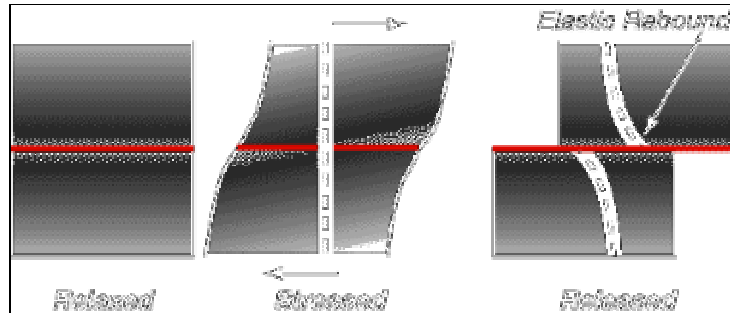


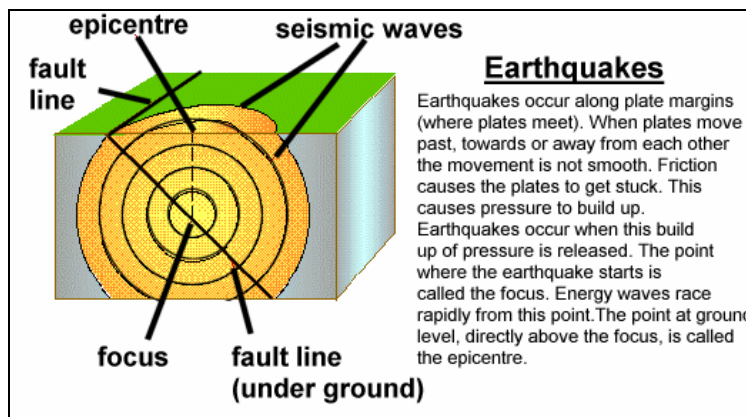
Introduction to Earthquakes**(Priority: High)**

Earthquakes correlate to the location of plate boundaries. 150k earthquakes strong enough to be felt are recorded each year, with 80% occurring on the circum-Pacific belt, 15% on the Mediterranean-Himalayan belt & 5% at spreading ridges and plate interiors.



<http://www.seismo.unr.edu/ftp/pub/lovie/class/100/seismic-waves.html>

- ✓ **Elastic rebound theory:** waves of energy from an earthquake result from the sudden release of strain stored up in rock as it deforms
 - Stress of plate motion builds strain in rocks till friction is overcome & sides along plate boundaries suddenly break loose
 - As two sides of fault plane lurch into new positions, enormous amounts of energy are released into surroundings
- ✓ **Focus / Hypocentre :** location on fault where slip first occurs
- ✓ **Epicentre:** position directly above it on ground surface

**Earthquakes**

Earthquakes occur along plate margins (where plates meet). When plates move past, towards or away from each other the movement is not smooth. Friction causes the plates to get stuck. This causes pressure to build up. Earthquakes occur when this build up of pressure is released. The point where the earthquake starts is called the focus. Energy waves race rapidly from this point. The point at ground level, directly above the focus, is called the epicentre.

<http://www.geography.learnontheinternet.co.uk/images/nathaz/earthquake.gif>

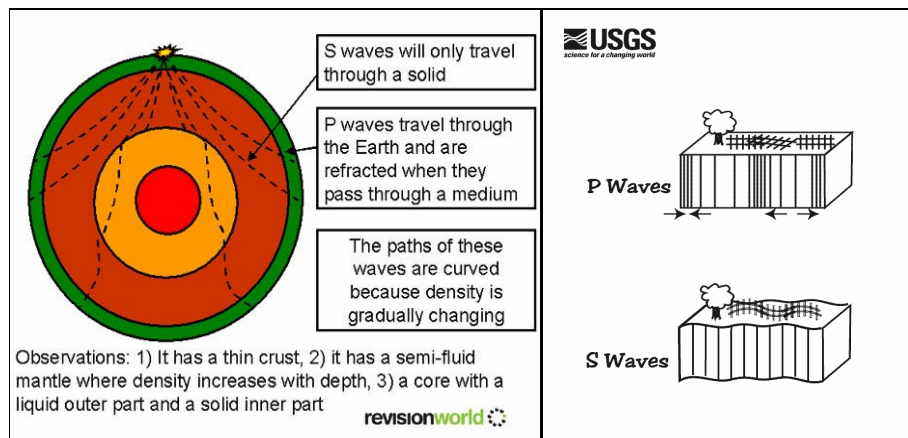
Categorization	Focal depth
Shallow	<60km
Intermediate	60 - 300km
Deep	>300km

