Earthquakes:
Because we don’t have enough to worry about.
Earthquakes:
Because we don’t have enough to worry about.
Chile has a different attitude towards earthquakes
Let’s see an earthquake on Live TV (2min)
Chile has a different attitude towards earthquakes
Let's see an earthquake on Live TV (2min)
It's 7:55 PM

Guest: It's while we're live!
It's 7:55 PM

Guest: It's while we're live!
Plenty of earthquakes!
Earthquakes always happen somewhere. Although the average number of large earthquakes per year is fairly constant, they can occur in clusters. However, that does not imply that earthquakes that are distant in location, but close in time, are causally related. The NEIC locates about 12,000–14,000 earthquakes each year. Those records are due to a more-than 10-fold increase in the number of seismic stations worldwide over the past century. The events on the right side of the tower show equivalent magnitude occurrence, and the number, the bigger the earthquake. Significant earthquakes are noted on the shaded tower. The shaded area indicates how many earthquakes of each magnitude occur every year.

**Effects**

- **Magnitude 10**: largest recorded earthquakes, destruction over vast area, massive loss of life
- **Magnitude 9**: great earthquake, severe economic impact, large loss of life
- **Magnitude 8**: major earthquake, damage ($billions), loss of life
- **Magnitude 7**: strong earthquake, property damage
- **Magnitude 6**: moderate earthquake, some property damage
- **Magnitude 5**: light earthquake, noticeable shaking
- **Magnitude 4**: minor earthquake, often felt
- **Magnitude 3**: generally not felt
- **Magnitude 2**: generally not felt

**Energy Equivalents**

- **Hiroshima Atomic Bomb**: magnitude 8.0, energy equivalent of 15,000,000,000,000 kilograms of TNT
- **Mount St. Helens Eruption**: magnitude 5.1, energy equivalent of 15,000,000,000 kilograms of TNT
- **Northridge (1994)**: magnitude 7.1, energy equivalent of 15,000,000,000 kilograms of TNT
- **Chile (1960)**: magnitude 8.0, energy equivalent of 15,000,000,000 kilograms of TNT
- **Japan (2011)**: magnitude 9.0, energy equivalent of 15,000,000,000,000 kilograms of TNT

**Number of Earthquakes per year (worldwide)**

Source: Incorporated Research Institutions for Seismology (US)
Earthquakes are always happening somewhere. Has earthquake activity been increasing? Although the average number of large earthquakes per year is fairly constant, they can occur in clusters. However, that does not imply that earthquakes that are distant in location, but close in time, are causally related. The NEIC locates about 12,000–14,000 earthquakes each year. Those records are produced due to a more-than 10-fold increase in the number of seismic stations world wide over the past century.

The largest recorded earthquake was the Great Chilean Earthquake of May 22, 1960 which had a magnitude of 9.5. The great earthquake in 2004 in Sumatra, Indonesia measuring magnitude 9.1 produced tsunamis that caused widespread disaster in 14 countries. A magnitude 9.0 earthquake in Japan produced an estimating $11 billion to reconstruct. The earthquake released the energy equivalent to 476 million tons of explosive, about 100 times the amount of energy that was released by the atomic bomb that destroyed the city of Hiroshima during World War II.

**Magnitude**

- 10: largest recorded earthquakes
- 9: destruction over vast area
- 8: great earthquake
- 7: severe economic impact
- 6: major earthquake
- 5: damage ($ billions)
- 4: strong earthquake
- 3: property damage
- 2: moderate earthquake
- 1: some property damage
- 0: light earthquake
- <1: generally not felt

**Effects**

- 10: largest recorded earthquakes
- 9: destruction over vast area
- 8: great earthquake
- 7: severe economic impact
- 6: large loss of life
- 5: minor earthquake
- 4: property damage
- 3: light earthquake
- 2: noticeable shaking
- 1: often felt
- 0: generally not felt

**Number of Earthquakes per year (worldwide)**

- 15,000,000,000,000
- 476,000,000,000
- 15,000,000,000
- 476,000,000
- 15,000,000
- 476,000
- 15,000
- 476
- 15

Source: Incorporated Research Institutions for Seismology (US)
Let’s go back in history…
There must be a scientist we can trust!
GEOLGY

AND

NATURAL HISTORY

OF THE

VARIOUS COUNTRIES

VISITED BY H. M. S. BEAGLE.

