Announcements

Homework

- Earthquake reading assignment worksheet due **Sunday, Oct. 20**

Midterm – Wednesday, Oct. 23 (in class)

- Covering storms and earthquakes
- Review session – Monday, Oct. 23, 5:00-7:00 pm,
  – Held in LIFE 2201

Earthquakes

Earthquakes

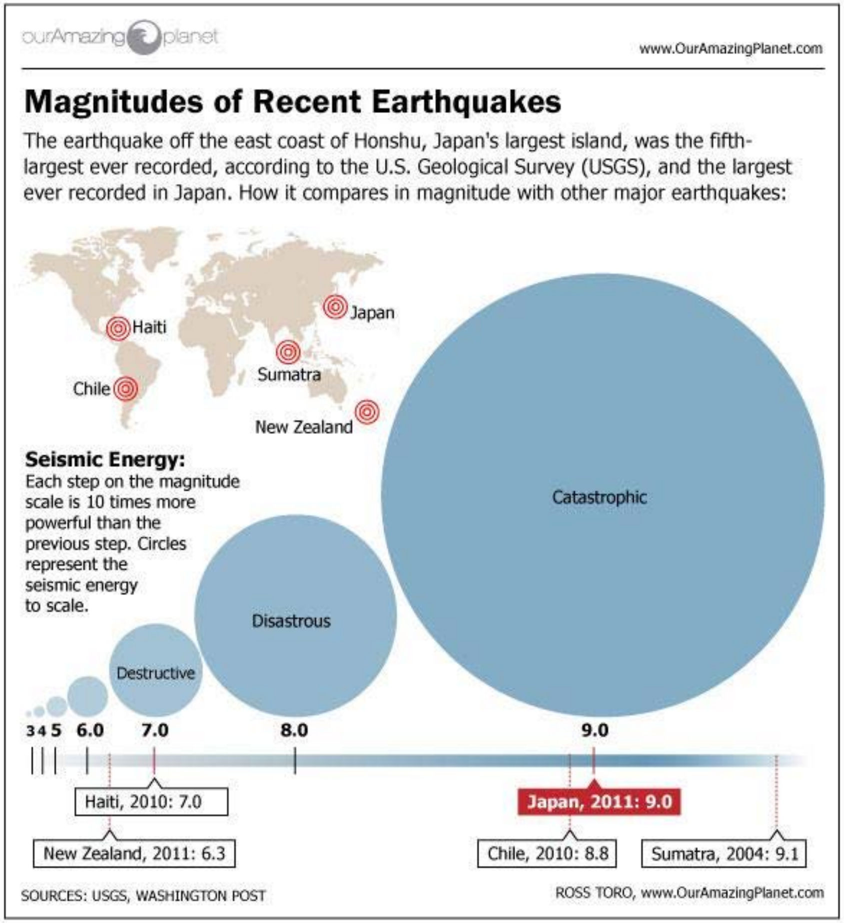
- Lecture 1 – Why and how the Earth moves
- Lecture 2 - Plate tectonics, plate boundaries, faulting
- Lecture 3 - Seismology, earthquake magnitude/intensity
- **Lecture 4 – Earthquake hazards and mitigation**
- Lecture 5 – Earthquake forecasting and survival

Learning Goals

- Compare and contrast earthquake magnitude and intensity scales (last time)
- List and describe five hazards related to earthquakes (ground shaking, liquefaction, fires, tsunami, landslides)
- Describe the importance of building design and ground conditions on earthquake damage to buildings and infrastructure
- Describe the basics of how buildings can be designed or retrofitted to better resist earthquakes (and reduce casualties and costs)
- Explain liquifaction and resonance and how those processes can affect buildings and other structures during earthquakes

Earthquake Magnitude

A **quantitative** measure of the maximum ground motion produced by the earthquake



- Moment Magnitude Scale (Mw)
- Proportional to energy release and depends on:
  rock strength x fault area x fault slip

As magnitude increases,
the earthquake:

- Affects a broader region
- Shakes the ground for longer
- Causes more damage!

Remember: unit magnitude increase equals 10x stronger ground shaking and 32x more energy released!

Earthquake Intensity

- Qualitative (descriptive) estimate of how ground motion affects population and structures
- It is what we feel in an earthquake, your **perception** of ground **shaking**
- The **damage** resulting from the vibrations
- We use the **Modified Mercali Scale**
  - Ranges from 1 (felt by very few or not at all) to 12 (total destruction)

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Last time - Earthquake Intensity

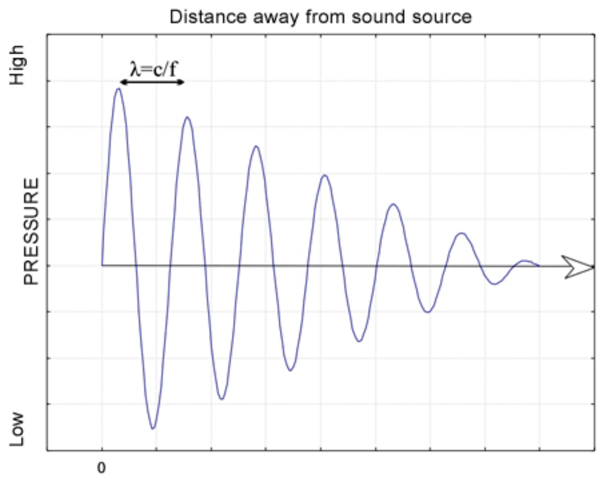
Factors that influence earthquake intensity:

1) Earthquake Magnitude

- Lower Magnitude = less intense
- Less energy = less damaging seismic waves

2) Distance from earthquake epicentre

- Further away = less intense
- Seismic waves weaken with distance



3) Duration - How long does the ground shaking last?

- Short duration = less intense
- Long duration = more intense
- Shaking from a Mw 9 earthquake will last several minutes!

