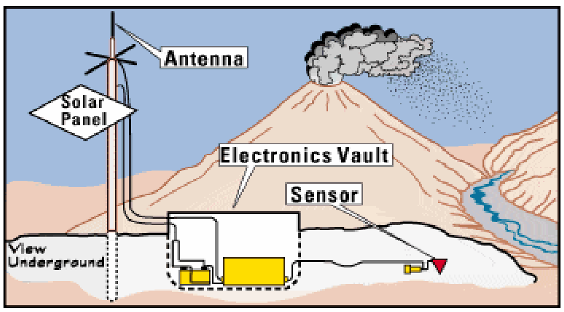

Figure 2. Simplified schematic of acoustic-flow

generated by earthquakes and most volcanic activity. An image of these meters is given in Figure 1. The geophones are arranged in stations as shown in Figure 2. The velocity signals are sent via telemetry signals to a central monitoring location.

An AFM is most sensitive to ground vibrations between approximately 10 and 300 Hz. This frequency domain is characteristic of the ground vibration generated by lahars.

The vibration is caused by rock fragments crashing together and into the channel bottom as a lahar moves downstream. Furthermore, the lahar generates a low rumbling noise that correlates with this frequency domain.

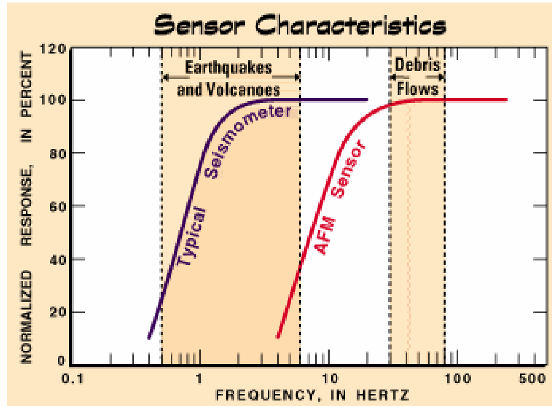

Figure 3. Sensor Frequency Response

On the other hand, a typical seismometer, which records earthquakes and volcanic eruptions, has a frequency response of 0.5 Hz to 20 Hz. A comparison of the two sensor types is given in Figure 3.

Redoubt Volcano, Alaska

Figure 4. Drift River Valley near Redoubt Volcano (Photograph by S.R. Brantley on April 23, 1990)

The first use of AFM geophones occurred at the Redoubt Volcano in Alaska.

This volcano had a series of eruptions in 1989-90. Nearly every volcanic event generated lahars in the Drift River Valley. The lahars were caused by sudden melting of snow and ice from hot pyroclastic flows and dome collapses that swept down the volcano's north flank.

Many of the lahars swept all the way to Cook Inlet (about 35 km), which raised concern about the safety of an oil-storage facility built on the bank of Drift River.

An eruption and a resulting lahar occurred on April 6, 1990. Scientists had previously installed a number of AFM sensors along the edge of the valley. A record of this eruption and lahar is shown in Figure 5.