UNDER THE COMMAND OF CAPTAIN FITZROY, R.N

FROM 1832 TO 1836.

BY

CHARLES DARWIN, ESQ., M.A. F.R.S.

SECRETARY TO THE GEOLOGICAL SOCIETY.
The voyage of the Beagle

a.k.a the “Oh look, Evolution!” world tour
The voyage of the Beagle
a.k.a the “Oh look, Evolution!” world tour
February 20th.—The day has been memorable in the annals of Valdivia, for the most severe earthquake experienced by the oldest inhabitant. I happened to be on shore, and was lying down in the wood to rest myself. It came on suddenly, and lasted two minutes; but the time appeared much longer.
February 20th.—The day has been memorable in the annals of Valdivia, for the most severe earthquake experienced by the oldest inhabitant. I happened to be on shore, and was lying down in the wood to rest myself. It came on suddenly, and lasted two minutes; but the time appeared much longer.

22D.—We sailed from Valdivia, and on the 4th of March, entered the harbour of Concepcion. ... The mayor-domo of the estate quickly rode down to tell us the terrible news of the great earthquake of the 20th;—“that not a house in Concepcion, or Talcuhano, (the port) was standing; that seventy villages were destroyed; and that a great wave had almost washed away the ruins of Talcuhano.” Of this latter fact I soon saw abundant proof; the whole coast being strewed over with timber and furniture, as if a thousand great ships had been wrecked. Besides chairs, tables, bookshelves, &c., in great numbers, there were several roofs of cottages, which had been drifted in an almost entire state.
After viewing Concepcion, I cannot understand how the greater number of inhabitants escaped unhurt.
Big earthquakes (since Darwin) (>= 8.0)
In current Chile

- 1835, Concepción, 8.1 (est)
- 1837, Valdivia, 8.8-9.5 (est)
- 1868, Arica, 8.5-9.0 (est)
- 1877, Iquique, 8.7-8.9
  (Tsunami killed 5000 in Fiji and 5 in Hawaii)
Big earthquakes (since Darwin) (>= 8.0)
In current Chile

- 1835, Concepción, 8.1 (est)
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- 1906, Valparaíso, 8.2
- 1922, Vallenar, 8.5 (15th prize!)
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• 1835, Concepción, 8.1 (est)
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• 1877, Iquique, 8.7-8.9
  (Tsunami killed 5000 in Fiji and 5 in Hawaii)
• 1906, Valparaíso, 8.2
• 1922, Vallenar, 8.5 (15th prize!)
• 1939, Chillán, 8.3
• 1943, Ovalle, 7.9-8.2
• 1960, Concepción, 8.3
• 1960, Valdivia, 9.4-9.6 (1st prize!)
Big earthquakes (since Darwin) (≥ 8.0)
In current Chile

- 1835, Concepción, 8.1 (est)
- 1837, Valdivia, 8.8-9.5 (est)
- 1868, Arica, 8.5-9.0 (est)
- 1877, Iquique, 8.7-8.9
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- **1960, Valdivia, 9.4-9.6** (1st prize!)
Big earthquakes (since Darwin) (>= 8.0) in current Chile

- 1835, Concepción, 8.1 (est)
- 1837, Valdivia, 8.8-9.5 (est)
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- 1943, Ovalle, 7.9-8.2
- 1960, Concepción, 8.3
- **1960, Valdivia, 9.4-9.6** (1st prize!)
- 1985, Algarrobo, 8.0
- 1995, Antofagasta, 8.0
- 2010, Concepción, 8.8 (6th prize!)
- 2014, Iquique, 8.2
- 2015, Illapel, 8.5
Big earthquakes (since Darwin) (>= 8.0)
In Canada and Contiguous United States

- 1899 Yukon-Alaska Border, 8.0
- 1949 Haida Gwaii, 8.1
Big earthquakes (since Darwin) (>= 8.0)
In Canada and Contiguous United States

- 1899 Yukon-Alaska Border, 8.0
- 1949 Haida Gwaii, 8.1
- That’s it.
THE REALLY BIG ONE

An earthquake will destroy a sizable portion of the coastal Northwest. The question is when.

