Tsunamis: The Japanese word for “large harbor waves”, produced by the sudden vertical displacement of ocean water
- Can be triggered by any rapid uplift or subsidence of the seafloor, such as submarine earthquake, landslide, volcanism, and impact of asteroid or comet
- Mega-tsunami, from asteroid impact, a wave about 100 times higher than the largest tsunami produced by an earthquake
- Tsunamis produced by earthquakes are by far the most common

Pre-Historic Tsunami
- ~65 Ma ago – Impact that killed dinosaurs (circum-Caribbean tsunami up to 300 m high, that ran inland over Gulf Coast 300 km!)

Historic Tsunamis
- ~1628 B.C. - Santorini – volcanic caldera collapse off coast of Greece – destroyed Minoan civilization
- 1883 – Krakatau eruption, Indonesia – ~36,000 deaths – ~37 m (120 ft) high!
- 1958 – Lituya Bay, AK – landslide into fjord produced wave over 500 m high!!!
- 1960 – M 9.5 quake in Chile caused tsunami that killed 61 in Hawaii (11 m wave in Hilo Bay)
- 1964 – M 9.2 quake in Alaska caused tsunami that killed 131 in AK and CA
- 2004 – M 9.1 quake in Indonesia caused tsunami that killed over 200,000 people around Indian Ocean basin (including some in Africa!)
- 2011 – M 9.0 quake off northeast coast of Japan caused tsunami that killed over 20,000 along coast and damaged nuclear power plant

Case History: Indonesian Tsunami
- December 26, 2004, within a few hours, close to 250,000 people were killed
- With no warning system in place
- The source of this tsunami was the largest earthquake on Earth in the past 4 decades, magnitude 9.1
- A large amount of displacement along the thrust faults in the subduction zone, geologists classify this earthquake as a “megathrust event”
- The total length of the rupture over 1500 km (930 mi)
- Over three-quarters of the deaths were in Indonesia
- A warning of a half hour or so would have been sufficient to move many people from low-lying coastal areas. The first tsunami wave took 1 to 2 hours to reach Sri Lanka and India; 7 hours to reach Somalia on the west coast of Africa
- In Thailand, a 10-year-old British girl sounded the warning in time for 100 people to evacuate a resort beach. In Sri Lanka, a scientist recognized signs (dramatic sea level change) and sounded the alarm. In Thailand, elephants, not people, sounded the warning and saved lives
• Vital role of education in tsunami preparedness

• Case Story: M 9.0 Quake – Japan (March 11, 2011)
  • 5th largest quake ever recorded
  • Occurred on convergent plate boundary
  • Typical/expected location for such large quakes
  • Largest measured quake to hit Japan
  • 12 million without power in Tokyo area
  • Power plants shut down
  • At least 1 nuclear plant with cooling problem
  • Best-documented tsunami ever
  • Could end up being the most expensive natural disaster of all time
  • 130 km off coast of Japan
  • 24 km focal depth
  • 9.0 Magnitude – 5th largest ever recorded
  • Up to 10 meter tsunami generated
  • May be most expensive disaster ever
  • Best-documented tsunami by far
  • Sendai (~1 million population) devastated
  • Hundreds caught in landslide near Sendai
  • 28 aftershocks of magnitude ≥5.5 in the 5 hours following the main quake
  • Japan’s nuclear plant disaster
    • Worst accident since Chernobyl in 1986
    • 2nd worst nuclear power accident ever (Chernobyl was much worse)
    • NOT caused directly by earthquake
    • Loss of cooling of nuclear fuel due to power loss following tsunami
    • Similar logistical problems at most U.S. plants involve powering of pumps, NOT quake/tsunami risks
    • Possible exceptions are Diablo Canyon, CA, on coast, near San Andreas Fault, And San Onofre, CA, on coast, at very low elevation!

• How Do Earthquakes Cause a Tsunami?
  • Cause a tsunami by movement of the seafloor and by triggering a vertical displacement/landslide
  • M 7.5 or greater earthquake create enough displacement of the seafloor to generate a damaging tsunami
  • A four-stage process that eventually leads to landfall of tsunami waves on the shore

• Tsunami Movement
  • When an earthquake uplifts the seafloor close to land, both distant and local tsunamis may be produced
  • Distant tsunami: Travels out across the deep ocean at high speed for thousands of kilometers to strike remote shorelines with very little loss of energy
• **Local tsunami:** Heads in the opposite direction toward the nearby land and arrives quickly following an earthquake
• When the initial tsunami wave is split, each (distant and local) tsunami has a wave height about one-half of that of the original dome of water

• Landslides Cause a Tsunami
  • Submarine landslides can generate very large tsunamis
  • Large rock avalanches falling from mountains into the sea can also generate very large tsunamis
  • 1998, a M 7.1 earthquake triggered a submarine landslide and caused a tsunami of 15 m (50 ft), leaving 12,000 people homeless and over 2,000 dead
  • Lituya Bay, Alaska, in 1958. The landslide set in motion by a M 7.7 earthquake on a nearby fault. The huge mass of broken rock caused waters in the bay to surge upward to an elevation of about 524 m (1720 ft) above the normal water level

