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

Guten Tag

The theme of this month's newsletter is the oscillations of the Earth and its waterways.

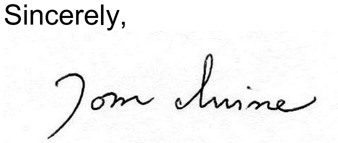
The first article recalls the Niigata, Japan earthquake in 1964. A phenomenon called soil liquefaction occurred whereby the soil changed from a solid to a dense liquid state. As a result, several apartment buildings tilted. Soil liquefaction has also occurred in other earthquakes, such as the Loma Prieta quake in 1989.

The second article discusses how a resonant effect called a seiche occurs in the Bay of Fundy, Nova Scotia. The seiche period nearly coincides with the lunar tidal period. The seiche thus amplifies the tides, producing the highest tides in the world.

Seiches also occur in Lake Geneva, Switzerland, as discussed in the third article.

The final article gives the Earth's fundamental period, and discusses how this period might affect the seiches in Lake Geneva and in the Bay of Fundy.

Sincerely,



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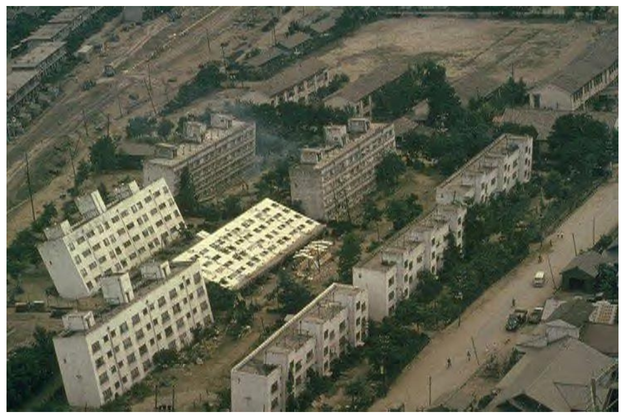
Feature Articles



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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
4. Test planning and support

Vibrationdata also performs finite element analysis.

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Three-Five Systems

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Niigata Earthquake 1964: Soil Liquefaction

