Acoustics • Shock • Vibration • Signal Processing **November 2004 Newsletter**

Aloha

"Catch a wave and you're sitting on top of the world." -- Brian Wilson, Beach Boys

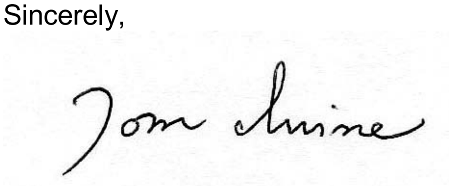
I have finally achieved a rather quirky and quixotic goal that I have had in mind for fourteen years. I constructed a Lehman style seismometer and acquired a magnitude 6.8 earthquake originating in the Solomon Islands.

This seismometer uses a pendulum boom to measure horizontal ground motion. It has a period of 14 seconds, which is suitable for measuring teleseismic events.

This concept has been around for one hundred years or so. Japanese seismologist Fusakichi Omori measured the 1906 San Francisco earthquake using a horizontal pendulum seismometer located in Tokyo.

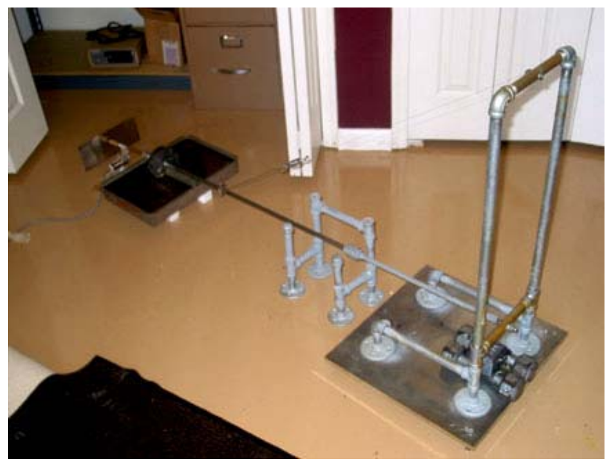
This type of seismometer is now referred to as a "Lehman seismometer" after James D. Lehman of James Madison University, who popularized this design in several science magazine articles in the late 1970s.

Sincerely,



Tom Irvine

Feature Articles



Homebuilt Lehman Seismometer

Solomon Island Earthquake

Figure 1. Lehman Seismometer

The boom is a horizontal pendulum. It has a period of 14.2 seconds, equivalent to a natural frequency of 0.071 Hz. A sensor at the free end measures the displacement. The boom length is 64 inch. The total frame height is 35 inch. The boom has a knife edge that pivots against a bolt head in the lower cross-beam of the frame.

The boom is suspended from the frame by a wire cable. The cable is attached to the top cross-beam of the frame. The other end of the cable is attached to the boom, about two-thirds of the distance from the pivot to the free end of the boom. The pivot point is offset from the top cable attachment point. Thus, the boom oscillates as if it were a “swinging gate.”

The plate supporting the frame has three adjustable mounting feet. The feet can be adjusted to tune the pendulum to the desired natural frequency. Furthermore, the wire cable has a turnbuckle which is used to adjust height of the free end of the boom.

The detached frame in the center of the figure is used for assembly and to limit the displacement during tuning.

Figure 2. Displacement Transducer

The sensor is a non-contact inductive linear displacement transducer. The model is Omega LD701. The sensor outputs a voltage proportional to the distance from the sensor head to the steel target, which is suspended underneath the wooden rod section of the boom.

The inductive sensor was my third, and by far most successful, measuring solution. I highly recommend this transducer.

The first sensor was a linear variable displacement transducer (LVDT) with its spring removed. The LVDT, however, had too much friction which increased the natural frequency of the boom to an unacceptable value.

The second sensor was a magnetic coil attached to the boom. The coil moved between the poles of a magnet, thus inducing a voltage proportional to the velocity. This is the classic sensor method used with most Lehman seismometers. The signal requires tremendous amplification. Regretfully, my coil, magnet, and amplifier set-up missed the Parkfield, California earthquake. This setback led me to the inductive displacement sensor, which has proven to be successful.