Types of Seismic Waves**(Priority: Medium)**

2 main types of waves: body waves (compression motion / P waves or shear motion / S waves) & surface waves trapped near Earth's surface (Love waves or Rayleigh waves) that are slower but larger vibration signals in seismogram

Body waves

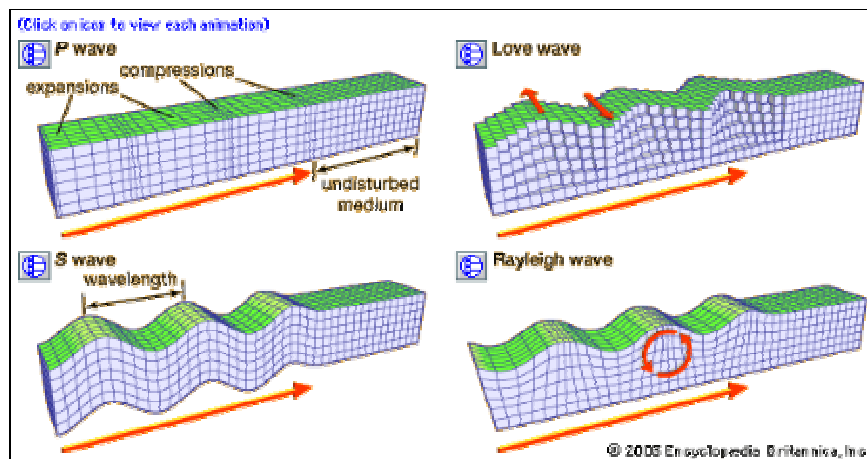
P (primary) waves	S (secondary) waves
First waves to be recorded by seismometer; travels at 6 - 8 km/s	Second to be recorded by seismometers
Compression waves deform rocks by volume change, consisting of alternating pulses of contraction & expansion along wave direction (PUSH-PULL)	Transverse / shear waves deform rocks by shape change, consisting of alternating series of side-wise movements (SIDE TO SIDE)
Move through solid rock & fluid layers of the Earth	Move through SOLID materials only



<http://www.revisionworld.com/files/seismic%20copy.jpg> & <http://earthquake.usgs.gov/learning/kids/coloring/waves.gif>

Surface waves

1. Love waves
 - ✓ Shear wave vibrations on ground surface, comparable to S wave travelling horizontally
2. Rayleigh waves
 - ✓ Combining shear & compression vibrations, involving motion in both vertical & horizontal directions