Earthquake Intensity

Factors that influence ***our perception*** of earthquake intensity:

4) Structural Damage

More damage we see the larger the perceived intensity of the earthquake

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
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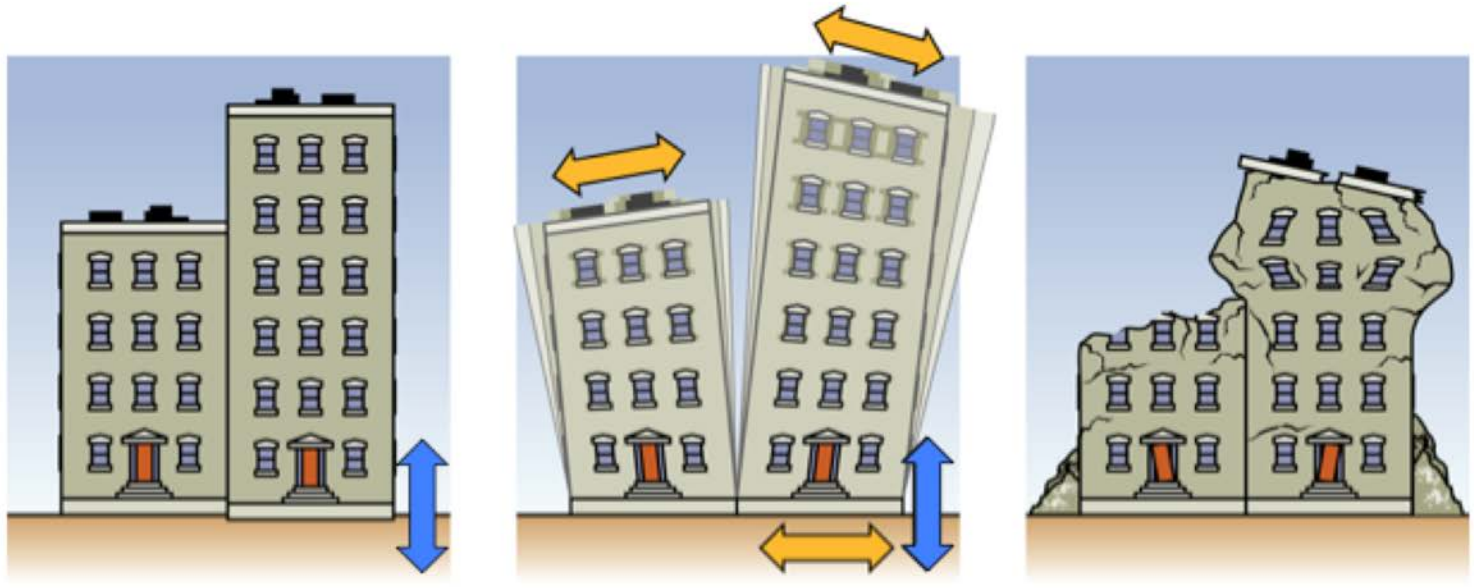
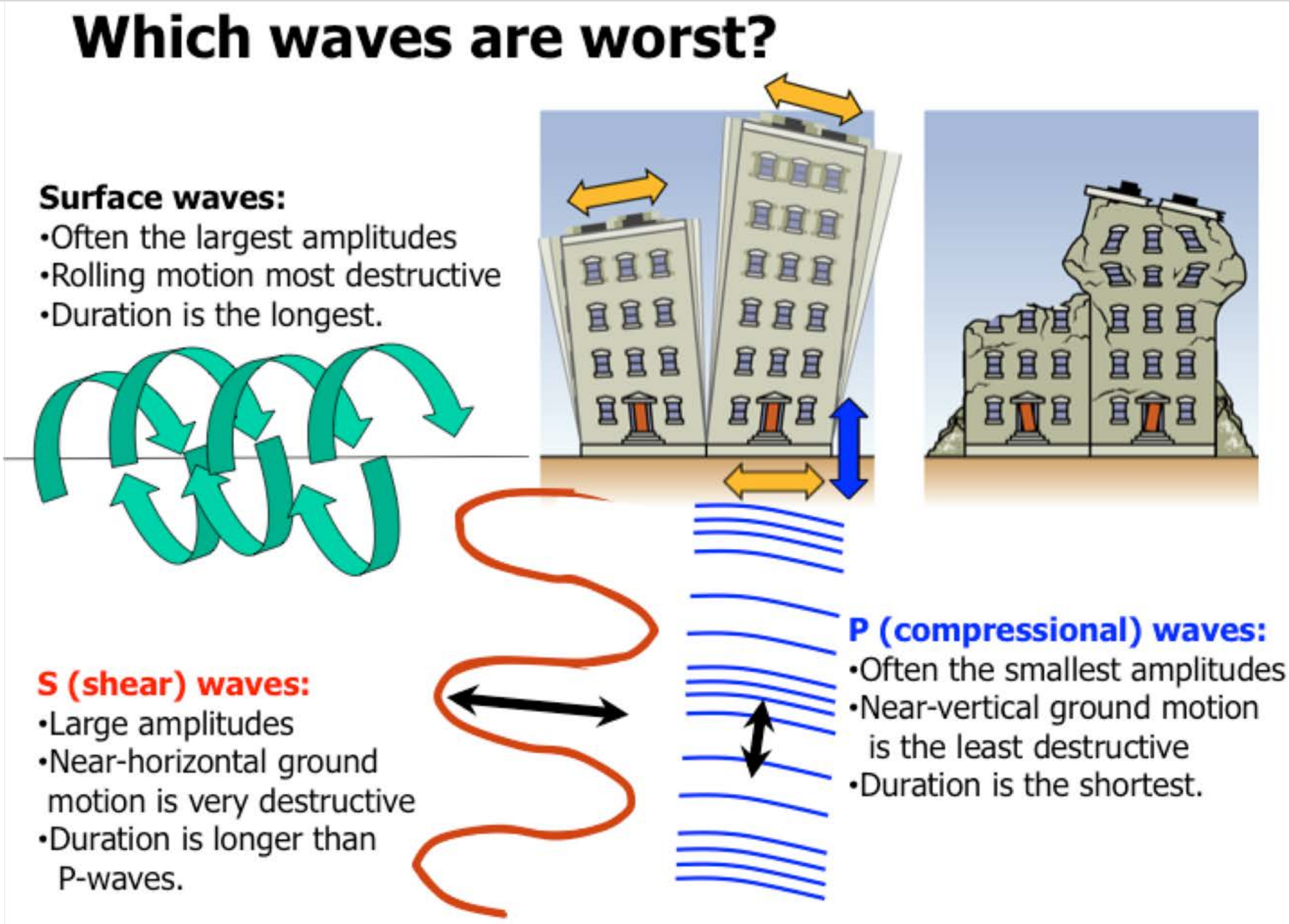
Buildings

Structural damage is caused by shaking

- Structures are designed to support a **vertical** load
- Earthquake waves shake the ground vertically and horizontally
- **Horizontal** shaking (or acceleration) is particularly damaging
- The longer a building shakes ……. the worse the damage is!