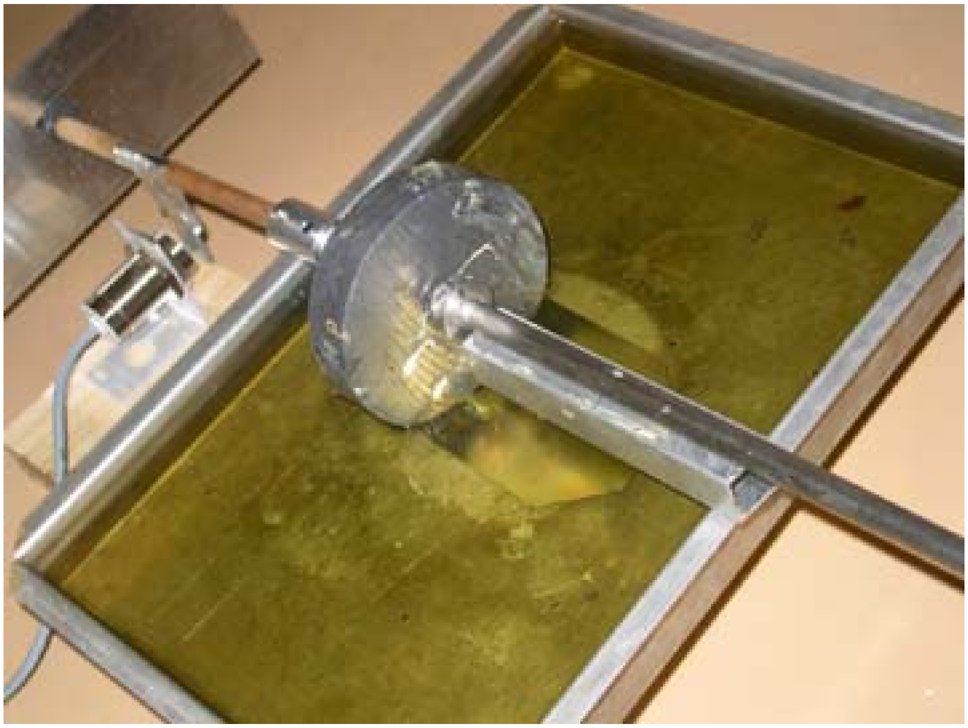


Figure 3. Damping Method

The lead disk is used for ballast. The pan contains canola oil which is used for viscous damping, both in the vertical and horizontal axes. A horizontal plate is connected to the disk and is fully submerged in the oil. Furthermore, the bottom side of the disk dips into the oil. The resulting viscous damping is 9.8%.

The thin aluminum plate at the free end of the beam was used for an alternative damping method that was abandoned in favor of the oil method.

The displacement sensor is also shown in this figure.

Figure 4. Pivot End of the Boom

This end of the boom is actually a chisel blade. Its edge butts up against a chrome plated bolt head. Ballast weights are located on the plate below the pivot point.

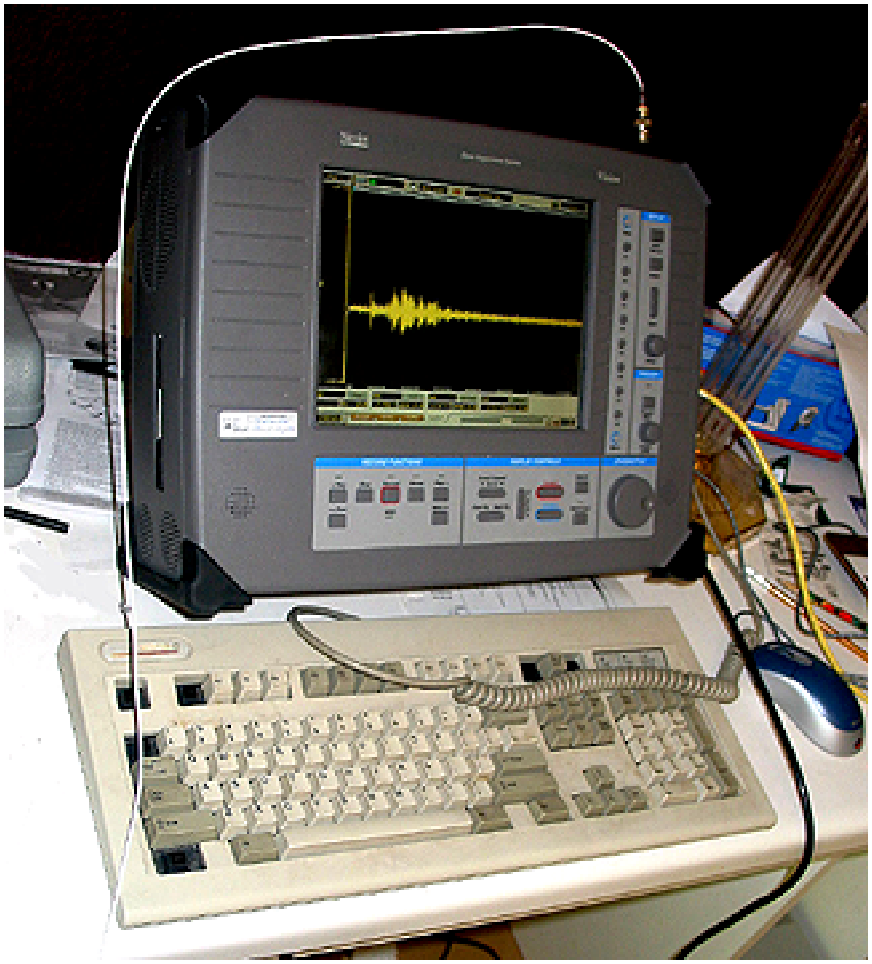


Figure 5. Nicolet Vision Data Acquisition System

The trace is the displacement time history of the Solomon Island earthquake as measured by the Lehman seismometer via the inductive sensor.

I use this same acquisition system for measuring pyrotechnic shock in launch vehicle stage separation tests. I also use it for rocket nozzle frequency response tests.

The Nicolet is a completely gold-plated Cadillac solution for the Lehman seismometer, but I wanted to do this science project with some style.

The Nicolet sample rate is set to 50 samples per second. Its lowpass filter is set to 5 Hz.

Figure 6. Highpass Filter

The Krohn-Hite filter is used to highpass filter the displacement signal at 0.03 Hz prior to its input to the Nicolet system. It also provides a 20 dB gain.

This filter was purchased on eBay.