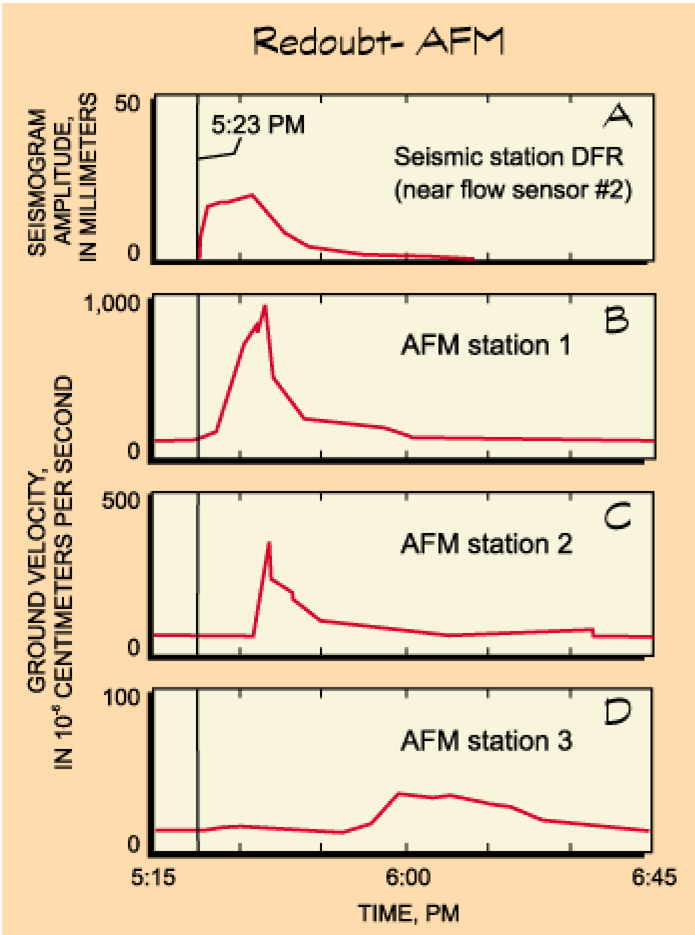

Figure 5. Redoubt Eruption Record

The graph shows the amplitude envelope of a seismic signal (top curve) that was caused by the eruption at 5:23 p.m.

Note the delay in time before the AFMs (bottom 3 curves) recorded an increase in ground vibration caused not by the resulting lahar that moved progressively downstream.

Note the change in scale for each sensor. The AFMs were insensitive to the low-frequency ground vibrations caused by the eruption. Thus, the AFMs clearly recorded the passage of the lahar at each station.

Mount Pinatubo

Mount Pinatubo in the Philippines erupted on June 15, 1991. The eruption deposited more than 1 cubic mile (5 cubic kilometers) of volcanic ash and rock fragments on the volcano's slopes.

Heavy rains followed the eruption within a few hours. The rain flow began to wash the ash and debris down into the surrounding lowlands in giant, fast-moving mudflows, or lahars.

Lahars also formed in the next four rainy seasons, causing further damage in the lowlands.

Fortunately, the Philippine Institute of Volcanology and Seismology and the U.S. Geological Survey installed a system of AFM sensors to monitor and warn of lahars. This system saved hundreds of lives by enabling warnings to be sounded for most of the major lahars at Pinatubo.

Mount Rainier, Washington

Figure 6. Mt. Rainier

Mt. Rainier is the highest peak in the Cascade Range, at 14,410 feet. It is also an intermittently active volcano with a voluminous cap of ice and snow.

The steep-sided mass of rock and ice is a potential danger, given the likelihood of another eruption. The rock and ice would form a devastating lahar as a result. Furthermore, a landslide could be triggered by some event other than an eruption.

Prehistoric lahars flowed all the way to Puget Sound. More than 100,000 people now live on the deposits of lahars formed within the past 6,000 years. Future lahars could affect many of the 700,000 people who live in Tacoma and the nearby communities of Pierce County.

Lahars would be detected by an array of AFM monitors, which have been erected throughout the mountain and surrounding valleys.

Each AFM station consists of a microprocessor-based data logger that measures the amplitude, frequency and duration of ground vibrations detected by the sensors. Software analyzes the incoming data and triggers an automatic alarm when a significant lahar is detected.

Geologists estimate a travel time of less than one hour for large-scale lahars to reach the Carbon and Puyallup Valleys and the towns contained within. This estimate drops to 30 minutes for the town of Orting.

Government officials have erected a series of sirens throughout these communities to warn the townspeople in the event of an approaching lahar. Emergency officials have also established evacuation plans.

Hopefully, there would be precursor signs that would give greater time for an orderly evacuation. These signs would be detected by other types of sensors.

For example, gas sensors might detect tiny whiffs of carbon dioxide leaking from the volcano prior to an eruption.