Structural damage



Structural damage

We can design buildings to withstand earthquakes!

More damage (and feels more intense) in:

- Taller buildings
- Poorly designed buildings
- Less cohesive or flexible materials
- **Brick and unreinforced concrete = bad**
  Wood, steel, and reinforced concrete = better

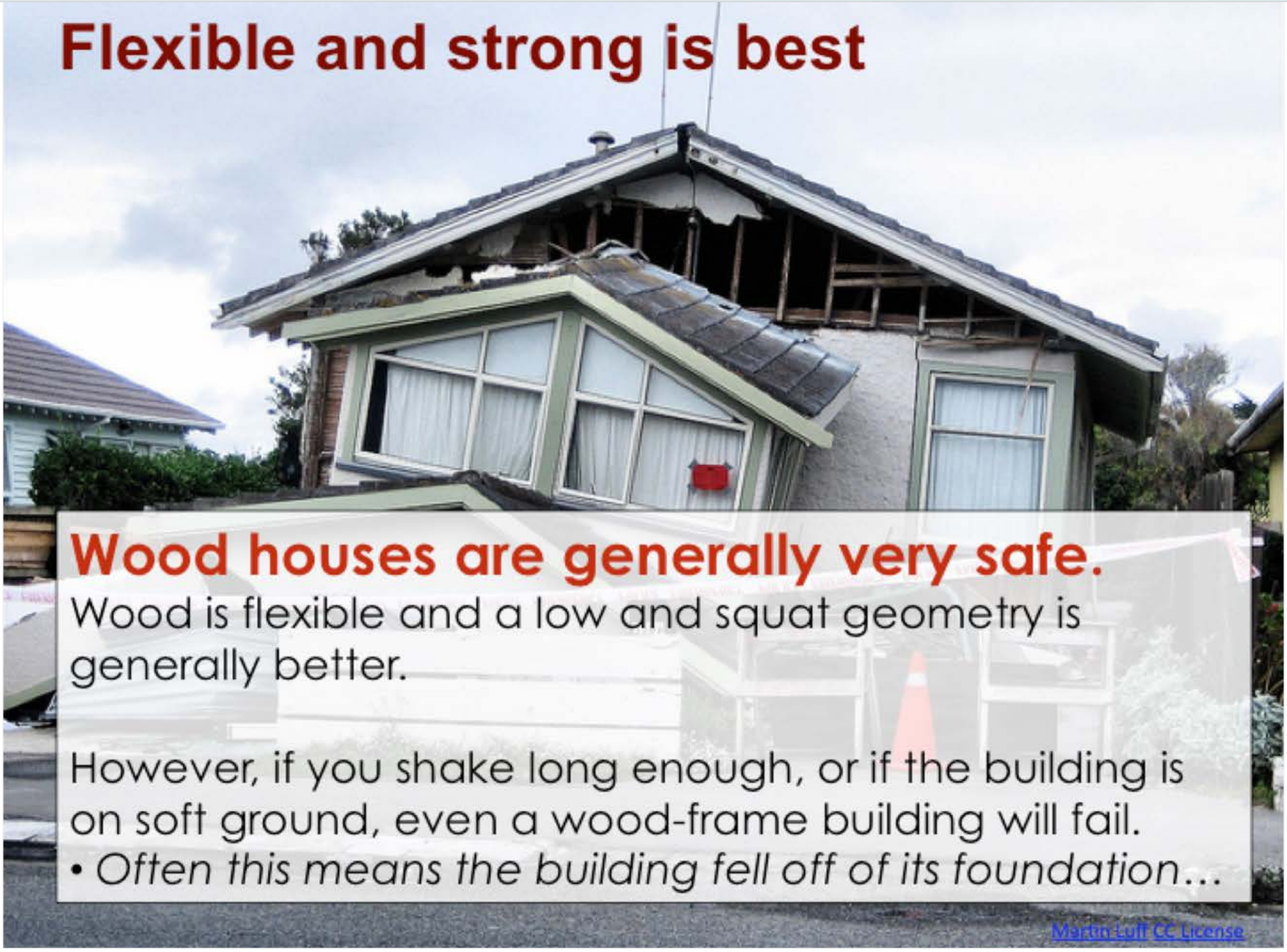
http://www.youtube.com/watch?v=h7qf2JpZ2p4

Structural Damage

Building design and construction:
Will your building survive (at least long enough for you to get out and away!?)

- Type of materials – strength and flexibility
- Design
- Size/proportions of building
- How it was actually built… ?
- When it was built?
- Was it retrofitted to withstand earthquakes?

Building design



Building design

Flexible and strong is best

Stone and masonry buildings have challenges…

Brittle construction with poor shear strength

Heavy roofs above even worse

Aquila, Italy
Mw 6.3
Depth 8.8km

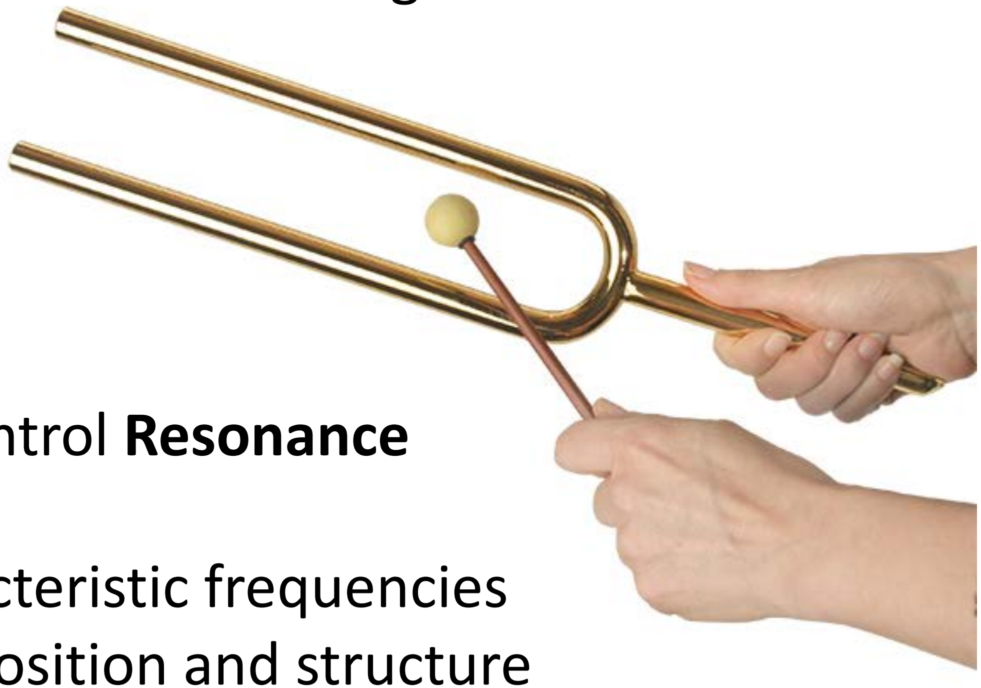
287 killed
1000 injured
40000 homeless

Building design

Vibrations and Resonance

If you shake a structure hard enough, or for long enough…..it will fail.