By Tom Irvine

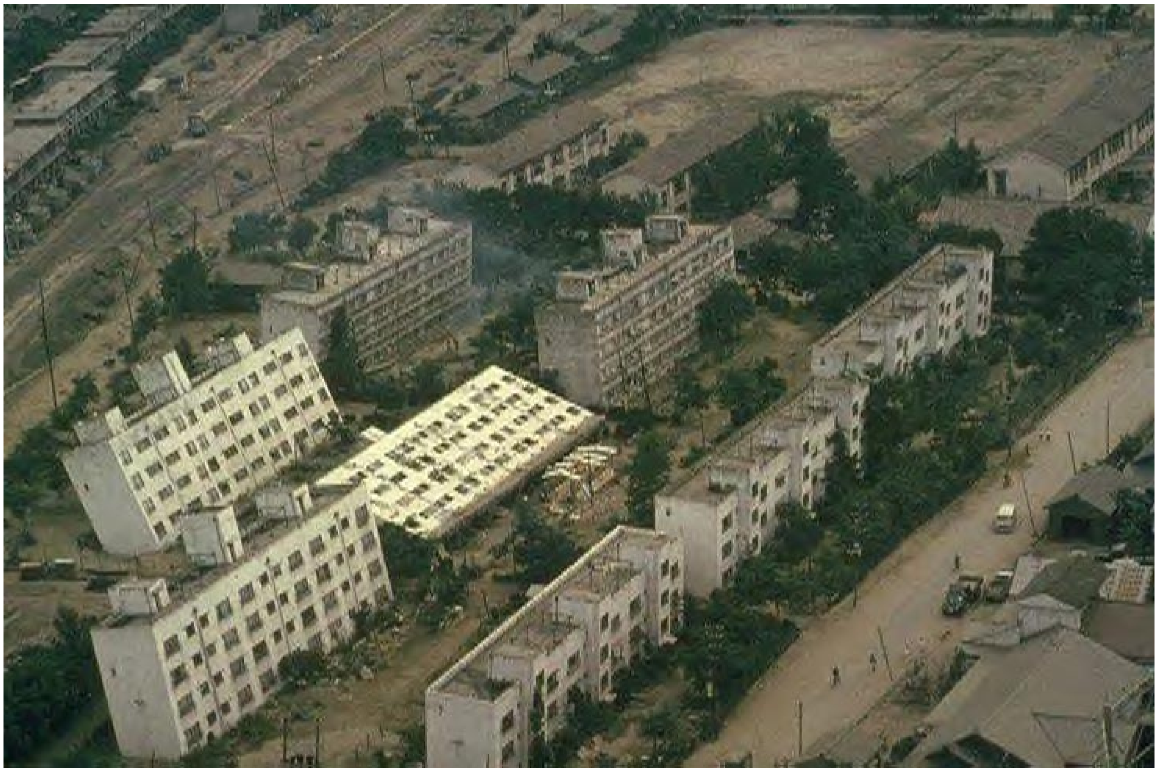

Figure 1-1. Niigata Apartment Buildings

Introduction

Niigata is a city in Japan, about 100 km north of Tokyo. It is a coastal city, located on the Sea of Japan.

The Niigata earthquake occurred on June 16, 1964. The magnitude was 7.5. The death toll was 28.

Soil Liquefaction

Many of Niigata's buildings were constructed on loose, sandy soil with a shallow ground water table. The soil was thus saturated, and it lacked cohesion.

During the earthquake, soil liquefaction occurred. This was an effect whereby the seismic vibration caused the ground water pressure to increase rapidly. The water pressure between the sand grains increased to a level where the pore pressure overcame the external pressures on the soil.

The water also lubricated the sand particles. The grains could thus easily move relative to one another. The soil was

Figure 1-2. Showa Bridge

transformed from a solid to a dense, viscous fluid.

Building Response

The liquefied soil lost its ability to withstand shear forces. Foundations could no longer support their buildings.

As a result, numerous buildings were damaged, of which approximately 200 settled or tilted rigidly without appreciable damage to the superstructure. The superstructures remained rigid because they were constructed from reinforced concrete. Tilting occurred, however, because these buildings were constructed on very shallow foundations or friction piles in loose soil.

For example, several apartment buildings in Kawagishi-Cho, Niigata tilted as shown in Figure 1-1. The building in the center of Figure 1-1 tilted about 70 degrees with respect to the vertical axis.

Most of the apartment buildings were later set back into an upright position using jacks and winches. The buildings were then underpinned with piles and reused.

On the other hand, similar concrete buildings founded on piles bearing on firm strata at a depth of 20 meters did not tilt or suffer damage.

Other Failures

Other types of failures also occurred. The Showa Bridge collapsed as shown in Figure 1-2. This collapse was due to movement of the pier foundations. As a result, the bridge decks shifted off their piers and fell into the riverbed.

Furthermore, the fault rupture generated a tsunami that destroyed the port of Niigata.

The earthquake also caused fires in a number of oil storage tanks.

The Bay of Fundy Resonance

By Tom Irvine

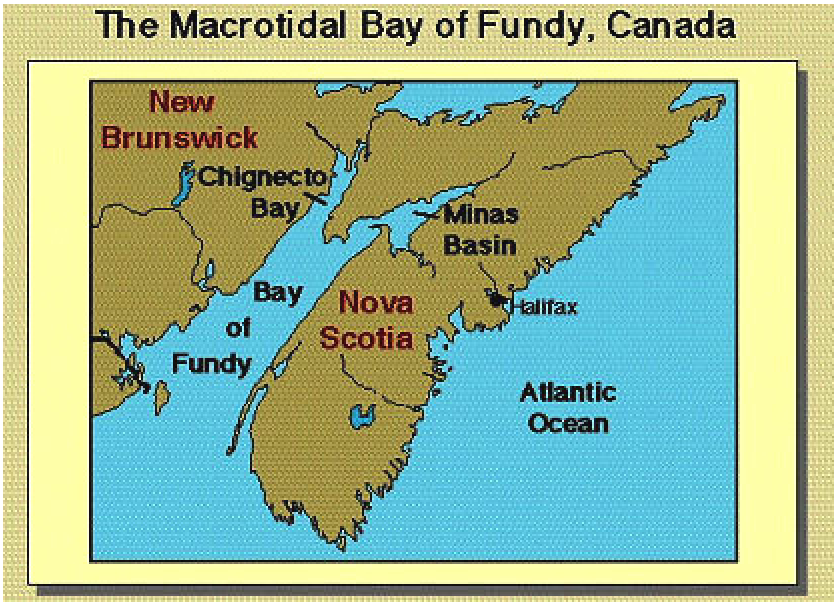

Figure 2-1. Map Courtesy of Nan Schmidt, University of South Florida

Introduction

The Bay of Fundy is located between New Brunswick and Nova Scotia, as shown in Figure 2-1.