• Regions at Risk
  • All ocean and some lake shorelines are a risk for tsunamis, some coast are more at risk than others
  • Coasts close to a major subduction zone or directly across the ocean basin from a major subduction zone are at greatest risk
  • The greatest tsunami hazard with return periods of several hundred years
  • High risk regions: The Cascadia subduction zone, the Chilean trench, the subduction zones off the coast of Japan, parts of the Mediterranean, as well as the northeastern side of the Indian Ocean

• Effects of Tsunamis
  Primary
  • Damage to both the landscape and human structures from resulting flooding and erosion
  Secondary
  • Fires may start in urban areas from ruptured natural gas lines or from the ignition of flammable chemicals
  • Water supplies may become polluted
  • Damaged wastewater treatment systems
  • Disease outbreaks
  • Minimizing the Tsunami Hazard
    • Detection and warning
    • Structural control
    • Construction of tsunami runup maps
    • Land use planning
    • Probability analysis
    • Education
    • Detection and Warning
• For distant tsunamis: Can be detected in the open ocean and accurately estimated their arrival time to within a few minutes
• A tsunami warning system has three components:
  • A network of seismographs to measure submarine movements
  • Automated tidal gauges to measure unusual rises and falls of sea level
  • A network of sensors connected to floating buoys
• Structural Control
  • Many houses and small buildings are unable to withstand the impact of an 1 to 2 meter high tsunami
  • Larger structures, such as high-rise hotels and critical facilities, can be engineered to greatly reduce or minimize the destructive effects of a tsunami
  • The current building codes and guidelines do not adequately address the effect of a tsunami on buildings and other structures
• Tsunami Runup Maps
  • Shows the level to which the water traveled inland
  • Before a tsunami strikes, a community can produce a hazard map that shows the area that is likely to be inundated by a given height
  • Many coastal cities and areas have produced tsunami runup maps, and this trend will undoubtedly continue
• Land Use Planning
  • The 2004 Indonesian tsunami showed tropical ecology played a role in determining tsunami damage
  • Villages spared from destruction were partly protected from the energy of the tsunami by either a coastal mangrove forest or several rows of plantation trees that reduced the velocity of incoming water
  • Planting or retaining native vegetation could provide a partial buffer from a small to moderate tsunami attack
  • Don’t rely on land use planning, the best and safest approach to lessen the tsunami hazard is quick evacuation. Trees cannot stop large tsunami
• Probability Analysis
  • The risk of a particular event may be defined as the product of the probability of that event occurring and the consequences
  • Developing a probabilistic analysis of the tsunami hazard is to:
    • Identify and specify the potential earthquake sources
    • Specify relationships that will either attenuate or reduce tsunami waves
    • Apply probabilistic analysis to the tsunami hazard similar to what is currently being done for earthquake hazard analysis
    • Probabilistic approach to tsunami hazard assessment is still being developed
• Education
  • The educational component is of particular importance. Most people don’t even know if a tsunami watch or warning is issued
  • In 2005 in Santa Barbara, nothing was said about the size of the possible tsunami, some people, on hearing the notice, drove too far to the top of a nearby mountain pass thousands of feet above sea level
• No plan for people to directly observe the tsunami, some went to sea cliff and some climbed up trees, bad approaches
• Educate coastal residents and visitors as to the difference between a tsunami watch and tsunami warning
  • **Tsunami watch:** An earthquake that can cause a tsunami has occurred
  • **Tsunami warning:** That a tsunami has been detected and is spreading across the ocean toward their area
• Tsunamis come in a series of waves, and that the second and third waves may be larger than the first one
• Tsunami Ready Status
  • Establish an emergency operation center with 24-hour capability
  • Have ways to receive tsunami warnings from the National Weather Service, Canadian Meteorological Centre, Coast Guard, or other agencies
  • Have workable ways to alert the public
  • Develop a tsunami preparedness plan with emergency drills
  • Promote a community awareness program to educate people concerning a tsunami hazard
• Adjustment to Tsunami Hazard(1)
  • If you feel a strong earthquake and are at the beach, leave the beach and low-lying coastal area immediately
  • If the trough of a tsunami wave arrives first, the ocean will recede. This is one of nature’s warning signs, run from the beach
  • A tsunami may be relatively small at one location, it may be much larger nearby
  • Generally consist of a series of waves, and there can be up to an hour between waves, stay out of dangerous areas until further notice
  • Coastal communities, as they gain tsunami readiness status, will have warning sirens
  • Move away from the beach to higher ground, at least 20 m (60 ft)
  • If you are aware that a tsunami watch or warning has been issued, do not go down to the beach to watch the tsunami

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