Building designers want to maximise strength and resilience.



A key design factor is to control **Resonance**

All objects vibrate at characteristic frequencies

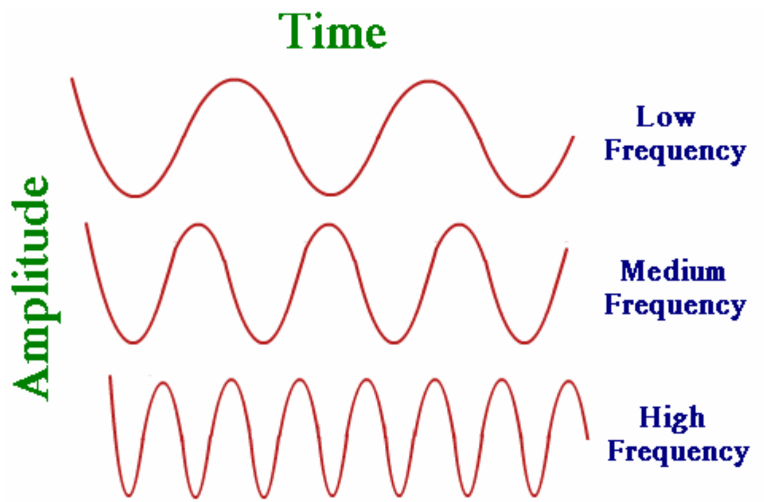
- Controlled by size, composition and structure
- Complex structures (almost all structures) will have many modes of vibration, but will have one or perhaps a few dominant modes or resonances.

Vibrations and Resonance

Resonance Disasters

If the ‘forcing’ vibrations are tuned to one of the primary resonance frequencies of the structure
……. bad things can happen.

Hard Science – How to break a glass with your voice experiment (don’t try this with your most expensive wine glasses!)
https://www.youtube.com/watch?v=z6oqPB07X3o



Resonance - Tacoma Narrows Bridge

More info on the Tacoma Narrows Bridge
https://www.youtube.com/watch?v=3mclp9QmCGs

Experiment!

In groups of 3

- Send one person to the front to pick up 2 sticks of spaghetti
- And two raisins
- Stick the raisins on the end of the spaghetti – make sure you have 2 different lengths

Experiment!

Predict – how fast do you need to vibrate the spaghetti to get it to resonate?

- Hold the two pieces in one hand and vibrate them back and forth a very small amount
- Slowly at first
- Increase your frequency
- Find a frequency that excites one, but only one of the spaghetti sticks!
  Makes it move A LOT!
- See if you can change the frequency to excite the other stick.....

Experiment!

Predict – how fast do you need to vibrate the spaghetti to get it to resonate

- The shortest one will be the hardest – you will have to shake it pretty fast!
- The spaghetti is bending back and forth – that's elastic bending or deformation!
- If you shake too hard they will break – that's brittle deformation!
- No ductile deformation…..not at these pressures, temperatures and the high speeds at which the forces are being applied

Structural resonance

Short, squat, low mass buildings tend to be stiffer

- Resonate at high frequencies, fast vibrations with low amplitudes

Tall, skinny higher mass buildings tend to be more flexible

- Resonate at low frequencies, slow vibrations with large amplitudes

Resonance Vibration Test – see what happens when we increase the 'forcing' frequency

https://www.youtube.com/watch?v=LV_UuzEznHs

Structural resonance

Engineers and architects can tune buildings to avoid resonance disasters

Development of building codes:

- Flexible, strong materials
  Avoid critical resonance at earthquake (and other) frequencies
- Learning from mistakes like the Tacoma Bridge

Civil Engineering @ UBC

Structural resonance

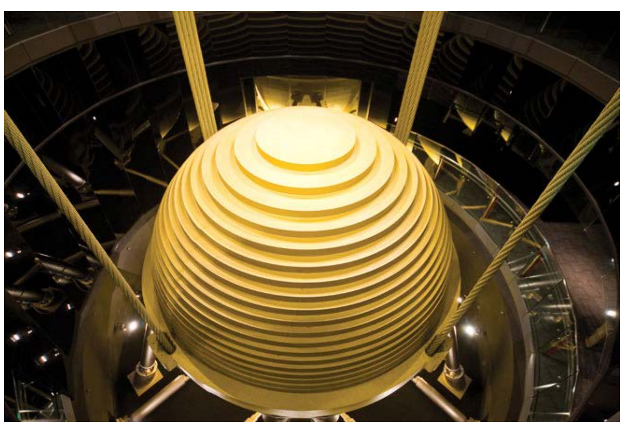
Engineers and architects can tune buildings to avoid resonance disasters

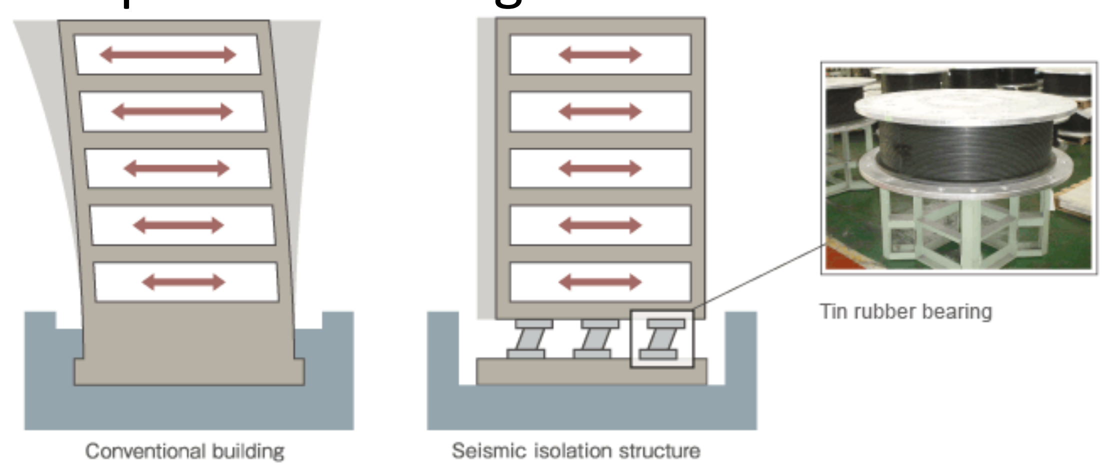
Many types of seismic vibration control e.g.