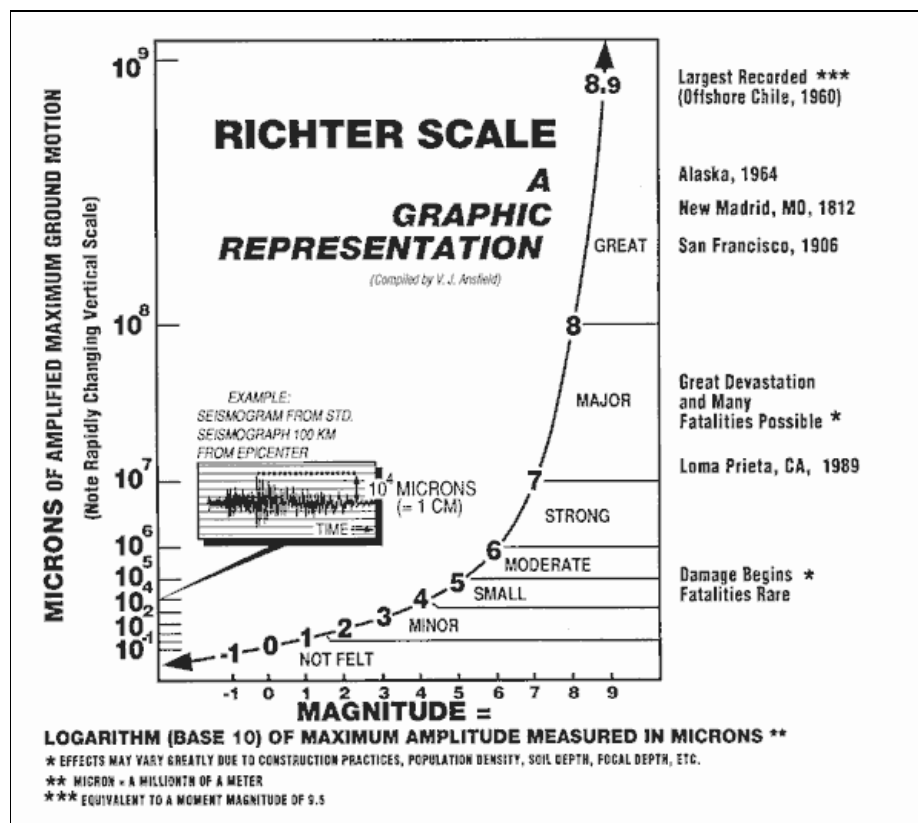


<http://updatecenter.britannica.com/eb/image?binaryId=73334&rendTypeId=4>

Measuring Earthquakes

(Priority: Medium)

- ✓ **Seismometers:** record vibrations of Earth caused by earthquakes in relation to stationary mass on rotating drum / magnetic tape (inertia)
 - Earthquakes' epicentre calculated from arrival times of P & S waves at seismometer
 - Time gap between arrival of waves at seismograph increases precisely with distance from earthquake
- ✓ Scales used to measure earthquake sizes:
 - **Modified Mercalli Intensity scale:** intensity of shaking & damage
 - **Richter Magnitude scale:** wave amplitude measured by seismographs
 - **Moment Magnitude scale:** estimate of earthquake size (by total energy released), a newer & more accurate measurement
- ✓ Intensity of earthquake measure of destructive effects of earthquake
- ✓ Modified Mercalli scale measures on arbitrary scale of 12 degrees, using information supplied by residents living in quake area
 - Not entirely reliable as subjective information depends not just on magnitude of earthquake but also distance from epicentre, depth of focus & local surface / subsurface geology
- ✓ Richter scale measures on logarithmic scale which each whole number signifying a 31.5X increase in energy



http://www.geographyalltheway.com/year9_geography/hazards/tectonic_hazards/imagesetc/earthquakes/richter_scale.gif

Intensity	Observed Effects
I	Felt by only a few people under very special circumstances
II	Felt by only a few people at rest, especially on the upper floors of buildings
III	Felt noticeably indoors, especially on upper floors of buildings
IV	Felt indoors by many people, outdoors by a few; some awaken
V	Felt by nearly everyone; many awaken; dishes and windows break; plaster cracks
VI	Felt by everyone; many frightened and run outdoors; heavy furniture moves
VII	Everyone runs outdoors; slight to moderate damage in ordinary structures
VIII	Considerable damage in ordinary structures; chimneys and monuments fall
IX	Considerable damage in all structures; ground cracks; underground pipes break
X	Most structures destroyed; rails bend; landslides occur; water splashes over banks
XI	Few structures left standing; bridges destroyed; broad fissures in the ground; underground pipes break
XII	Damage total; waves seen on ground surfaces; objects thrown in air

<http://www.regentsprep.org/Regents/earthsci/units/earthquakes/mercalli.gif>

Earthquake Hazards

(Priority: High)