Figure 7. DC Power Supply for Displacement Sensor

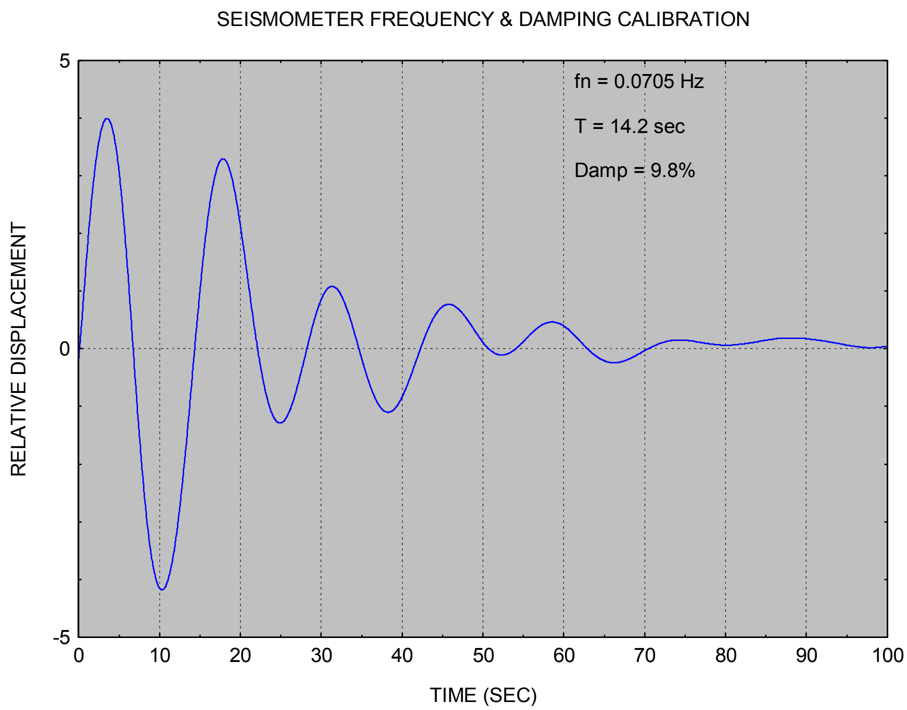


Figure 8.

The seismometer was set in to oscillation by tapping the ballast disk near the free end. The resulting signal is approximately a damped sinusoid.

Here are some references for building seismometers:

1. "The Amateur Scientist," Scientific American, pp 152-162, January, 1963.

2. Lehman, J.D., Practical seismograph tracks tremors, The Science Teacher, v. 44, no. 8, 43-45, 1977.

2. Walker, J., "How to build a simple seismograph to record earthquake waves at home," Scientific American, vol 241, #1, pp. 152-161, 1979.

3. Averill, G.E., "Build your own seismograph: An earth-shaking, in-class project," The Science Teacher, vol 62, #3, pp. 48-52, March 1995.

Solomon Island Earthquake by Tom Irvine

Introduction

The Solomon Islands consist of over 900 islands, some of which were formed by volcanoes. These islands are located near the boundary where the northward-moving Indo-Australian plate is subducted below the Pacific plate.

The Solomon Islands are a part of the Pacific "Ring of Fire." Volcanoes and earthquakes are common along this ring. As an example, Kavachi is an active underwater volcano, located approximately 25 km south of Vangunu Island in the Western Solomon region. This volcano had an eruption in May 2002.

October Earthquake

A magnitude 6.8 earthquake occurred about 65 km SSE of Kira Kira, San Cristobal, which is one of the Solomon Islands. The date was October 8, 2004. The focal depth was 37.5 km.

Fortunately, no injuries or property damage were reported. A formal description of the earthquake from the U.S. Geological Service is given at the end of this article.

Earthquake Seismograms

The Earth is an extraordinary conductor of seismic energy. Earthquake waves of sufficient magnitude that originate on one side of the globe can be detected by seismometers on the opposite side.

I was thus able to measure waves from the Solomon Island quake on my Lehman seismometer, located at my home in Mesa, Arizona. The results are plotted in the following figures.

