Seismic Monitoring

Presentation to:
Year 3 Physics Students
Class of 2009
UWI, St. Augustine
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Seismic Research Centre, UWI

Les Saintes Earthquake (2006). Damage to church in Northern Dominica
Seismic Monitoring

1. Nature of Earthquakes
2. Earthquakes in the Caribbean
3. Earthquake Hazards and Risk
4. Need for monitoring
5. Just what are we looking for?
6. Seismometry
7. Seismic Networks
What is an Earthquake?

A sudden, sometimes violent movement in the earth that is caused by rupture on a sub-surface fault.

The energy which is released is converted to seismic waves which radiate from the earthquake focus. These seismic waves cause ground shaking and can be measured using seismometers.
Earthquake can be Extremely Damaging to the built environment

The number one cause of damage from earthquakes is due to failures in the built environment from ground shaking

(The number two cause is tsunamis)

1999 Izmit, Turkey earthquake
Caribbean Plate

Northern & Eastern margins are Ocean-Ocean plate boundary

South-eastern margin - Triple junction

Eastern margin - Subduction Zone >> Volcanism & Inclined plane seismicity

Northern margin - Subduction, Strike-Slip and spreading zone
The Quill, St. Eustatius
The Bottom, Saba
The Quill, St. Eustatius

Sulphur Springs, St. Lucia

Morne Aux Diables, Dominica

Volcanoes of the Eastern Caribbean

Mt. Liamuiga, St. Kitts
Nevis Peak, Nevis

Morne Aux Diables, Dominica

La Soufriere, Guadeloupe

Soufriere Hills, Montserrat

Sulphur Springs, St. Lucia

Montagne Pelee, Martinique

The Soufriere, St. Vincent

Kick ‘em Jenny

Mt St. Catherine, Grenada
Caribbean earthquakes The instrumental Period

This slide shows earthquakes since 1964. Note that although there is far greater detail, the general pattern is the same.
Historical Seismicity of the Caribbean
Caribbean Fatalities from Earthquakes and Tsunamis (1500 – 2000)

**Earthquake Fatalities (1600-1999)**

- Total Deaths – 16,500

**Destructive Tsunamis and some Fatalities (1500-1999)**

- Total Deaths – 360, 20 events
## Return Periods of Large Earthquakes

<table>
<thead>
<tr>
<th>Earthquake Magnitude</th>
<th>Caribbean</th>
<th>Atlantic and Caribbean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felt Event</td>
<td>85/year</td>
<td>N/A</td>
</tr>
<tr>
<td>Mw &gt;= 5.0</td>
<td>50/year</td>
<td>N/A</td>
</tr>
<tr>
<td>Mw &gt;= 6.5</td>
<td>1/3 years</td>
<td>1/year</td>
</tr>
<tr>
<td>Mw &gt;= 7.0</td>
<td>1/5 years (?)</td>
<td>1/3 years (?)</td>
</tr>
<tr>
<td>Mw &gt;= 7.5</td>
<td>1/8 years (?)</td>
<td>1/6 years (?)</td>
</tr>
<tr>
<td>Mw &gt;= 8.0</td>
<td>1/100 yrs (?)</td>
<td>1/50 yrs (?)</td>
</tr>
</tbody>
</table>
Probabilistic seismic hazard model (after Cornell 68)
Probabilistic method of analysis - Cornell method

1. Selection of a homogenous earthquake catalogue for the target region

2. Identification of active and potentially active seismic sources from
   Patterns of seismicity
   Surface geological features
   General seismotectonic theory

3. Estimation of the rate of activity of each source

4. Selection of appropriate attenuation relationships for estimation of
   an appropriate measure of strong ground motion as a function of
   earthquake magnitude, distance and focal depth.