2 types of hazards: primary hazards (ground motion) and secondary hazards (other hazards resulting from the ground motion)

<i>Primary Hazards</i>	<i>Secondary Hazards</i>
<ul style="list-style-type: none"> ✓ Ground motion ✓ Fault breaks on ground surface → buildings / roads split 	<ul style="list-style-type: none"> ✓ Gas / electric lines broken → fires ✓ Ground motion → landslides ✓ Ground motion on water-saturated soil → liquefaction ✓ Seismic sea waves (tsunami)

Case Study: 1985 Mexico City

- ✓ Subduction of Cocos plate beneath North American plate; epicentre on Pacific Ocean floor
- ✓ Magnitude 7.5 - 8.1 on Richter scale
- ✓ Effects of earthquake:
 - 2m tsunami waves hit coastal areas
 - Collapse of buildings in Mexico City
 - 20k killed, 30k homeless
- ✓ Reasons for severity of earthquake / high death toll:
 - Mexico City built on soft silt & peat of former lake → amplified vibrations → liquefaction
 - Densely built-up area with 18m people
 - Lack of automatic shutoff for gas mains
 - Huge fires with no water to douse them as water pipes broken

Case Study: 1988 Armenia

- ✓ Eurasian plate & Arabian plate converge; epicentre in Spitak, Armenia
- ✓ Magnitude 6.9 - 7.2 on Richter scale
- ✓ Effects of earthquake:
 - 25k killed, 500k homeless
 - Entire town of Spitak destroyed (25k residents)
- ✓ Reasons for high death toll:
 - Poorly constructed buildings during stagnation era of Cold War

- Earthquake occurred in morning during schooling hours, causing many students to be trapped beneath school building
- Cold winter temperatures hampered rescue / relief efforts

Earthquake Hazards Management

(Priority: High)

Absence of short-term precursors makes it impossible to predict an earthquake in short-term, hence long-term forecasting is done instead.

FORECASTING	MITIGATION	RESPONSE
1. Recurrence interval prediction	4. Hazard-resistant structures	7. Provision of basic necessities
2. Geophysical forecasting	5. Evacuation planning & public warning systems	8. Provision of technical / financial / goods aid
3. Geological forecasting	6. Hazard mapping	

Volcanic Hazard Forecasting

(Priority: High)

1. Recurrence interval prediction

- ✓ Statistical probability to forecast magnitude & frequency of earthquake
- ✓ Assuming fault behaves in future like in past with characteristic number of earthquakes of certain magnitude

2. Geophysical forecasting

- ✓ Identifying seismic gaps along faults where strain may be building up
 - If portion of fault locked for some time, strain may have built up to high levels → large quake may occur in near future
- ✓ (-) Lack of seismic activity could be caused by fault creep or because of dead fault unlikely to move again!
 - **Fault creep:** gradual slip produced by yielding of rocks along weak boundary of fault, occurring so slowly no detectable seismic waves are generated

3. Geological forecasting

- ✓ Studying long-term geologic history of earthquakes along faults to identify where faults are due for future big movement
 - Areas that have stored seismic strain for long time
 - Going beyond human history of recorded earthquakes to deduce ancient earthquakes
- ✓ Similar to statistical method
 - (+) Provides long time frame to study earthquakes
 - (-) Age & magnitude of prehistoric earthquake hard to determine
- ✓ Asperities: rough, slip-resistant areas along fault planes holding rock back from sliding
 - Study asperities in geological method as asperities lock faults longer, allowing bigger strain to build up