Motion Sickness

by Tom Irvine

Introduction

Passengers in aircraft, amusement park rides, automobiles, ships, and spacecraft may experience motion sickness. Occupants in tall buildings with a height greater than 50 meters may also experience this condition.

An individual's likelihood of becoming nauseated in response to vibration from these sources depends on many factors such as age, gender, previous motion experience, visual reference frame, head movement, etc.

The symptoms of motion sickness include dizziness, sweating, and vomiting. Furthermore, dehydration may result from vomiting.

Vibration Frequency

Motion sickness is caused by very low frequency vibration in the domain from 0.1 Hz to 0.5 Hz.

M.J. Griffin wrote in the Handbook of Human Vibration:

> Motion sickness occurs with motions of low frequencies at which the posture of the torso does not greatly alter the amount of translational motion transmitted to the upper parts of the body: transmissibility for vertical excitation is very near to unity at frequencies below 1 Hz in all persons.

Physiological Causes

Three sensory systems appear to have a role in motion sickness: visual, vestibular, and somatosensory.

The role of sight is straightforward. Some individuals even become nauseated while viewing films with excessive motion, or while training in a car simulator.

The vestibular system consists of the cavities and semicircular canals in the ear. Hair cells in the cavities detect translational movement. The semicircular canals sense rotational movement of the head.

Somatosensory organs are spread throughout the body. These organ sense force and displacements.

One theory is that these systems may provide the brain with conflicting information during motion or even apparent motion, thus causing illness.

Ships

M.J. Griffin cited a study where 5% of the passengers on a ship experienced vomiting while the ship underwent a 0.2 m/sec^2 acceleration amplitude during a 3 hour voyage. The corresponding amplitude would have been approximately 25 cm (10 inches) peak-to-peak, assuming a 0.2 Hz sinusoidal frequency.

The probability for motion sickness also depends on the direction of the oscillations. The vertical and pitch axes are worst-case translational and rotational axes respectively in ships.

Note that the vertical motion in ships is partly caused by pitch oscillation. The problem of seasickness can be reduced to some extent by locating passengers at the center of the ship.

Unfortunately, the principal vertical acceleration frequency of most large ships is close to 0.2 Hz, which is within the domain of maximum human sensitivity.

Aircraft

Motion sickness in aircraft is most likely to occur during turbulence. Passenger aircraft fly at high altitudes to avoid areas of turbulent airflow. The incidence of airsickness is thus reduced.

On the other hand, military pilots flying maneuvers in high-performance aircraft may be more likely to experience nausea.

Automobiles

The fundamental frequency of a passenger car is typically 1.0 to 1.5 Hz. Fortunately, this domain is at least one octave above the 0.1 Hz to 0.5 Hz domain of human sensitivity.

Researchers have thus found that the vertical oscillation of an automobile does not tend to correlate with carsickness. Rather, carsickness tends to result from horizontal oscillations of the vehicle.

Furthermore, horizontal oscillations can be of greater magnitude in the horizontal axis than in the vertical axis, over the domain of sensitivity. Horizontal oscillations tend to be most severe during braking maneuvers and during travel down a winding road.

Tall Buildings

The vibration modes of a building may be excited by wind. The wind excitation mechanism is oncoming turbulence, as well as possible vortex shedding in the wake.

The buildings may sway back and forth or even twist in response to the wind.

The swaying problem is particularly severe at the top floors of the building. The twisting problem is most severe at the building's corners.

Fortunately, a structure can be stabilized by active, semi-active, or passive control systems to dampen the movement.

For example, the Citicorp Tower in New York City has a fundamental frequency of 0.15 Hz, which is within the sensitivity domain. The Tower has a "tuned mass damper" system that counteracts vibration at this frequency, however. This system is described in the January 2002 edition of the Vibrationdata Newsletter.

Calculation Methods

Calculation methods for human exposure to low frequency vibration are given in British Standards 6841.