5. Estimation of the probability of different levels of ground motion in
   different periods of time
IBC2000 uses hazard maps in which the Maximum Credible Earthquakes Spectral Accelerations at 0.2s and 1.0s are determined.
RISK $F(NH, V)$

Underlying Risk Sources

Uncontrollable

Natural Hazards

Severe Natural Event

Resilience of Environment

Controllable

Vulnerability

Presence of Human Settlement

Fragility to Natural Hazards

Environmental Degradation
Performance objectives as a function of hazard level for different building types.
Information gathered from Seismic Monitoring are Key ingredient for activities in an Earthquake Risk Reduction Program
SEISMIC MONITORING

What do we want to measure?

Movements of the Earth’s surface

Deformation => Tilt, Strain
Vibrations => Elastic Waves

Sources of such movement:

Tectonics        Tides
Erosion          Earthquakes
Volcanoes        Meteorites
                 anthropogenic
The Electromagnetic Spectrum

\[ \mu m = \text{micron} \]

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Type of radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^5 \text{m} )</td>
<td>Long radio waves</td>
</tr>
<tr>
<td>(10^4 \text{m} )</td>
<td>AM radio broadcasts</td>
</tr>
<tr>
<td>(10^3 \text{m} )</td>
<td>short radio waves</td>
</tr>
<tr>
<td>(10^2 \text{m} )</td>
<td>TV broadcasts</td>
</tr>
<tr>
<td>(10 \text{m} )</td>
<td>FM radio broadcasts</td>
</tr>
<tr>
<td>(1 \text{m} )</td>
<td>TV broadcasts</td>
</tr>
<tr>
<td>(0.1 \text{m} )</td>
<td>Microwaves</td>
</tr>
<tr>
<td>(0.01 \text{m} )</td>
<td>Infrared radiation</td>
</tr>
<tr>
<td>(1 \text{mm} )</td>
<td>visible light</td>
</tr>
<tr>
<td>(0.1 \text{mm} )</td>
<td>Ultraviolet radiation</td>
</tr>
<tr>
<td>(0.01 \text{mm} )</td>
<td>X rays</td>
</tr>
<tr>
<td>(0.001 \text{mm} )</td>
<td>Gamma rays</td>
</tr>
<tr>
<td>(0.0001 \text{mm} )</td>
<td></td>
</tr>
</tbody>
</table>

- red light: \(0.710 \mu m\)
- orange light: \(0.647 \mu m\)
- yellow light: \(0.585 \mu m\)
- green light: \(0.575 \mu m\)
- blue light: \(0.491 \mu m\)
- violet light: \(0.420 \mu m\)
Spectrum of Earth Mechanics

- Slumps, Landslides, Rockfalls
- Erosion
- Eigen-Vibrations
- Cracking in Rocks
- Mountain Building
- Isostatic Rebound
- Tides
- Seismic Waves
- Plate Drift
- Rupture Processes, Earthquakes, Chem. and Nuclear Expl.

Time Scale

10000 yr 100 yr 1 yr 1 mo 1 wk 1 d 1 h 1 m 1 s 0.1 s 0.01 s
Spectrum of Earth Vibrations

- Wide Band Seismometer
  - computed response for quiet site, high signal-to-noise ratio
  - direct response
  - Cultural Noise
- LP Wind Noise
- SP Wind Noise
- Seismic Prospecting
- Ocean Microseisms
- Volcanic Tremor
- Earth Tides
- Surface Waves
- Eigenvibrations
- Body Waves

Period/Frequency

$10^5$ $10^4$ $10^3$ $10^2$ $10^1$ $10^0$ $10^{-1}$ $10^{-2}$ $10^{-3}$ [s]

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^0$ $10^1$ $10^2$ $10^3$ [Hz]

$10^{-2}$ $10^{-1}$ $10^0$ $10^1$ [mHz]
Earth's vibrations (transient motions) cover a period range of > 9 orders of magnitude (>1d to <1/1000 sec)

**Instruments used:**

- Seismometers
- Gravimeters
- Tiltmeters
- Strainmeters
- Dilatometers
- GPS
Every Earthquake generates Seismic Waves
What are Seismic Waves?