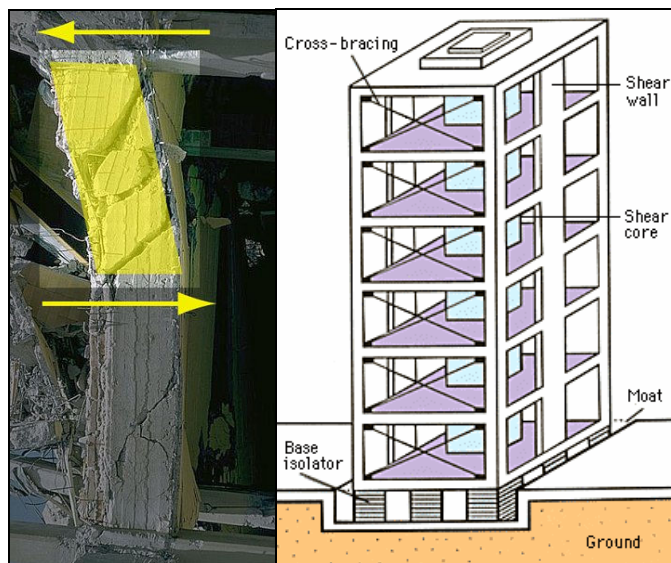
- Large asperity areas: fewer but larger earthquakes
- Fewer asperity areas: more but smaller earthquakes
- No asperities: fault creep but no earthquakes

Earthquake Hazard Mitigation (Priority: High)

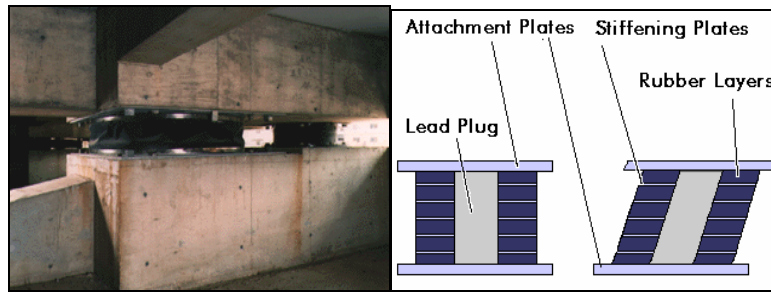
Hazard	Mitigation
<i>Ground shaking damaging structures</i>	<u>Construction methods</u> increasing resistance to shaking or <u>isolating structures</u> from shaking
<i>Liquefaction</i>	<u>Hazard mapping</u> to locate vulnerable soils
<i>Land uplift / subsidence along faults</i>	<u>Hazard mapping</u> to locate faults
<i>Fire caused by ruptured gas / electrical systems</i>	<u>Adequate shut-off systems</u> & <u>public education</u>
<i>Tsunami</i>	<u>Public warning systems</u> & <u>hazard mapping</u> of inundation-prone areas

1. Ground shaking

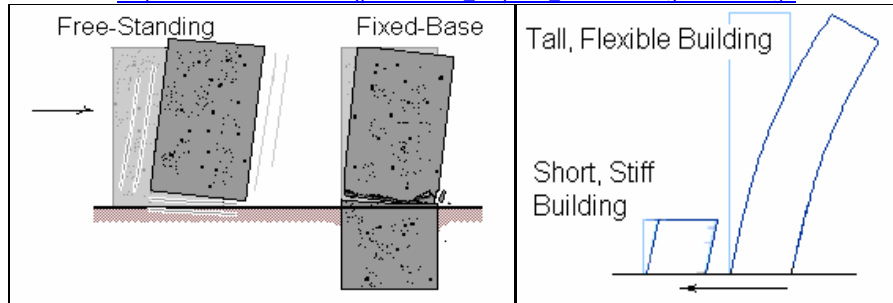
- ✓ Most deaths occur when S waves & surface waves cause shaking buildings to collapse, as a result of base shear
 - **Base shear:** horizontal ground acceleration deforming building from rectangle to parallelogram
- ✓ To mitigate against base shear:
 - **Shear wall:** diagonal braces built into walls to prevent deformation
 - **Foundation bolting:** prevent building from sliding off
 - **Base isolation:** building on large rubber pads, rolling wheels or Teflon plates to allow ground movement under building
 - **Seismic joints:** flexible connections between different parts of building to allow independent shaking
 - New construction practices like retrofitting existing columns with steel jackets to strengthen them