By Kathryn Schulz
July 13, 2015
Big earthquakes (since Darwin) (>= 8.0)

In current Chile

- 1835, Concepción, 8.1 (est)
- 1837, Valdivia, 8.8-9.5 (est)
- 1868, Arica, 8.5-9.0 (est)
- 1877, Iquique, 8.7-8.9
  (Tsunami killed 5000 in Fiji and 5 in Hawaii)
- 1906, Valparaíso, 8.2
- 1922, Vallenar, 8.5 (15th prize!)
- 1939, Chillán, 8.3
- 1943, Ovalle, 7.9-8.2
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- **1960, Valdivia, 9.4-9.6** (1st prize!)
- 1985, Algarrobo, 8.0
- 1995, Antofagasta, 8.0
- **2010, Concepción, 8.8** (6th prize!)
- 2014, Iquique, 8.2
- 2015, Illapel, 8.5
February 27th, 2010
(a Saturday)
February 27th, 2010 (a Saturday)
(If the roof collapses over my bed, can I easily get out of the rubble? ...)
(If the roof collapses over my bed, can I easily get out of the rubble? ...
(If the roof collapses over my bed, can I easily get out of the rubble? ... Yes.
(If the roof collapses over my bed, can I easily get out of the rubble? ... Yes.
(If the roof collapses over my bed, can I easily get out of the rubble? ...)

Yes. Let’s ride it out and go back to sleep.
(If the roof collapses over my bed, can I easily get out of the rubble? …

Yes. Let’s ride it out and go back to sleep.
Sister: “Is everybody alright?? Where’s Felipe??”
Sister: “Is everybody alright???
Where’s Felipe??”
Me:
Sister: “Is everybody alright???
Where’s Felipe??”
Me: (Damn, I’ll have to get up now.)
Sister: “Is everybody alright???
Where’s Felipe??”
Me: “I’m ok, I’m up!”
There’s no power.
Power is gone
[Araneda et al. 2010]

- Immediate blackout with 4.5 GW out of the power grid (for reference, that’s the total power generation capacity of the province of Saskatchewan)

- Distribution (transformers, power lines etc) in several places take days or even weeks to repair.
There’s no power.
Lesson 1: 
You’ll need a light source
Mom: “Get all the pots and fill them with water, also the tub.”
There’s no power.
There's no power.
There's no power,
There's no water.
There’s no power,
There’s no water.
The water mains of Metro Vancouver
The water mains of Metro Vancouver
Map created on Fri Nov 27 2020

Metro Vancouver makes no warranties or representations regarding the accuracy or currency of information provided on this map.

This map may not be reproduced or redistributed without the consent of Metro Vancouver.
Lesson 2:
You’ll need water.
about 4lt per person per day
(plan for 3 days min)

plus the toilet
Everybody is safe, we have (some) light, we have water.
Everybody is safe, we have (some) light, we have water.

Q: Is everybody else safe?
Text “We are safe” to someone out of the area
Text “We are safe” to someone out of the area

The internet should work
Text “We are safe” to someone out of the area.

The Internet should work.
Text “We are safe” to someone out of the area.

The internet should work.
“I’ll check on the news sites some info about the earthquake”
(1 min for page loading)
(generalities about the earthquake)
(refresh)
Network connection error.
There’s no power.
There’s no power in the whole country
Internet y el Terremoto 2010
Tomás Barros, José Piquer, Víctor Ramiro, Pablo Sepúlveda

Vista de Rutas
NIC Chile 3:37 AM

Internet y el Terremoto 2010
Tomás Barros, José Piquer, Víctor Ramiro, Pablo Sepúlveda

Vista de Rutas
NIC Chile 3:41 AM
Vista de Rutas
NIC Chile 3:37 AM

Vista de Rutas
NIC Chile 4:07 AM

Internet y el Terremoto 2010
Tomás Barros, José Piquer, Víctor Ramiro, Pablo Sepúlveda
Everybody is safe, we have (some) light, we have water.