Elastic vibrations which propagate through the Earth
Two types of Seismic Waves exist:

- **Body Waves**
- **Surface Waves**

The diagram shows the propagation of waves with distances marked as:
- $t = 75\, \text{ms}$
- $t = 150\, \text{ms}$
- $t = 225\, \text{ms}$
- $t = 300\, \text{ms}$

The velocity is given as $v = 1500\, \text{m/s}$.
Body Waves come in two flavors......
Body Waves

\[ v_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{\kappa + 4\mu/3}{\rho}} \]

Bulk modulus \( \kappa = \Delta P / (\Delta V / V) \) \( \Rightarrow \)

Shear modulus or "rigidity" \( \mu = (\Delta F / A) / (\Delta L / L) \) \( \Rightarrow \)

Young’s or “stretch” modulus \( E = (F / A) / (\Delta L / L) \) and Poisson ratio \( \sigma = (\Delta W / W) / (\Delta L / L) \) \( \Rightarrow \)

\[ \frac{v_p}{v_s} = \sqrt{3} \]

Deformation of material samples for determining elastic moduli

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Surface Waves

- Form at the free surface
- Amplitude decays exponentially with depth.
<table>
<thead>
<tr>
<th>Period</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body waves</td>
<td>0.01 to 50 sec</td>
</tr>
<tr>
<td>Surface waves</td>
<td>10 to 350 sec</td>
</tr>
<tr>
<td>Free Oscillations</td>
<td>350 to 3600 sec</td>
</tr>
<tr>
<td>Static Displacements</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

Courtesy J. Mori
Seismometer:

- An instrument to record seismic waves (vibrations caused by earthquakes or explosions)
- Today’s seismometers use electromagnetic feedback to hold the mass still. This allows seismometers to be made more compact and sensitive.

Guralp CMG-3T

Teledyne GS-13

Streckeisen STS-2
Realisation: Inertial pendulum with damping

transient ground motion $x(t)$ is converted via inertial mass motion $y(t)$ into a time dependent reference frame $z(t)$

$M = \text{mass}$

$S = \text{spring}$

$R = \text{damping}$
3.1 Mechanical Systems

Horizontal Pendulum
Forces Acting on the System

mass' inertia \( F_m = m \frac{dy^2}{dt^2} \)

damping \( F_R = c \frac{dy}{dt} \)

spring (Hooke's law) \( F_s = -k y \)

ground movement \( F_g = -m \frac{dx^2}{dt} \)

\[ F_m + F_R + F_s = F_g \]

Equation of Motion
divide by m and substitute k/m = \omega_0^2
c/m = 2\beta\omega_0

define eigenfrequency \omega_0
damping constant \beta

\frac{dy^2}{dt^2} + 2\beta\omega_0 \frac{dy}{dt} + \omega_0^2 y = -\frac{dx^2}{dt^2}

Basic Equation for Seismometry

complex solution

y(t) = y_0 e^{i\omega t}
change from time domain to frequency domain

\[ x(t) => X(\omega) \quad y(t) => Y(\omega) \]

\( X(\omega) \) spectrum of ground movement
\( Y(\omega) \) spectrum of seismometer output

\[
H(i\omega) = \frac{Y(\omega)}{X(\omega)}
\]

Transfer Function
Transfer Function

describes response of seismometer in amplitude \( H(\omega) \) and phase \( \phi(\omega) \)

\[
H(\omega) = \frac{\omega^2}{((\omega_0^2 - \omega^2)^2 + 4\beta^2\omega_0^2\omega^2)^{1/2}}
\]

\[
\phi(\omega) = \frac{2\beta \omega_0 \omega}{\omega_0^2 - \omega^2}
\]
Electromagnetic Transducer
current induction due to ground movement
Transfer Functions

- Displacement
- Velocity
- Acceleration

Mechanical sensor

Electromagnetic sensor
Modern Seismic Instruments use feedback principle to extend
The dynamic and frequency range of the response.