<http://urban.arch.virginia.edu/~km6e/tti/tti-summary/full/mex-city-shear-col-noted-2.jpeg> & http://www.nasa.gov/images/content/110946main_earthquake1.gif



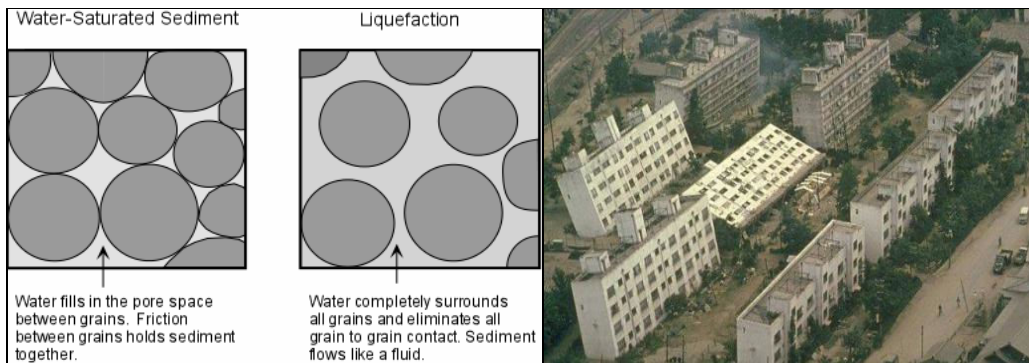
<http://earthsci.org/processes/geopro/seismic/seismic.html> &
http://www.takenaka.co.jp/takenaka_e/quake_e/menshin/gif/sekisou.gif



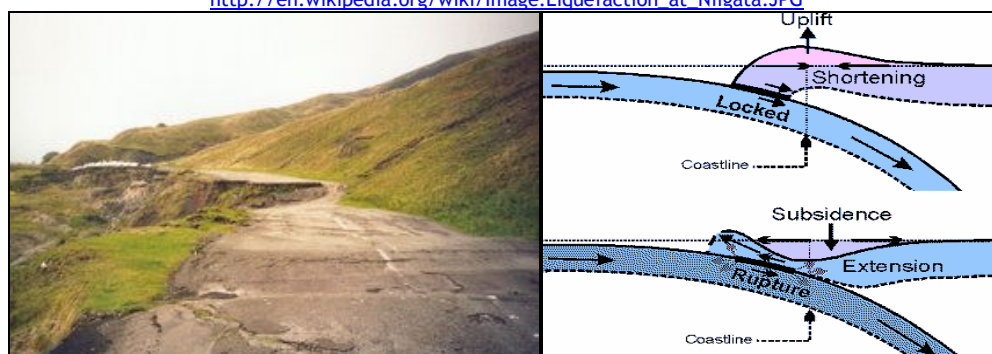
<http://earthsci.org/processes/geopro/seismic/seismic.html>

2. Liquefaction

- ✓ **Liquefaction:** occurring in water-saturated soils, shaking of water-saturated soil causes particles to settle, driving water out from between particles & forcing water upwards, liquefying soil above
- ✓ Mitigation involves identifying vulnerable areas
 - By deep drilling into rock
 - (-) Expensive to do over large areas



http://wapi.isu.edu/EnvGeo/EG5_earthqks/eg_mod5.htm &
http://en.wikipedia.org/wiki/Image:Liquefaction_at_Niigata.JPG



<http://content.answers.com/main/content/wp/en/thumb/2/21/300px-SubsidedRoad.jpg> &
<http://cgc.rncan.gc.ca/geodyn/images/mega07.gif>