Is everybody else safe?
Mom: Get the Battery Radio
Mom: Get the Battery Radio
Not much going on in the radio, but there is one radio transmitting: Not knowing much, but calming people.
THIS IS IMPORTANT:
If you live alone, you will want to hear from someone, and there might be NO INTERNET.
Also you want to know:
Tsunami? Is water potable?
Evacuation alerts? etc.
Lesson 3:
Get a battery-powered FM/AM radio.
ESPECIALLY IF YOU LIVE ALONE
Agreement: There’s nothing else we can do now. Let’s go to bed.
There is no power, but the houses around look all OK
Power comes back.
Internet y el Terremoto 2010
Tomás Barros, José Piquer, Víctor Ramiro, Pablo Sepúlveda
Internet y el Terremoto 2010
Tomás Barros, José Piquer, Víctor Ramiro, Pablo Sepúlveda

Vista de Rutas
NIC Chile 9:15 AM

Vista de Rutas
NIC Chile 9:14 AM
Internet comes back.
TV comes back.
We are here
Modern engineered buildings generally performed very well, with only a few cases of collapse noted. EERI (2010) reported that approximately 50 multi-story reinforced concrete buildings were severely damaged, and four experienced partial or total collapse. Based on building surveys in the metropolitan region, the Engineers Association of Chile (2010) estimated that approximately 2% of engineered buildings experienced severe damage or collapse; 12% were damaged such that they were not usable until repaired; and 86% were usable immediately following the earthquake.

The Department of Civil Engineering, Faculty of Mathematics and Physical Sciences at the University of Chile maintains a strong-motion network in central and southern Chile. More than 20 stations recorded free-field ground motions from the 2010 Maule earthquake (Boroschek et al., 2010). Table 1-1 summarizes ground motion recordings with reported peak ground accelerations ranging as high as 0.93g. Selected acceleration response spectra are shown in the figures that follow.

Table 1-1 Summary of Ground Motion Recordings from the 2010 Maule Earthquake (Boroschek et al., 2010)

<table>
<thead>
<tr>
<th>No.</th>
<th>Station</th>
<th>Region</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Station Type</th>
<th>Peak Ground Acceleration, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Angol</td>
<td>IX</td>
<td>-37.7947° (S)</td>
<td>-72.7081° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>2</td>
<td>Concepción</td>
<td>VIII</td>
<td>-36.8281° (S)</td>
<td>-73.0547° (W)</td>
<td>SMA-1</td>
<td>Long.</td>
</tr>
<tr>
<td>3</td>
<td>Constitución</td>
<td>VII</td>
<td>-35.3401° (S)</td>
<td>-72.4057° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>4</td>
<td>Copiapo</td>
<td>III</td>
<td>-27.355° (S)</td>
<td>-70.3413° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>5</td>
<td>Curico</td>
<td>VII</td>
<td>-34.9808° (S)</td>
<td>-71.2364° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>6</td>
<td>Hualane</td>
<td>VII</td>
<td>-34.95° (S)</td>
<td>-71.80° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>7</td>
<td>Lloleó</td>
<td>V</td>
<td>-33.6167° (S)</td>
<td>-71.6176° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>8</td>
<td>Matanzas</td>
<td>VI</td>
<td>-33.9593° (S)</td>
<td>-71.3727° (W)</td>
<td>SMA-1</td>
<td>Long.</td>
</tr>
<tr>
<td>9</td>
<td>Papudo</td>
<td>V</td>
<td>-32.5114° (S)</td>
<td>-71.4471° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>10</td>
<td>Santiago-Centro</td>
<td>RM</td>
<td>-33.46° (S)</td>
<td>-70.69° (W)</td>
<td>SSA-2</td>
<td>Trans.</td>
</tr>
<tr>
<td>11</td>
<td>Santiago-LaFlorida</td>
<td>RM</td>
<td>-33.5248° (S)</td>
<td>-70.5383° (W)</td>
<td>K2</td>
<td>NS</td>
</tr>
<tr>
<td>12</td>
<td>Santiago-Maipu</td>
<td>RM</td>
<td>-33.5167° (S)</td>
<td>-70.7687° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>13</td>
<td>Santiago-Penalén</td>
<td>RM</td>
<td>-33.55° (S)</td>
<td>-70.57° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>14</td>
<td>Santiago-Puente Alto</td>
<td>RM</td>
<td>-33.5769° (S)</td>
<td>-70.5811° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>15</td>
<td>Talca</td>
<td>VII</td>
<td>-35.4233° (S)</td>
<td>-71.66° (W)</td>
<td>SMA-1</td>
<td>Long.</td>
</tr>
<tr>
<td>16</td>
<td>Vallenar</td>
<td>III</td>
<td>-28.5716° (S)</td>
<td>-70.759° (W)</td>
<td>QDR</td>
<td>NS</td>
</tr>
<tr>
<td>17</td>
<td>Valparaíso-UTFSM</td>
<td>V</td>
<td>-33.0356° (S)</td>
<td>-71.5963° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>18</td>
<td>Valparaíso-Almendral</td>
<td>V</td>
<td>-33.0458° (S)</td>
<td>-71.5068° (W)</td>
<td>SMA-1</td>
<td>Trans.</td>
</tr>
<tr>
<td>19</td>
<td>Valdivia</td>
<td>X</td>
<td>-39.8244° (S)</td>
<td>-73.2133° (W)</td>
<td>QDR</td>
<td>EW</td>
</tr>
<tr>
<td>20</td>
<td>Viña del Mar-Centro</td>
<td>V</td>
<td>-33.0253° (S)</td>
<td>-71.5508° (W)</td>
<td>QDR</td>
<td>EW</td>
</tr>
<tr>
<td>21</td>
<td>Viña del Mar-ElSalto</td>
<td>V</td>
<td>-33.0469° (S)</td>
<td>-71.51° (W)</td>
<td>Elta</td>
<td>NS</td>
</tr>
</tbody>
</table>