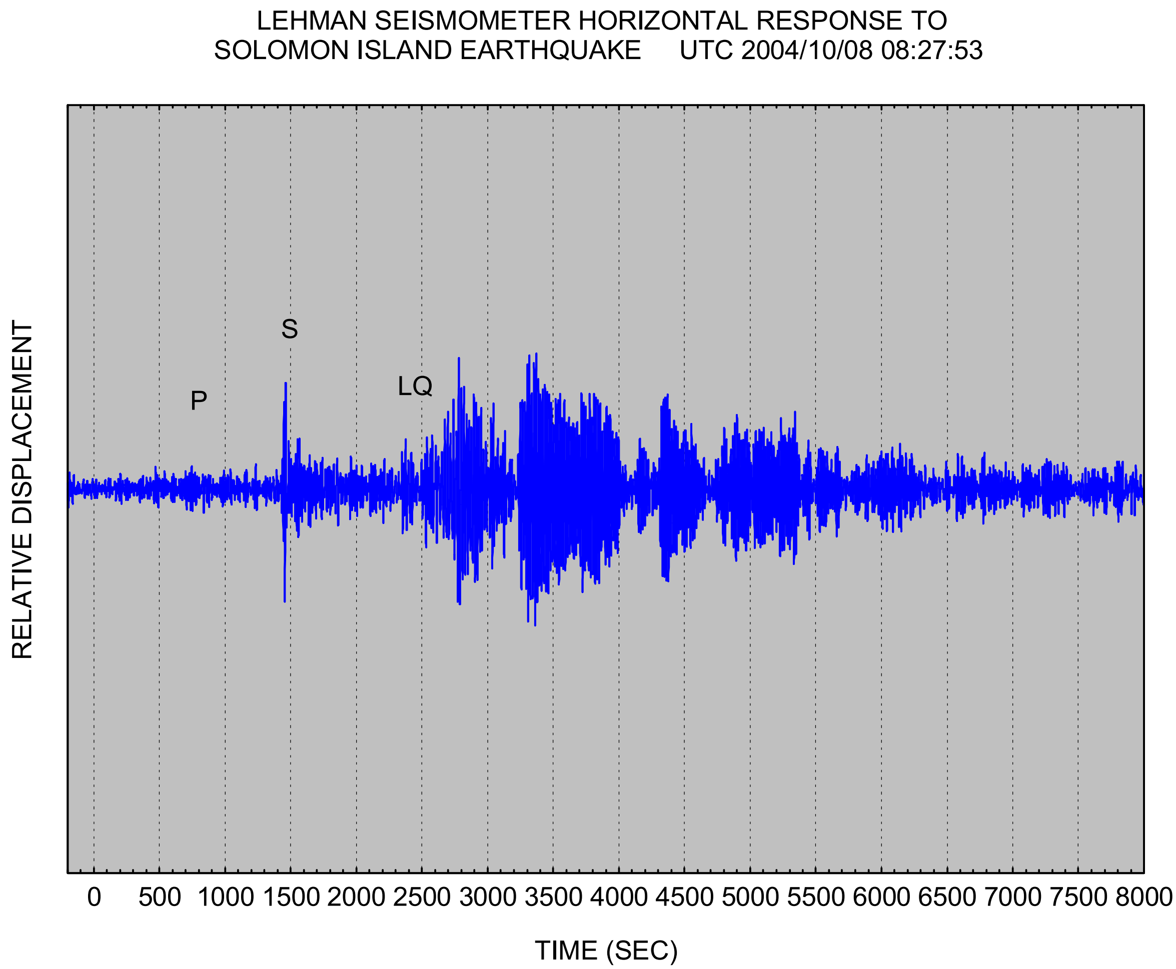


Figure 1.

The time is referenced to the earthquake occurrence using the USGS data. The plot's Y-axis is labeled as relative displacement because it is the response of the boom relative to the ground. Further calculation would be required to estimate the true ground motion.

The time history shows that the Earth is remarkably reverberant. The oscillations last well over one hour.

The phase components are

P	primary wave
S	secondary or shear wave
LQ	Love wave

The P-wave is indiscernible against the background microseismic noise. Nevertheless, it can be extracted by additional filtering, as shown in the next figure.

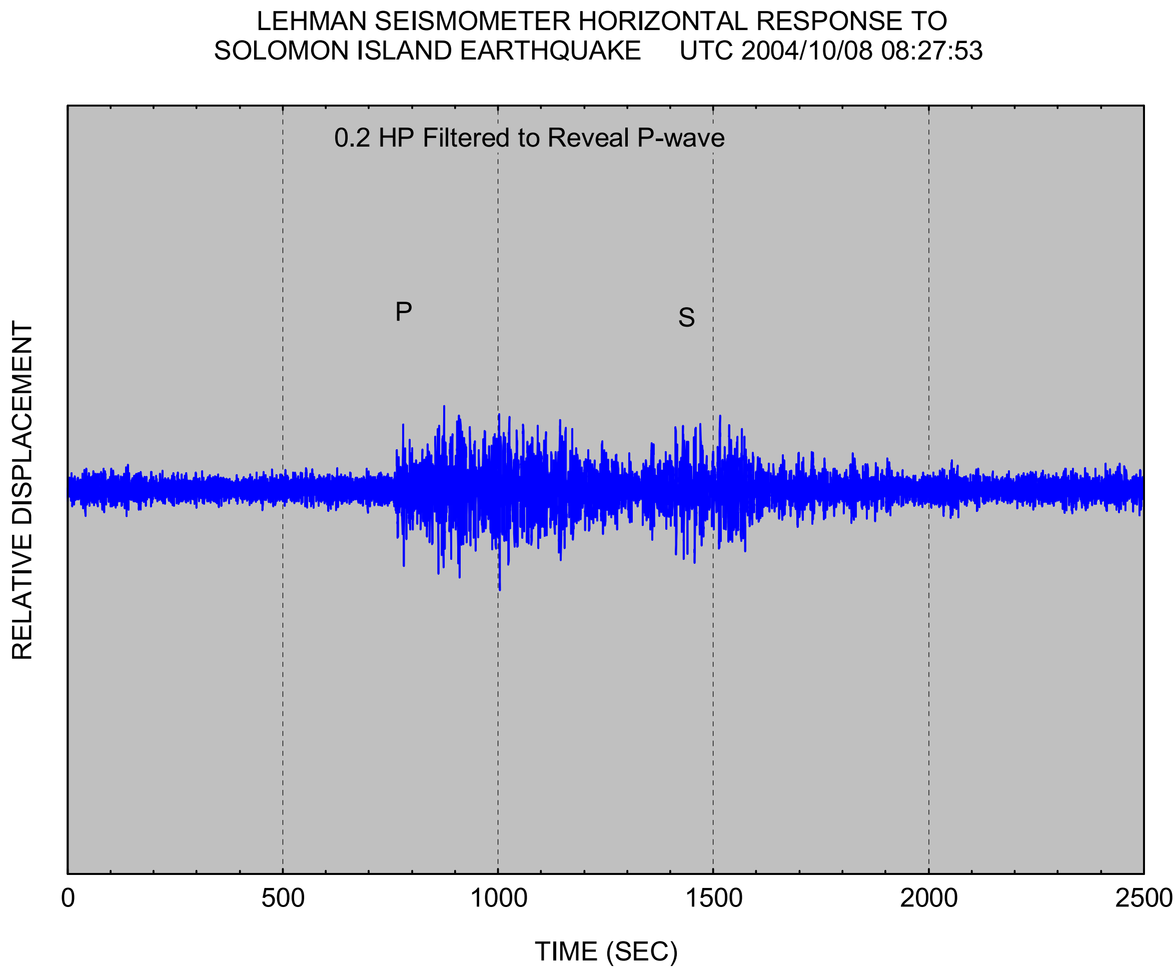

LEHMAN SEISMOMETER HORIZONTAL RESPONSE TO
SOLOMON ISLAND EARTHQUAKE UTC 2004/10/08 08:27:53
0.2 HP Filtered to Reveal P-wave
P
S
RELATIVE DISPLACEMENT
0
500
1000
1500
2000
2500
TIME (SEC)

Figure 2.