- Tuned mass dampers

  Massive pendulum within a building is designed to counter the building sway and resonance from earthquakes or wind
- Seismic base isolation systems

  Structural elements that decouple the building from its base



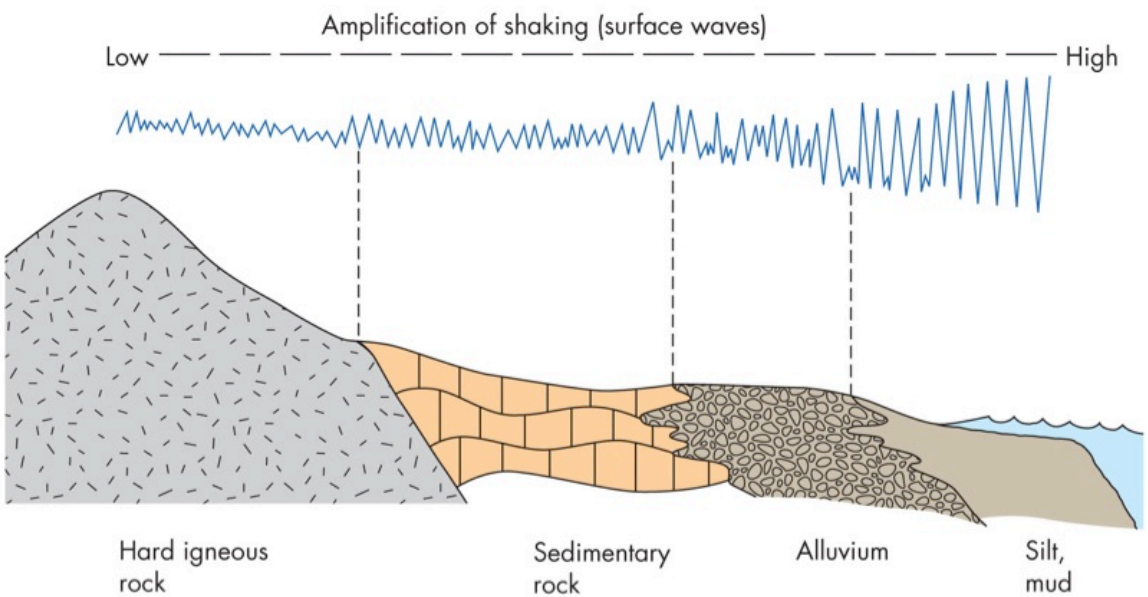


Earthquake Engineering – large scale experiments
https://www.youtube.com/watch?v=kzVvd4Dk6sw

Ground properties

5) Underlying soil + geology (Ground properties)

- Bedrock = less intense ground motion
- Well compacted sediment = moderate ground motion
- Water saturated sediment = MORE intense ground motion



Where you build matters!

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Ground properties (cont)

The ground you build on matters!

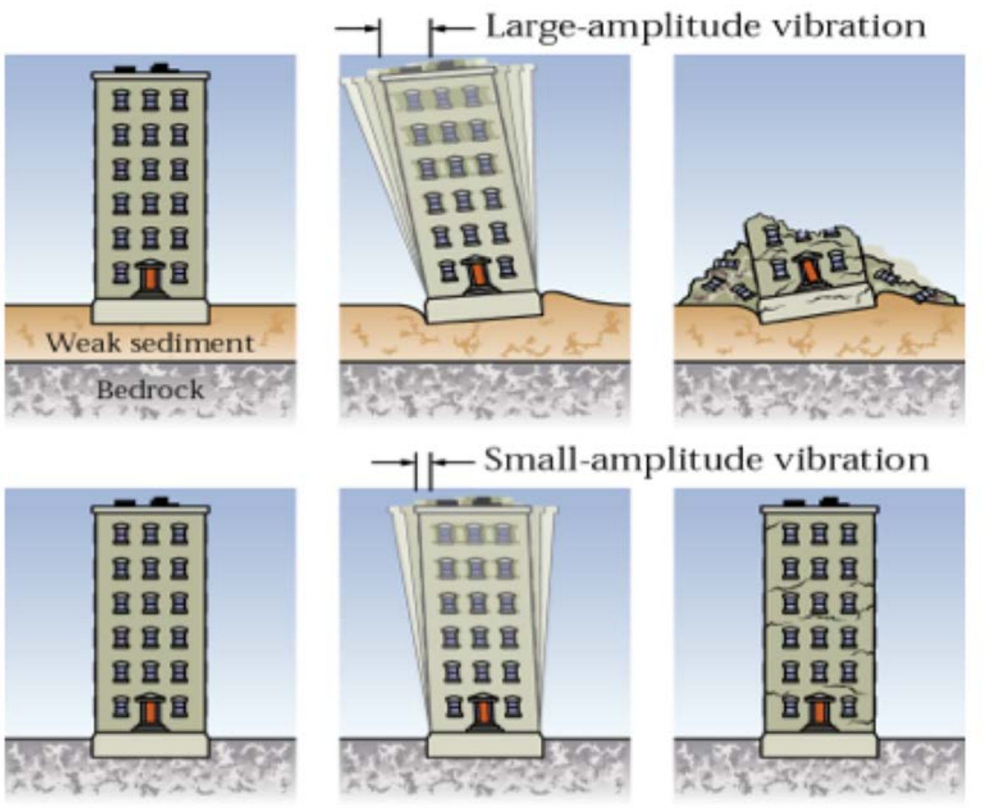
- The ground ‘filters’ the frequencies of the earthquake
- Affects how long the shaking continues
- Influences the stability of structures (foundations)
- **Soft ground is more problematic!**
- **Liquifaction** of water-saturated sands