2 Station soil-structure interaction under evaluation.
Portland is about 10296 km (6400 miles, 92.76°) from the location of this earthquake.

The S waves arrived 24 minutes and 6 seconds (1446 seconds) after the earthquake.

It took 13 minutes and 6 seconds (786 seconds) for the compressional P waves to travel a curved path through the mantle from Chile to Portland. PP waves are compressional waves that bounce off the Earth’s surface halfway between the earthquake and the seismic station. PP energy arrived 16 minutes and 48 seconds (1008 seconds) after the earthquake.

Surface wave energy required approximately 39 minutes and 14 seconds (2354 seconds) to travel the 10296 km (6400 miles) around the perimeter of the Earth from Chile to Portland, Oregon.
February 20th.—The day has been memorable in the annals of Valdivia, for the most severe earthquake experienced by the oldest inhabitant. I happened to be on shore, and was lying down in the wood to rest myself. It came on suddenly, and lasted two minutes; but the time appeared much longer.

22d.—We sailed from Valdivia, and on the 4th of March, entered the harbour of Concepcion. ... The mayor-domo of the estate quickly rode down to tell us the terrible news of the great earthquake of the 20th;—"that not a house in Concepcion, or Talcuhano, (the port) was standing; that seventy villages were destroyed; and that a great wave had almost washed away the ruins of Talcuhano." Of this latter fact I soon saw abundant proof; the whole coast being strewed over with timber and furniture, as if a thousand great ships had been wrecked. Besides chairs, tables, bookshelves, &c., in great numbers, there were several roofs of cottages, which had been drifted in an almost entire state.
Earthquake-safe buildings: You will be able to get out
5.2 Observed Earthquake Damage

The case study building sustained significant damage as a result of the 2010 Maule earthquake. Damage consisted of horizontal and diagonal cracking, spalling, crushing, and bar buckling in the reinforced concrete shear walls. Damage was concentrated primarily in the first story of the transverse shear walls, which led to differential vertical displacements on the order of 40 cm (16 in.) in the upper stories that damaged reinforced concrete beams and floor slabs.

Photos of observed damage are shown in Figures 5-3 through 5-7. Cracking and spalling were attributed to the "flag-shaped" configuration of the shear walls, which resulted in reduced cross-sections and increased stresses where demands were expected to be the highest. Crushing and bar buckling were attributed to a lack of confinement reinforcing in the form of closed hoops and cross ties in the shear wall boundary zones. In spite of the observed damage, however, the case study building did not collapse.