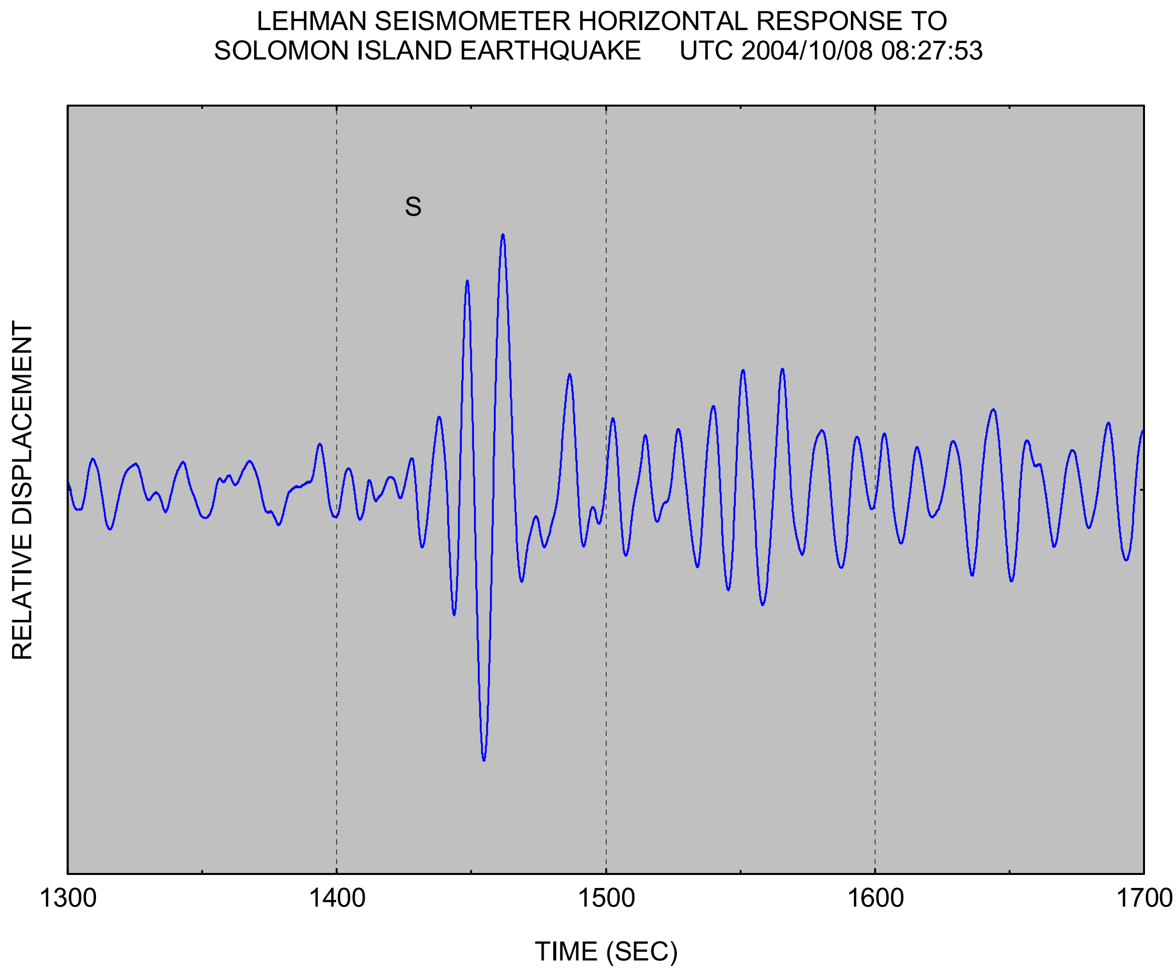

LEHMAN SEISMOMETER HORIZONTAL RESPONSE TO
SOLOMON ISLAND EARTHQUAKE UTC 2004/10/08 08:27:53
S
RELATIVE DISPLACEMENT
1300
1400
1500
1600
1700
TIME (SEC)

Figure 3.