Ground properties

The ground properties partly control what frequencies the buildings will be shaken at, and how long they will shake

Soft sediments
- Larger amplitudes
- Lower frequencies
- Longer shaking (think jello)

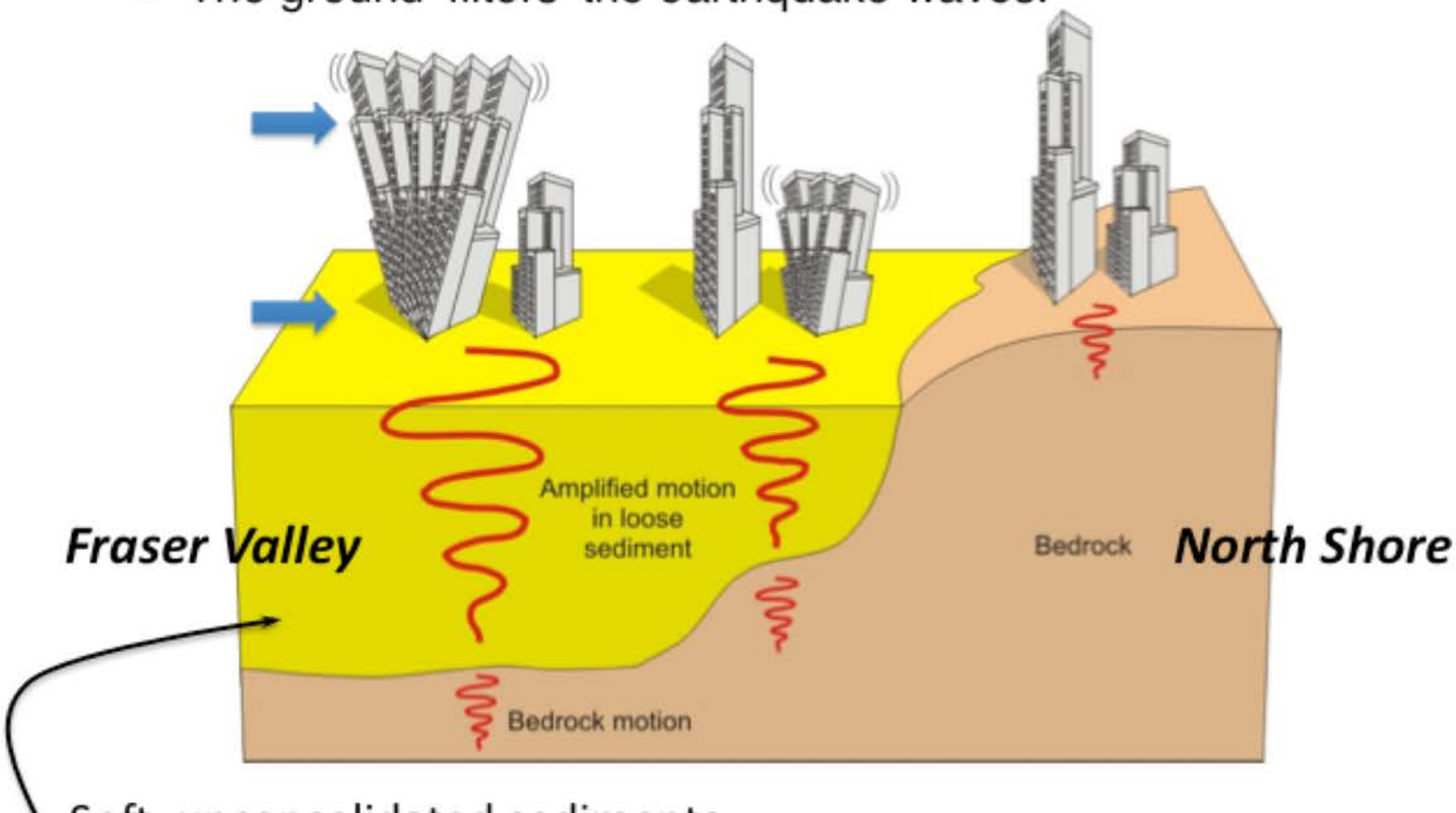
Hard ground or bedrock
- Smaller amplitudes
- Higher frequencies
- Shorter duration of shaking



Ground properties

Ground properties:

- The ground ‘filters’ the earthquake waves.



Soft, unconsolidated sediments
Often water-saturated
River sediment, glacial till, landfill

From *Vancouver:City on the Edge*.

Ground properties

The Marina District hit hardest in San Francisco was built on an old garbage dump. Foundations tilted, sunk, collapsed.

Mw 6.9 “World Series Earthquake” Loma Prieta, CA 1989

Earthquake Hazards

Direct effects:

1) Ground shaking
   Falling/failing buildings - Damaged depends strongly on building design and ground properties – are the waves amplified?
2) Liquefaction

Important hazards triggered by earthquakes:

3) Fire
4) Tsunami
5) Landslides

Earthquake Hazards

1) Ground Shaking

What might fall on you from above?

Earthquake faults rarely break the ground surface

- Sometimes there can be "cracks" in the ground, but not huge cracks that swallow buildings

Only in Hollywood

- Earthquakes don't kill people, buildings kill people…….

Liquefaction

2) Liquefaction

In soft wet soils and sediments, shaking causes unconsolidated materials to liquefy

- Soil loses its cohesion and flows
- Soil loses its strength and heavy objects can sink (people, cars, buildings)
- Sand volcanoes – cones of sediment brought to the surface with the water as it flows

Degree of liquefaction depends on sediment properties and wave frequencies

http://www.groundtruthtrekking.org/photo/liquefaction-dance/

Liquefaction

Sand ‘volcanoes’