Figure 5-3 Transverse elevation of the case study building showing differential vertical displacements following the 2010 Maule earthquake (photo courtesy of Patricio Bonelli).
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Figure 5-3 Transverse elevation of the case study building showing differential vertical displacements following the 2010 Maule earthquake (photo courtesy of Patricio Bonelli).

Figure 5-4 Overall damage sustained in the first-story transverse shear walls of the case study building (photo courtesy of Patricio Bonelli).

Figure 5-5 Cracking, spalling, crushing, and bar buckling in the transverse shear wall on Line 9 (photo courtesy of Patricio Bonelli).

Figure 5-6 Cracking, spalling, crushing, and bar buckling in the transverse shear wall on Line 5 (photo courtesy of Patricio Bonelli).

Figure 5-7 Crushing and bar buckling in the transverse shear wall on Line 1 resulting in significant differential vertical displacement (photo courtesy of Patricio Bonelli).
Coastal Chile has a history of very large earthquakes. Since 1973, there have been 13 events of magnitude 7.0 or greater.

The February 27 shock originated about 230 km north of the source region of the magnitude 9.5 earthquake of May, 1960 – the largest earthquake worldwide in the last 200 years or more.

An outline of the approximate rupture from this Magnitude 8.8 earthquake and it’s relationship to the largest earthquakes along the coast of Chile this century.
The 2010 Chile (Concepción) earthquake

- By GPS, Concepción moved 10 feet (~3m) west. Santiago, 24cm west, Buenos Aires, 4cm west.
- Shortened the day by 1.26 microseconds
- Moved the earth’s axis by ~8cm
- Seiches in Lake Pontchartrain, New Orleans.
The 2010 Chile (Concepción) earthquake and Tsunami

- By GPS, Concepción moved 10 feet (~3m) west. Santiago, 24cm west, Buenos Aires, 4cm west.
- Shortened the day by 1.26 microseconds
- Moved the earth’s axis by ~8cm
- Seiches in Lake Pontchartrain, New Orleans.
Tsunami WARNING

Flooding: Feb 28, 2010 1130-1430 (local time)
A research product from NOAA PMEL
Issued Feb 28, 2010 02:00 (local time)

Tsunami WARNING
Flooding: Feb 28, 2010 1130-1430 (local time)
If the earthquake is strong enough that you can’t stand, Tsunami risk is high
Aftershocks

A large vigorous aftershock sequence can be expected from this earthquake. At this time, ~90 aftershocks > M 5 have been recorded, including a M 6.9. Aftershocks typically follow earthquakes, as motion of the crust in one location puts pressure on weak spots along earthquake fault lines, triggering further motion. This figure was created with the IRIS Earthquake Browser (IEB).

Use the IEB to explore the aftershock sequence!

An earthquake large enough to cause damage will probably be followed by several felt aftershocks within the first hour. The rate of aftershocks decreases quickly—the decrease is proportional to the inverse of time since the main shock. This means the second day has about 1/2 the number of aftershocks of the first day and the tenth has about 1/10 the number of the first day. These patterns describe only the overall behavior of aftershocks; the actual times, numbers and locations of the aftershocks are random.

Magnitude 8.8 OFFSHORE MAULE, CHILE Saturday, February 27, 2010 at 06:34:17 UTC
Aftershocks

- 130 by March 6th, 13 over 6.0.
- 6.9 on March 11th
- 6.7 on March 15th
Aftershocks

• 130 by March 6th, 13 over 6.0.
• 6.9 on March 11th
• 6.7 on March 15th
• That’s an aftershock the size of Los Angeles’ 1994 earthquake
A QUAKE, A QUAKE

WRITTEN BY RANDY ROGEL

DIRECTED BY AL ZEGLER
A QUAKE, A QUAKE

WRITTEN BY RANDY ROGEL

DIRECTED BY AL ZEGLER
Airport

- No damage on runways or control tower
Airport

- No damage on runways or control tower

- Time to commercial flight reopening:
  3 days (March 1st)
The university term back in Santiago