Waterfall FFT of Relative Displacement for Solomon Island Earthquake

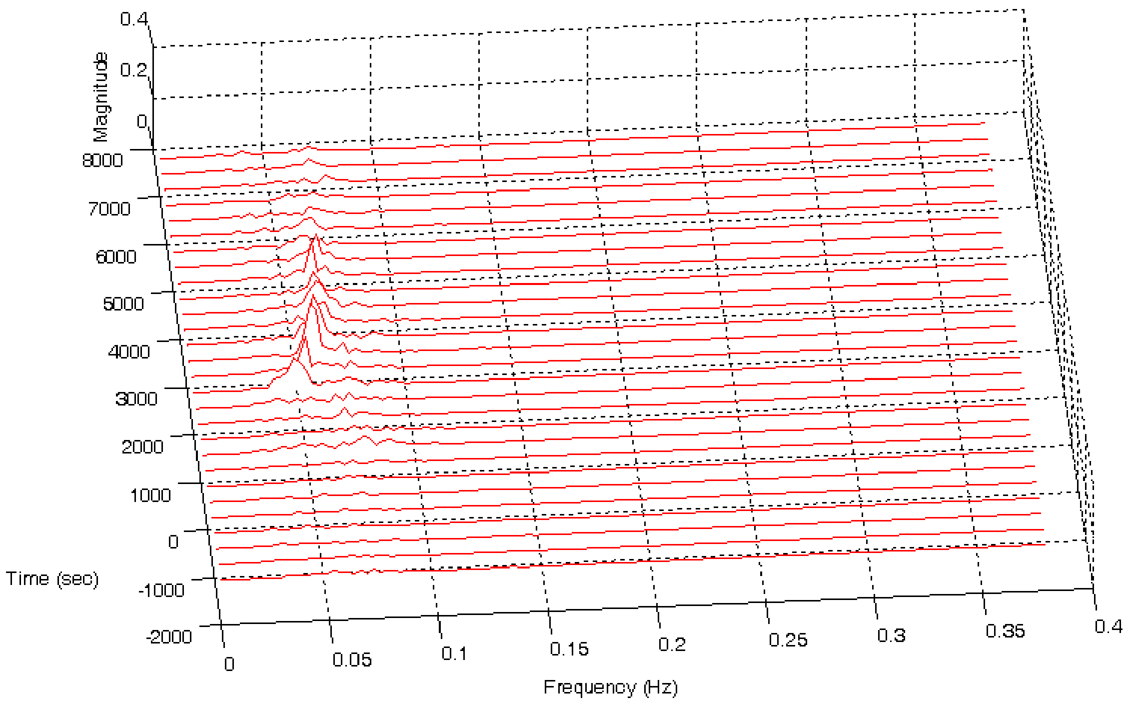


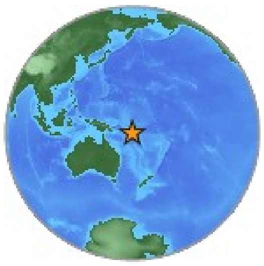
Figure 4.

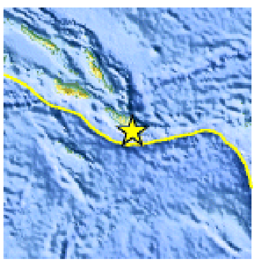
Again, the natural frequency of the seismometer is 0.07 Hz. The dominant spectral peak frequency tends to sweep slightly upward with respect to time.

Preliminary Earthquake Report

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

A strong earthquake occurred at 08:27:53 (UTC) on Friday, October 8, 2004. The magnitude 6.8 event has been located in the SOLOMON ISLANDS. (This event has been reviewed by a seismologist.)





Magnitude **6.8**

Date-Time **Friday, October 8, 2004 at 08:27:53 (UTC)**
= Coordinated Universal Time
Friday, October 8, 2004 at 7:27:53 PM
= local time at epicenter
Time of Earthquake in other Time Zones

Location 10.994°S, 162.141°E

Depth 37.5 km (23.3 miles) set by location program

Region **SOLOMON ISLANDS**

Distances
65 km (40 miles) SSE of **Kira Kira, San Cristobal, Solomon Isl.**
295 km (180 miles) SE of **HONIARA, Guadalcanal, Solomon Islands**
295 km (180 miles) SSE of **Auki, Malaita, Solomon Islands**
2055 km (1280 miles) NNE of **BRISBANE, Queensland, Australia**

Location Uncertainty horizontal +/- 7.5 km (4.7 miles); depth fixed by location program

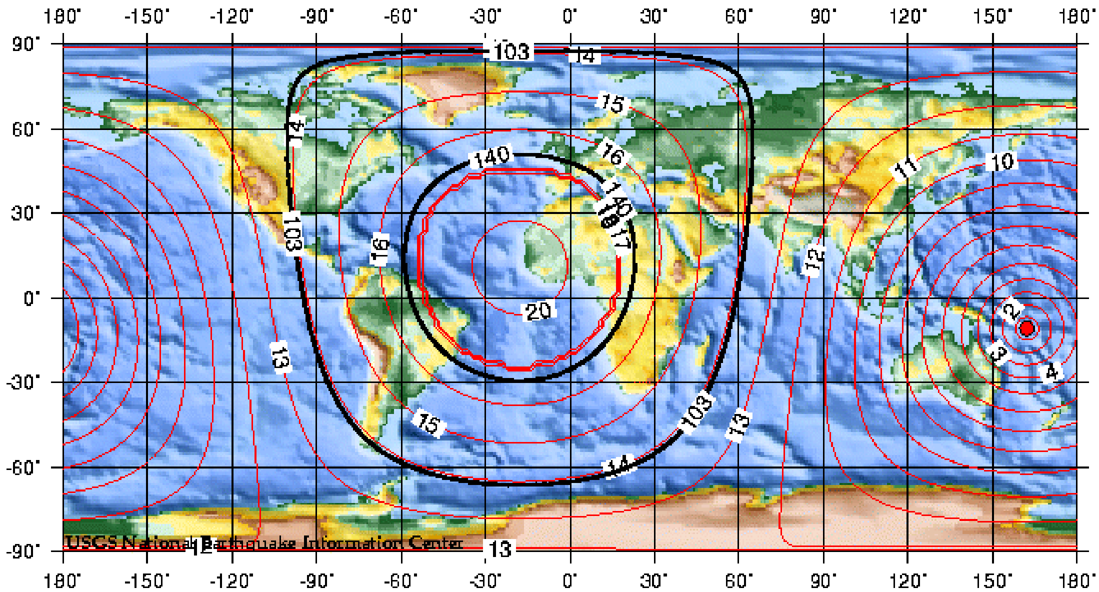
Parameters Nst=206, Nph=206, Dmin=>999 km, Rmss=0.88 sec, Gp= 25°,
M-type=moment magnitude (Mw), Version=8

Source USGS NEIC (WDCS-D)

Magnitude 6.8 SOLOMON ISLANDS
Friday, October 08, 2004 at 08:27:53 UTC

Preliminary Earthquake Report

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver



This map shows the predicted (theoretical) travel times, in minutes, of the compressional (P) wave from the earthquake location to points around the globe. The travel times are computed using the spherically-symmetric IASP91 reference earth velocity model. The heavy black lines shown are the approximate distances to the P-wave shadow zone (103 to 140 degrees).

Phase Arrival Times from Solomon Islands to Mesa, Arizona

The Mesa recording station (i.e. my home) has a latitude of 33.382 deg and a longitude of -111.866 deg.