3. Land uplift & subsidence

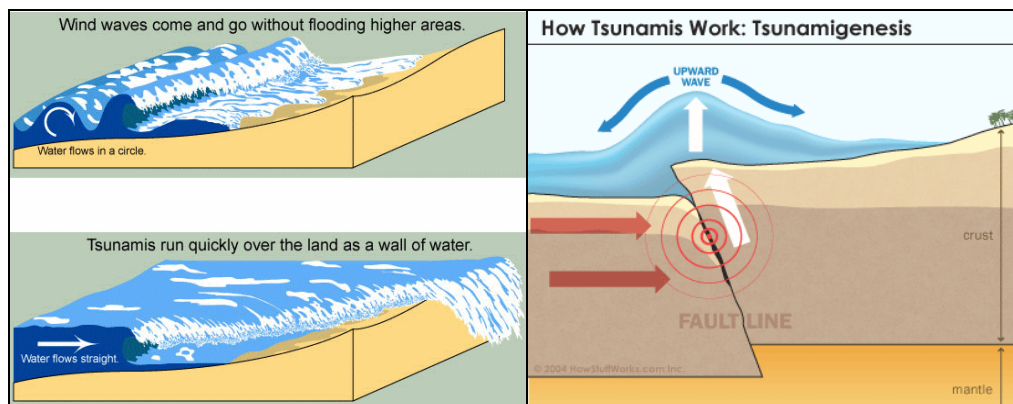
- ✓ Ground shaking from earthquake can damage structures far away from actual fault!
 - Areas next to fault experience direct damage from land uplift or subsidence
- ✓ Mitigation involves hazard mapping of potentially active faults

4. Fires

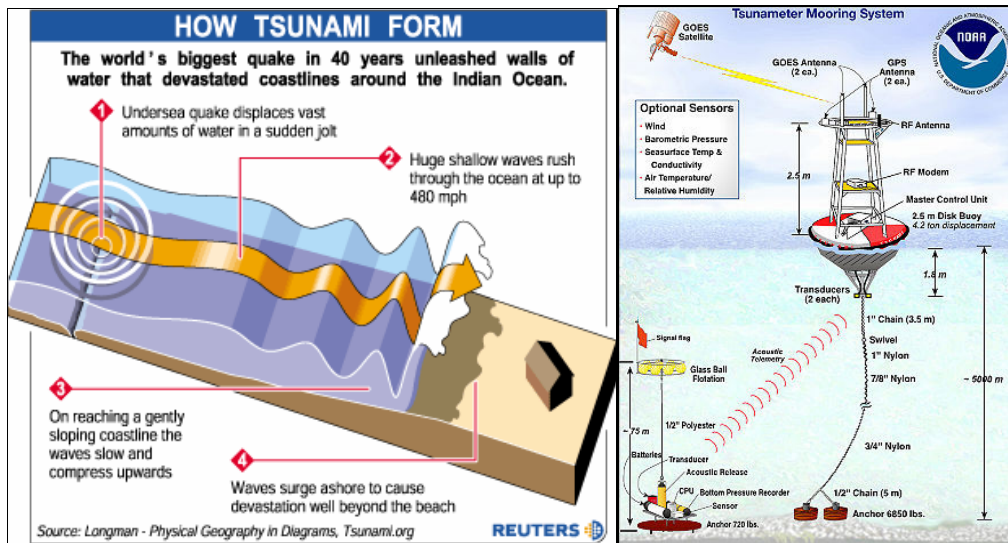
- ✓ Damage from fires greater than ground shaking in some urban quakes!
 - Biggest threat to home & neighbourhood in earthquake
- ✓ Mitigation through education & awareness about shutting off gas valves & electricity before / in earthquake

5. Tsunamis

- ✓ **Tsunami:** waves generated by physical disturbances of ocean
 - Often caused by earthquakes in sea floor
 - Undersea volcanic eruptions, landslides & meteoric impacts can also cause tsunamis
- ✓ In deep water tsunamis are low, fast-moving & virtually undetectable
 - As leading waves of tsunami approach shoreline, friction with sea floor slows waves down
 - **Shoaling:** waves coming together & stacking up, building up height & steepness of waves causing surge
- ✓ Most destructive tsunamis occur in Pacific Ocean
- ✓ Mitigation of tsunami destruction involves tsunami warning systems & inundation maps
- ✓ Tsunami warning systems send warnings when large, potentially tsunami-producing earthquake is located
 - (-) Such warning systems have ~75% false alarm rate
- ✓ **Inundation map:** shows areas of potential tsunami flooding based on elevation & orientation to open sea
 - Aim to make locals aware of their vulnerability to tsunamis, so that tsunami warnings are heeded
- ✓ Education, public awareness & hazard mapping are best mitigation strategies!