Delayed by …
The university term back in Santiago

Delayed by 3 weeks.
BASIC EMERGENCY KIT SUPPLIES

First aid kit, prescriptions and other personal items

Battery-powered or hand-crank radio

Battery-powered or hand-crank flashlight

Whistle

Emergency plan, copies of important documents and cash

Phone charger and battery bank

Non-perishable food for at least three days

Garbage bags, moist towelettes and plastic ties

Blanket, seasonal clothing and footwear

Water for at least three days; four litres per person per day

gov.bc.ca/PreparedBC
preparedbc.ca
Comparison of U.S. and Chilean Building Code Requirements and Seismic Design Practice 1985-2010

NEHRP Consultants Joint Venture
A partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering

specified compressive strength $f_{c'} = 4,000$ psi.
5.2 Observed Earthquake Damage

The case study building sustained significant damage as a result of the 2010 Maule earthquake. Damage consisted of horizontal and diagonal cracking, spalling, crushing, and bar buckling in the reinforced concrete shear walls. Damage was concentrated primarily in the first story of the transverse shear walls, which led to differential vertical displacements on the order of 40 cm (16 in.) in the upper stories that damaged reinforced concrete beams and floor slabs. Photos of observed damage are shown in Figures 5-3 through 5-7. Cracking and spalling were attributed to the “flag-shaped” configuration of the shear walls, which resulted in reduced cross-sections and increased stresses where demands were expected to be the highest. Crushing and bar buckling were attributed to a lack of confinement reinforcing in the form of closed hoops and cross ties in the shear wall boundary zones. In spite of the observed damage, however, the case study building did not collapse.

Figure 5-3  Transverse elevation of the case study building showing differential vertical displacements following the 2010 Maule earthquake (photo courtesy of Patricio Bonelli).
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Figure 5-3 Transverse elevation of the case study building showing differential vertical displacements following the 2010 Maule earthquake (photo courtesy of Patricio Bonelli).

Figure 5-4 Overall damage sustained in the first-story transverse shear walls of the case study building (photo courtesy of Patricio Bonelli).

Figure 5-5 Cracking, spalling, crushing, and bar buckling in the transverse shear wall on Line 9 (photo courtesy of Patricio Bonelli).

Figure 5-6 Cracking, spalling, crushing, and bar buckling in the transverse shear wall on Line 5 (photo courtesy of Patricio Bonelli).

Figure 5-7 Cracking and bar buckling in the transverse shear wall on Line 1 resulting in significant differential vertical displacement (photo courtesy of Patricio Bonelli).
In "T-shaped" wall configurations, ACI 318 specifies that the effective width of the flange should not exceed 25% of the height of the wall. The calculated tensile strain of 0.375 in/in exceeds the rupture strain of approximately 0.10 in/in. Excessive strain in the stem of "T-shaped" walls has been shown to limit the flexural capacity of the wall section, and negatively impact the ductility capacity. This result is consistent with observations of damage in the transverse shear walls following the 2010 Maule earthquake.

5.4 Design and Analysis of U.S. Configuration

In contrast with Chilean practice, U.S. practice is to configure buildings with longer spans and fewer structural walls. As a consequence, walls are thicker, allowing for easier placement of confinement reinforcing and lower compressive strains. A shear wall configuration for a hypothetical building was developed consistent with U.S. practice. A comparison with the Chilean shear wall layout is shown in Figure 5-24.

This comparison is intended to illustrate differences in structural design practice and quantify the effects on detailing and potential behavior. No attempt was made to optimize the design of the U.S. configuration. It should also be noted that the U.S. configuration would not be suitable for Chilean architectural practice in which concrete walls also serve as partitions, acoustical barriers, and fire protection between units.

In the Chilean wall configuration, set-backs were provided at the base of the transverse walls. In the U.S. configuration, fewer walls provide fewer obstacles to circulation within the building. As a result, the setbacks have been eliminated and the base of the walls expanded to improve overturning resistance. Typical Chilean and U.S. transverse shear wall elevations are compared in Figure 5-25.