The earthquake source parameters are:

DATE-(UTC)-TIME	LAT	LON	DEPTH	MAG
2004/10/08 08:27:53	10.99S	162.14E	37.5	6.8

US: SOLOMON ISLANDS

Expected 20s period surface wave amplitude
[3.44E+01 μm] [1.08E+01 μm/s]

Expected 1s period body wave amplitude
[3.98E-01 μm] [2.50E+00 μm/s]

The arrival time for the Solomon Island seismic waves to reach Mesa, Arizona are:

delta (deg)	azimuth (degrees clockwise from north) eq-to-station	station-to-eq
92.65	56.7	258.7

#	code	travel time(s)	arrival time dy	hr	mn	sec
1	P	787.78	0	8	41	0
2	PcP	788.30	0	8	41	1
3	pP	799.50	0	8	41	12
4	sP	804.04	0	8	41	17
5	PP	1009.51	0	8	44	42
6	PKiKP	1075.90	0	8	45	48
7	pPKiKP	1087.98	0	8	46	0
8	sPKiKP	1092.44	0	8	46	5
9	SKiKP	1287.33	0	8	49	20
10	SKSac	1417.87	0	8	51	30
11	pSKSac	1433.97	0	8	51	46
12	SKKSac	1435.08	0	8	51	48
13	sSKSac	1438.55	0	8	51	51
14	S	1449.62	0	8	52	2
15	ScS	1451.30	0	8	52	4
16	pS	1464.97	0	8	52	17
17	sS	1469.78	0	8	52	22
18	SP	1521.46	0	8	53	14
19	SPn	1522.76	0	8	53	15
20	PS	1526.52	0	8	53	19
21	PnS	1527.89	0	8	53	20
22	PKKPdf	1816.55	0	8	58	9

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23  PKKPbc    1818.78   0  8 58 11
24  SS        1823.77   0  8 58 16
25  SKKPdf    2027.91   0  9  1 40
26  PKKSdf    2032.37   0  9  1 45
27  SKKPbc    2034.93   0  9  1 47
28  PKKSbc    2039.40   0  9  1 52
29  SKKSdf    2243.55   0  9  5 16
30  SKKSac    2254.29   0  9  5 27
31  P'P'df    2310.39   0  9  6 23
32  S'S'df    3170.87   0  9 20 43
33  S'S'ac    3172.55   0  9 20 45
34  LQ        2351.65   0  9  7  4
35  LR        2610.00   0  9 11 23
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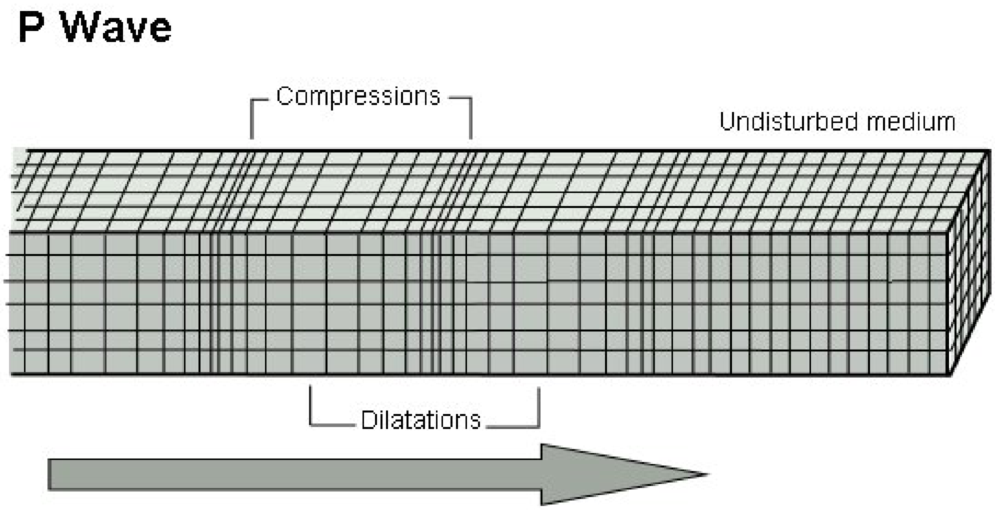
* *

Characteristic Seismic Wave Periods		
Wave Type	Period (sec)	Natural Frequency (Hz)
Body	0.01 to 50	0.02 to 100
Surface	10 to 350	0.003 to 0.1

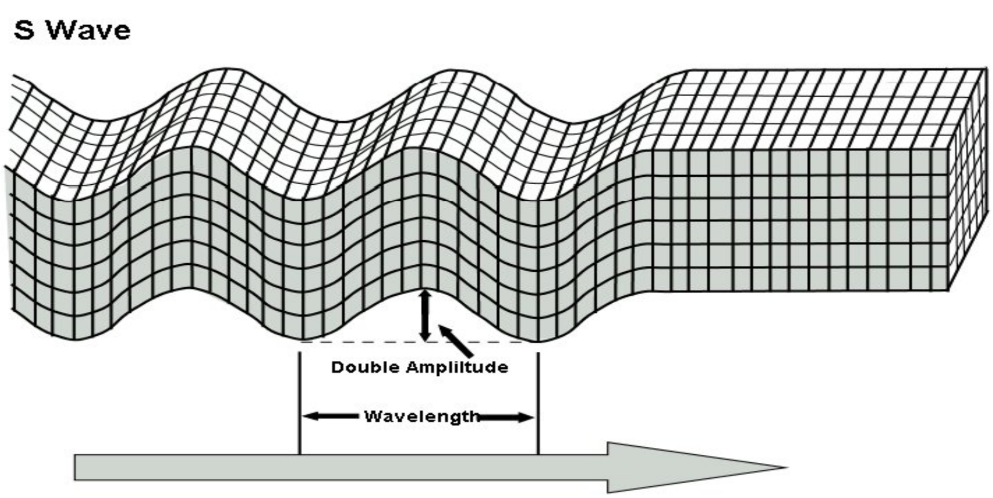
Reference: Lay and Wallace, Modern Global Seismology

Seismic Waveform Review by Tom Irvine



The primary wave, or P-wave, is a body wave that can propagate through the Earth's core. This wave can also travel through water.