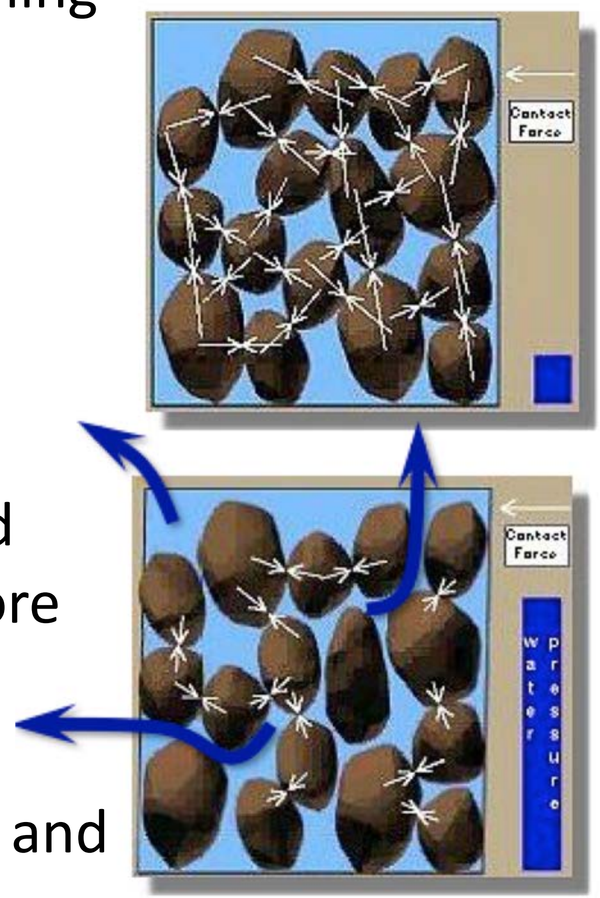
- Water seeps to surface bringing with it a lot of sediment
- Forms cones of sediment

Liquefaction

Why do water saturated sediments lose strength during an earthquake?

Typically in sediments the grains are touching in many places

- Contact forces are high
- The sediment is strong



During an earthquake:

- The vibrations wiggle the grains around
- Increasing the water pressure in the pore spaces
- This pushes the grains apart
- Contact forces decrease and the grains and water can move more easily
- The sediment 'liquefies'

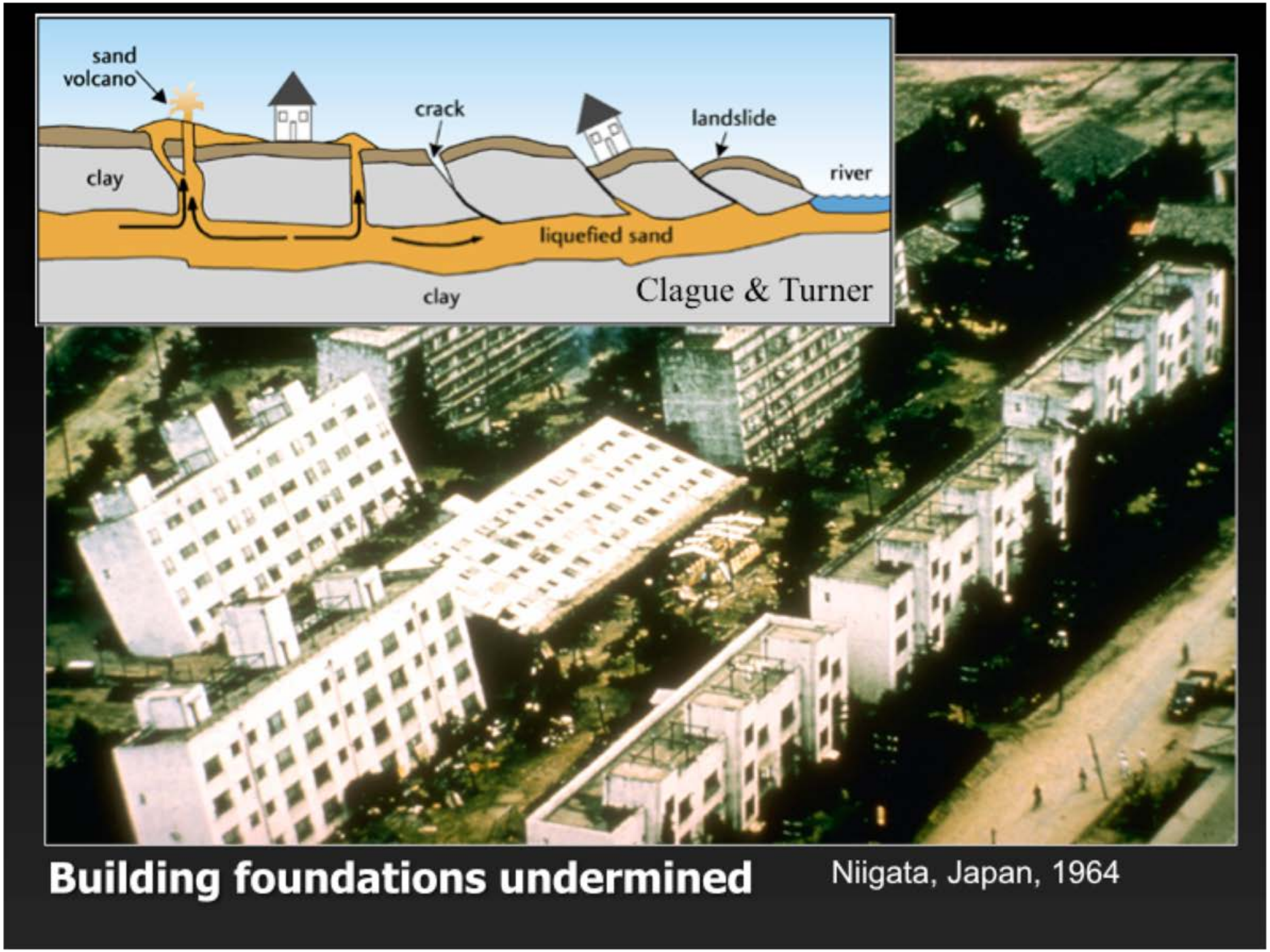
What happens when the ground stops shaking?

Liquefaction

As soon as the shaking stops……..
……..the water pressure drops, the grains stop vibrating and touch each other, the sediments becomes firm again!