The Bay of Fundy is 270 km long. It is 80 km wide at its mouth. It forms two basins at its head, Chignecto Basin and Minas Basin.

Tides

The Bay of Fundy experiences two high tides per day. These lunar tides result from the mutual gravitation between the Earth and the Moon. A tidal bulge is created on the side of the Earth closest on the Moon. A second bulge is created on the opposite side of the Earth, since the Earth is also being pulled toward the moon and away from the water on the far side.

As the Earth rotates on its axis, the Bay of Fundy enters one bulge. Approximately twelve hours later, it enters the other bulge. A more precise time difference is 12 hours and 25 minutes. Thus, a high tide occurs about one hour later each day.

The moon actually orbits the earth in an elliptical pattern, taking 27.3 days to complete one orbit. At the Moon's closest approach to the Earth, the tides are substantially higher.

In addition, the Sun affects the Earth's tides. The Sun exerts a gravitational force on the Earth that is 180 times as strong as the Moon's force on the Earth. The Moon is so much closer to Earth, however, that the variation in the Moon's force across the Earth is 2.2 times larger than the variation in the Sun's force. It is this variation that produces tides.

With every tide, 100 cubic kilometers of water enters or exits the Bay. This is equal to the discharge of all the world's fresh water rivers.

Resonance

Water in an enclosed basin rocks rhythmically back and forth from one end to the other. The period of this oscillation depends on the basin's geometry. In a cylindrical tank, this rocking motion is called “slosh.” In a natural basin, it is called a “seiche.” This term is pronounced as “saysh.” It is an old Swiss French word meaning "to sway."

The Bay of Fundy basin is effectively bounded at its outer end by the edge of the continental shelf, which has an approximate 40:1 increase in depth.

The Bay’s seiche period nearly coincides with the tidal period. The Bay’s period is 13 hours and 18 minutes, which is close to the 12 hour and 25 minute period of the dominant lunar tide of the Atlantic Ocean.

Thus a resonance condition results whereby the tidal flow excites the seiche. The seiche amplifies the tidal flow, thus producing the world’s highest tides. Furthermore, the Bay narrows and becomes shallower toward its head, thus squeezing the water even higher.

From low to high tide, the average differential in the water levels is 12 meters. The peak difference is 16 meters, when the various factors affecting the tides are in phase. The peak occurs at Wolfville, in Nova Scotia’s Minas Basin, as shown in Figure 2-2.

In contrast, the average tidal difference in the Atlantic Ocean is 1 to 2 meters. Thus, the resonance amplifies the tidal difference by a factor between 8 and 12.

Tidal Bores

A tidal bore is a wave that travels against the flow of a river, as shown in Figure 2-3. When the tide is coming in, tidal bores surge up several rivers that flow into the Minas Basin. Some tidal bores can be seen on the St. Croix, Meander, Maccan, Petitcodiac, and Salmon Rivers. The tidal bores can reach one meter in height with a speed of 15 km per hour.

Furthermore, the tides force the cascading falls of the Saint John River to reverse.

Figure 2-2. Minas Basin Tides

Hopewell Cape

Hopewell Cape is located on the New Brunswick shore of Bay Fundy. The cape has red sandstone rock formations, as shown in Figure 2-3.

The ebb and flow of tides have eroded these formations into mushroom-like shapes. The formations are called “Flower Pot Rocks” because they are capped by evergreens.

Figure 2-3. The Tidal Bore making its way up the Petitcodiac River.

Figure 2-4. Flower Pot Rocks at Hopewell Cape, Courtesy of David Lee

The Lake Geneva Seiche

By Tom Irvine

Figure 3-1. Space Shuttle Image of Lake Geneva

Introduction

Lake Geneva, also known as Lac Léman, is crescent-shaped lake, as shown in Figure 3-1. It is located on the Swiss-French border, between the Alps and the Jura mountains. It has a maximum depth of 310 meters. It is approximately 70 km long. The Rhône River traverses the lake, emerging at the western end near the city of Geneva.

Seiche Oscillations

Lake Geneva is subject to seiche oscillations that suddenly change the lake's level. The level of water of the lake frequently varies from 0.6 to 1.5 meters in half an hour.

A seiche is a standing wave that forms on the surface of a lake or landlocked bay. A seiche may be caused by high winds, atmospheric pressure changes, or seismic disturbances.

A seiche in a lake has a wavelength equal to twice the length of the body of water on which it occurs, as shown in Figure 3-2.