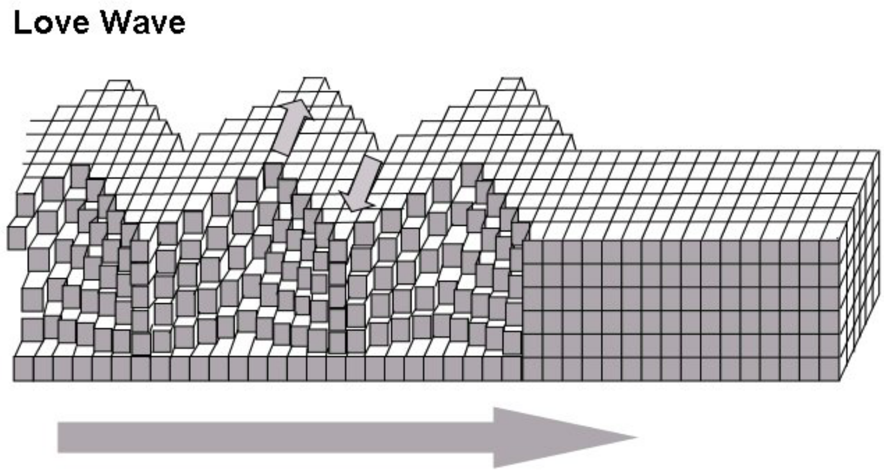
The P-wave is also a sound wave. It thus has longitudinal motion. Note that the P-wave is the fastest of the four waveforms.



The secondary wave, or S-wave, is a shear wave. It is a type of body wave.

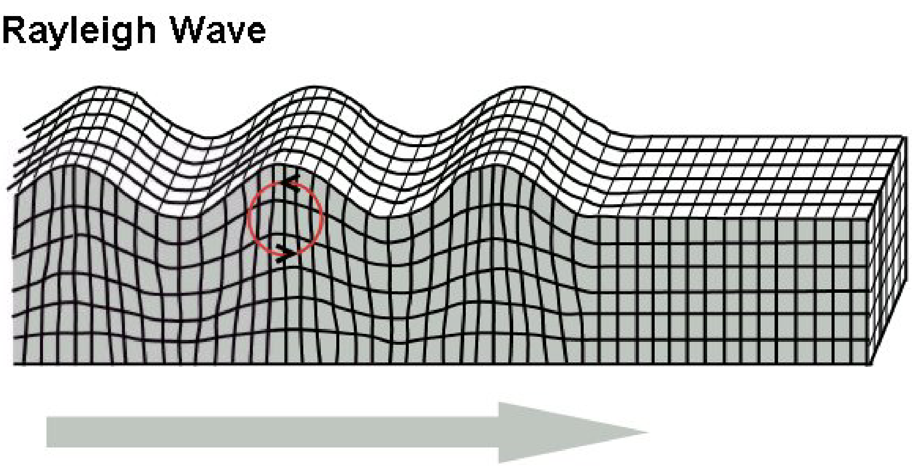
The S-wave produces an amplitude disturbance that is at right angles to the direction of propagation.

Note that water cannot withstand a shear force. S-waves thus do not propagate in water.



Love waves are shearing horizontal waves. The motion of a Love wave is similar to the motion of a secondary wave except that Love wave only travel along the surface of the Earth.

Love waves do not propagate in water.



Rayleigh waves travel along the surface of the Earth.

Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

A Quake! A Quake! By the Animaniacs

Yakko: It's a quiet, peaceful night
The moon is shining bright
Giving not a hint of what's in store
A few hours before morning
Without a single warning
Something strange begins to move the floor

A quake, a quake
The house begins to shake
You're bouncing 'cross the floor
And watching all your dishes break

You're sleeping; there's a quake
You're instantly awake
You're leaping out of bed
And shouting "Oh for heaven's sake!"

I ran outside with neighbors
Their faces full of shocks
That's because I'm standing there
In nothing but my socks

W+D : Oops!

Yakko: A quake, a quake
This must be a mistake
Just feel the ground
Go up and down
Won't someone hit the brake?

A quake, a quake
Oh, what a mess they make
The bricks, the walls
The chimney falls
Destruction in its wake

I did not have insurance
I called them from the scene
And suddenly I'm listening
To an answering machine

Say "Too late, too late
You shouldn't ought to wait
'Cause now you're stuck
We wish you luck
Here comes a six-point-eight!"

Whose fault, whose fault?
Blame it on the fault
'Cause Mister Richter Can't predict her
Kicking our asphalt

Seismologists all say
Tectonic plates are in between
An encroaching crustal mantle
Yeah, so what the heck's that mean?

It means a quake, a quake
W+D : Oh really, yeah, no fake?
We kind of had that feeling
When the ground began to shake

Yakko: And so we wait
Resign ourselves to fate
Because our lawn
Is sitting on
A continental plate

We shivered through a blizzard
Went swimming in a flood
Then we blew off a hurricane
And now we hear a thud

Of a quake, a quake
How much more can we take?
We thought that we had seen it all
But this one takes the cake

The dirt, the rocks
Those crazy aftershocks
It's just the planet
Moving granite
Several city blocks

*YW+D: Now the town is falling down
* While the ground
* Moves around
* We won't let it get us down
* Get beneath the door frame

Yakko: A quake, a quake
It's time to pull up stake
Dot : The worst is over
Y+W : We don't buy it
We're fed up
We can't deny it
We just want some peace and quiet
YW+D : So we're moving to Beirut!

* - sung to "London Bridge"

Transcribed by David Orozco