In designs with fewer walls, reliance on diaphragms and collectors to deliver loads to the walls is much greater. NCh433 requires that diaphragms have adequate strength and stiffness, but no other criteria are provided. ASCE/SEI 7-05 includes provisions for diaphragm design in which design forces are amplified relative to story forces to account for higher mode effects. Further amplification is required when certain building irregularities are present. Collector elements are intended to remain elastic, and special load combinations including the overstrength factor, $F_o$, are used to provide this behavior.
5.5 Observations and Conclusions on U.S. and Chilean Seismic Design Practice

Differences in U.S. and Chilean seismic design practice are the result of evolution in construction techniques, differences in labor costs as a portion of total construction costs, and differences in the roles that structural engineers play in the building design process. Traditional Chilean practice is to configure buildings with relatively short floor spans and many load-bearing walls providing gravity and seismic force resistance. As a result, typical Chilean buildings have highly redundant configurations. This practice likely contributed to the ability of many buildings to withstand severe damage without collapse. As a consequence of this redundancy, and past experience with typical building configurations, requirements for ductile detailing in Chile are relaxed relative to U.S. requirements.

In contrast, U.S. practice is to configure buildings with longer spans and fewer structural walls. As a result, walls are thicker, allowing for easier placement of confinement reinforcing, and increased ductility capacity. As a consequence, U.S. designs have comparatively less redundancy than Chilean designs.

The Chilean case study building experienced severe damage and differential vertical displacement in the transverse shear walls as a result of the 2010 Maule earthquake. Cracking and spalling were attributed to the “flag-shaped” configuration of the shear walls, and crushing and bar buckling were attributed to a lack of confinement reinforcing in the form of closed hoops and cross ties in the shear wall boundary zones. In spite of this damage, the building did not collapse.
In all cases, an accidental torsional eccentricity of 5% has been included.

Figure 5-12 Maximum story drift ratios in the longitudinal direction at the center of mass, calculated per NCh433.Of96.

Figure 5-13 Maximum story drift ratios in the longitudinal direction at an extreme corner, calculated per NCh433.Of96.

Figure 5-16 Maximum story drift ratios in the longitudinal direction at the center of mass, calculated per ASCE/SEI 7-05.

Figure 5-17 Maximum story drift ratios in the longitudinal direction at an extreme corner, calculated per ASCE/SEI 7-05.
In all cases, an accidental torsional eccentricity of 5% has been included.

Figure 5-12  Maximum story drift ratios in the longitudinal direction at the center of mass, calculated per NCh433.Of96.

Figure 5-13  Maximum story drift ratios in the longitudinal direction at an extreme corner, calculated per NCh433.Of96.

Figure 5-16  Maximum story drift ratios in the longitudinal direction at the center of mass, calculated per ASCE/SEI 7-05.

Figure 5-17  Maximum story drift ratios in the longitudinal direction at an extreme corner, calculated per ASCE/SEI 7-05.
Comparison of U.S. and Chilean Seismic Design Practice GCR 12-917-18

Figure 5-14 Maximum story drift ratios in the transverse direction at the center of mass, calculated per NCh433.Of96.

Figure 5-15 Maximum story drift ratios in the transverse direction at an extreme corner, calculated per NCh433.Of96.

Because the San Francisco spectrum includes a short period plateau, the Viña del Mar spectrum produced higher drifts in all cases. Although NCh433.Of96 specifies the use of gross section properties, drift demands exceeded ASCE/SEI 7-05 drift demands calculated using effective section properties and a displacement...
Figure 5-27 Maximum story drift ratios in the transverse direction for the U.S. building configuration, calculated per ASCE/SEI 7-05.

Figures 5-28 and 5-29 compare the maximum story drift ratios and maximum displacements in the transverse direction for the U.S. configuration and the Chilean configuration of case study building.

Figure 5-28 Comparison of normalized story drift ratios for the U.S. configuration and the Chilean configuration, in the transverse direction at the center of mass.

Because the San Francisco spectrum includes a short period plateau, the Viña del Mar spectrum produced higher drifts in all cases. Although NCh433.0996 specifies the use of gross section properties, drift demands exceeded ASCE/SEI 7-05 drift demands calculated using effective section properties and a displacement