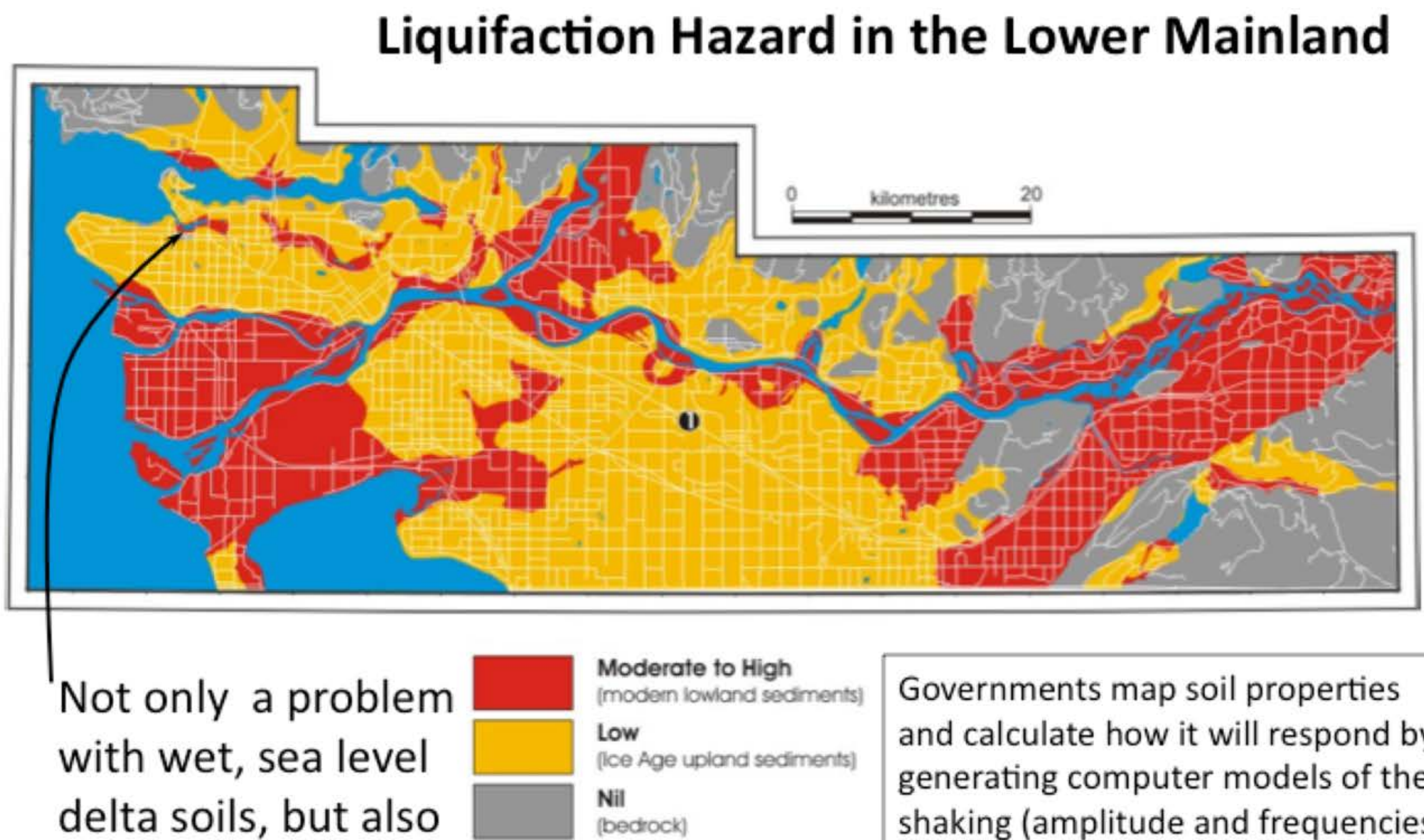
Christchurch earthquake, 2010
https://www.youtube.com/watch?feature=player_embedded&v=2WoKu5VxKgs

Liquefaction



https://www.youtube.com/watch?v=j-hyOwsI_NY

Liquefaction



Not only a problem with wet, sea level delta soils, but also in areas filled in for construction!
e.g., ***False Creek***

Governments map soil properties and calculate how it will respond by generating computer models of the shaking (amplitude and frequencies)

→ building codes

Important hazards triggered by earthquakes

3) Fire

This is one of the most serious concerns after an earthquake:

- Gas pipes broken by ground motion
- Electricity cables severed….sparks…..fire!
- Water lines severed – hard to fight fire without water!
- Transportation lines severed – hard to fight fire if the firefighters cant get there!

Recall: Risk = Hazard x **vulnerability**

Fukushima nuclear power plant after the 2011 earthquake

Important hazards triggered by earthquakes

4) Tsunami

Generally caused by normal or reverse faulting under the sea

- The wave is caused by the fault rupturing the seafloor (or lake bed) and lifting/dropping the entire water column above the rupture zone
- NOT caused by the earthquake (seismic) waves

Discussed in detail by May Ver earlier this term

Which of these is a real tsunami??

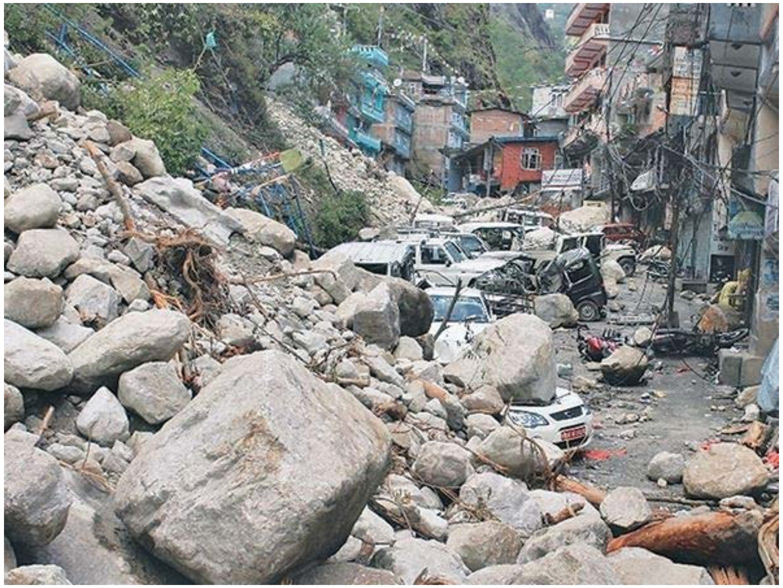
Important hazards triggered by earthquakes

5) Landslides

Earthquakes can trigger landslides

- Unstable ground can fail when it is shaken
- Bigger the earthquake, the more likely there will be landslides
- Landslides are abundant in mountainous areas….like BC!

More about landslides with David Sasse later in the course!



Gorkha earthquake, Nepal, 2015

Sichuan earthquake, China, 2008

Next Lecture

Earthquake prediction and risk!