The seiche period T follows the proportionality equation

$$T \propto L/\sqrt{g\,d}$$

where

L is the length

g is gravity

d is the depth

The term seiche came from a professor named Francois Alphonse Forel (1841-1912). He was the first scientist to explain the mechanisms that cause seiches. He also reported a surface seiche in Lake Geneva that lasted 8 days with 200 oscillations, a period of 73 minutes, and an amplitude of 20 cm.

The primary cause of the Lake Geneva seiche is barometric changes in air in the mountains above the lake.

The period of the Lake Geneva seiche is compared to seiche periods worldwide in Table 3-1.

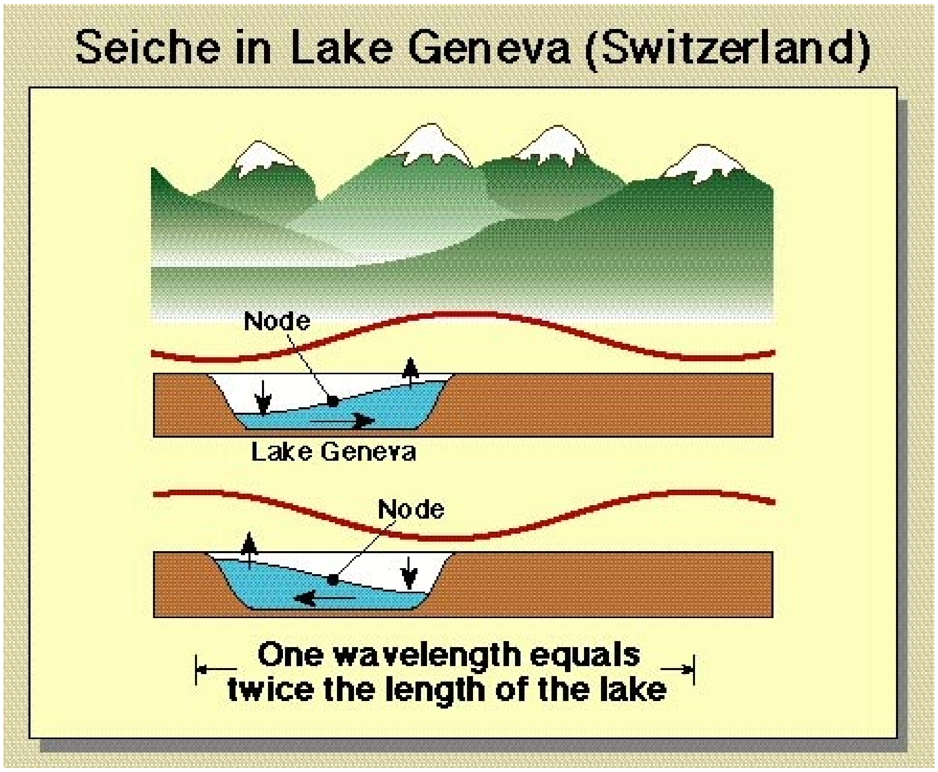

Figure 3-2. Image Courtesy of Nan Schmidt, University of South Florida

Table 3-1. Seiche Periods Worldwide	
Body	Period
Aral Sea	22.8 hr
Bay of Fundy, Nova Scotia	13.3 hr
Lake Erie	13.1 hr
Lake Superior	8 hr
Lake Geneva, Switzerland	73 min
Lake Constance, Switzerland	55.8 min
Hilo Bay, Hawaii	30 min
Loch Earn, Scotland	14.5 min

The Earth's Natural Frequency

By Tom Irvine

Introduction

The Earth is highly elastic. The Earth experiences seismic events that excite its vibration modes.

The fundamental natural frequency of the Earth is 309.286 micro Hertz, per Reference 4-1. This is equivalent to a period of 3233.25 seconds, or approximately 54 minutes.

This period was measured during a 1960 earthquake in Chile. This earthquake was the largest ever recorded, with a 9.5 moment magnitude.

In addition, at least 40 overtones were observed, each with a shorter period than the fundamental period.

Seiche Excitation

The Lake Geneva seiche period is 73 minutes. An earthquake could excite the Lake Geneva seiche since the lake's period is only 1.35 times longer than the Earth's fundamental period.

The Lake Constance seiche period is 55.8 min, which nearly coincides with the Earth's fundamental period of 54 minutes. Lake Constance thus appears to be at risk for resonant excitation of its seiche.

On the other hand, the Bay of Fundy seiche period is 798 minutes, which is too long for seismic excitation.

Reference

4-1. T. Lay and T. Wallace, Modern Global Seismology, Academic Press, New York, 1995.