Capacitive transducer feeds information about inertial mass
movement into coil, which holds the mass in place.
Short period sensors do not record long period signals.
Where is a good place to put a seismometer?

- Far from human-generated noise (roads and machinery)
- At a secure location
- Far from the ocean
- On solid (competent) rock
- In a temperature-stable environment
Accelerometers

An “insensitive” (strong motion) seismometer: good for recording violent shaking

Kinemetrics FBA-23
Why more than one kind of seismometer is used

Global networks choose instruments capable of recording long period waves. Local arrays may use short period sensors to record local earthquakes.
A note on noise at seismic stations.

The quietest stations in the world are on continents.

Stations near the ocean are noisier.
Sensor Selection and DAS Resolution

- LC4 SP Seis.
- Guralp CMG4T BBSeis (110 dB)
- CMG 5T Accel.
- 16-bit ADC -2 gain ranges
- Kinemetric K2 with FBA Accel. on serial port of DAS
Other equipment needed:

- Clock to time the data
- “DAS” to convert electric current to numbers for a computer to process
  - The DAS converts electrical current from the seismometer into numbers to be processed by the computer. The electrical current from the seismometer is continuous, but the DAS produces numbers only at set intervals of time, the *digitization rate*. The DAS bundles these numbers into a packet called a *data record*. 
Data Telemetry

To transmit data, the following must be considered:

- Type of circuit to carry the data
- Format of the data
- The computer application(s) to manage the data transmission

Types of circuits

- local area network (LAN)
- leased telephone lines
- VSATs
- local Internet service provider (ISP)
Data archiving:
On-site recording media

- DAT tape
- CD-R
- DVD?
Analog Seismic Station (1954)

Wilmore photographic seismograph
Ten broadband sensors and 5 strong motion recorders added since 1998

Eruption of the Soufriere Hills Volcano (Montserrat)

Eruption of La Soufriere Volcano (St. Vincent)

Introduction of Telemetry
Micro-earthquake Network (1971)

Components of a Microearthquake Network
Hybrid Network (1985)

Remote Seismic Station → Analog Signal Reception → Analog/Digital Converter → Digital Recording and Data Processing System → Central Recording/Processing Site

Analog Signal Reception

Analog Data Transmission

Time Sync
Each Field Station or monitor can record up to 15 channels of data.

It may be configured to log data continuously or in event triggered mode.

The data is accessed via telephone or via the internet.
Distributed Hybrid System (1998)
Remote Station Equipment

2 x 3-Chan. 24-bit Digitizers

NMXBus cable

Satellite Modem/Transceiver

Satellite Antenna

POWER 12 Volts Mains and/or Solar with Battery Bank

Accelerometer

BB Seismometer
Installing CTEWS Contributing Station at La Pointe, Dominica

VSAT and Vault

Mounting Solar Panel

Battery Pack

Complete Installation, Almost
Array of Real-time HDR/BB Seismic Stations in the Eastern Caribbean for SRU Use

SRU (UWI, T&T)
TRN, SPEY, SVB, DTRR, MCLT, SKI

USGS (U.S.A.)
GRGR, BBGH, ANWB, SDV

IPGP (French W.I.), KNMI (Dutch W.I.)
FDF, SEUS, SABA, SMRT

PRSN (P. Rico)
SJG, MPR, CDVI, ABV

FVIS (Venezuela)
MONV, FUNV, CRUV, GURV, GUIV
Tsunami Monitoring Network Using VSN Technology (Over 40 Stations)
Network Detection Time: SRU TWS

Time (mins) for P-wave from an earthquake in each 1 degree grid cell to be detected by the first 9 stations of a SRU TWS Network. P-wave travel time modeled with the Tau-P method using the IASPEI91 Earth model.
ECSN
Data Processing
Thanks for your attention…

Q & A