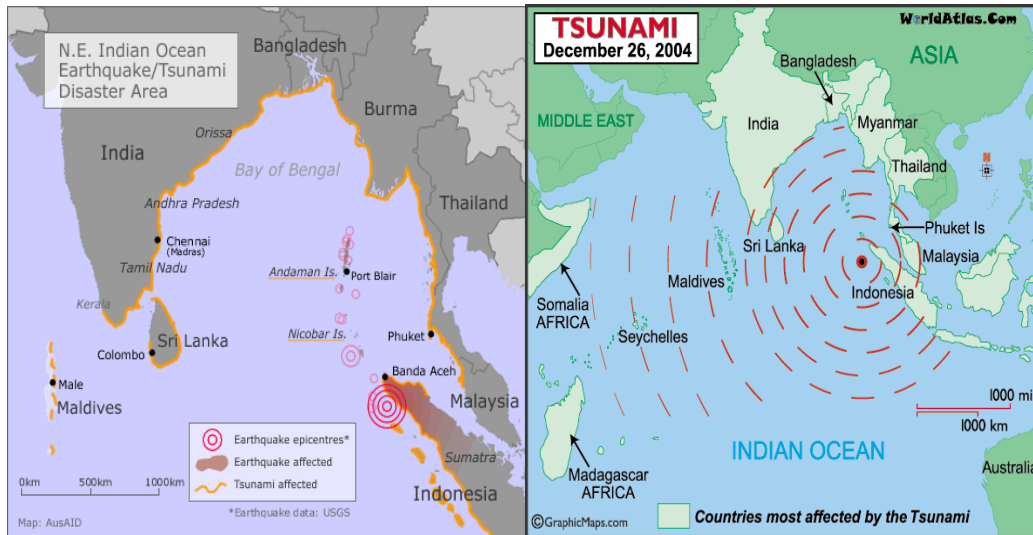
http://mail.colonial.net/~hkaiter/earth_science_images/tsunami1-1.gif &
<http://static.howstuffworks.com/gif/tsunami-formation.gif>



http://www.ramdac.org/images/tsunami_form_graphic.gif &
<http://upload.wikimedia.org/wikipedia/en/thumb/8/87/Tsunami-dart-system2.jpg/350px-Tsunami-dart-system2.jpg>

2004 Indian Ocean Earthquake & Tsunami (Priority: Medium)

Occurred on 26 December 2004, magnitude 9.3 at 30km depth within Earth, on subduction zone where India plate & Burma plate collide. Tsunami generated claimed about 230k lives in countries on Indian Ocean fringe.



<http://www.USAID.gov.au/hottopics/images/tsunamiregion2.gif>,
<http://www.worldatlas.com/atlas/infopage/tsunami.gif>

- ✓ A key factor for high death tolls was lack of tsunami-warning system unlike Pacific Ocean
 - Risk of tsunami too small and system (that might never be used) too costly: tsunami alert structure costs Japan \$20m annually
- ✓ Warnings were issued by earthquake monitoring centres in Hawaii, Indonesia, Australia & Japan but no widespread alert was issued
 - Tsunami likelihood warning not released by Australia as fear of breaching diplomatic protocol

- ✓ Besides technology for a warning system, skilled personnel, open communication lines, planning for emergency & evacuation procedures are necessary to reduce loss of lives
- ✓ Aid was rendered by many countries in tsunami aftermath, but accessibility to worst-hit areas affected as roads & airstrips are damaged, flooded or blocked by debris
- ✓ Tsunami buoy as part of warning system finally laid in Indian Ocean in December 2006, provided by the USA
 - (-) Problems: red tape, where to locate? Who pays for system?