EARTHQUAKE HAZARDS

LESSON 1: GROUND SHAKING

Earthquakes result from the abrupt movement of large rock masses along fault lines in the Earth's crust and upper mantle. The Earth's surface is made up of tectonic plates, which are huge, irregular slabs of rock. The rough edges of these plates become stuck as they move, eventually releasing stored energy when the friction is overcome, causing **seismic waves**. These waves propagate through the Earth, emitting energy in all directions, leading to surface shaking. Two main types of seismic waves exist: **body waves**, which travel through the Earth's interior, and **surface waves**, which move along the Earth's surface.

Primary (P) waves are the initial seismic waves to reach the Earth's surface, causing light shaking by moving the ground back and forth in the direction they travel. **Secondary (S) waves**, which move perpendicular to their propagation direction, shake the ground more strongly than P waves but travel slower. **Surface waves**, including Love waves and Rayleigh waves, remain near the surface. **Love waves** move horizontally perpendicular to their direction of travel, while **Rayleigh waves** produce rotational ground shaking with no transverse motion.

The intensity of an earthquake is determined by assessing both the energy it releases, known as its **magnitude**, and its impact on individuals and human-built structures, which we refer to as **intensity**.

Frequency refers to how often ground shaking occurs within a specific timeframe. **High-frequency earthquakes** primarily impact smaller buildings, as they experience rapid, successive waves, akin to a small boat being rocked by multiple waves, potentially leading to capsizing. Conversely, tall structures such as skyscrapers are more affected by **low-frequency earthquake** waves or prolonged, slow shaking, causing them to sway significantly.

Ground shaking stands as the foremost factor behind the damage inflicted upon human-made constructions during earthquakes. This shaking leads to the collapse of buildings and infrastructure, potentially causing injuries or fatalities. In instances where it ruptures water dams, flash floods may ensue. Furthermore, if the shaking disrupts electric and gas lines significantly, **fire** emerges as a secondary hazard. Moreover, ground shaking initiates additional earthquake-related dangers like **landslides and liquefaction**.

A **building code** establishes construction standards to ensure buildings are constructed safely. When adhered to, it helps ensure buildings can withstand earthquakes with minimal damage, thus safeguarding occupants. While earthquake-resistant buildings are not impervious to earthquakes, they sustain less damage compared to conventional structures.

LESSON 2: GROUND RUPTURE

Ground rupture refers to the observable fracturing and displacement of the Earth's surface along a fault line. This displacement can manifest as vertical, lateral, or a combination of both movements, depending on the specific fault type responsible.

Strike-slip faults are nearly vertical fractures in the Earth's crust that move rocks horizontally. When observing such faults, if the block on the opposite side shifts to the left, it indicates a **sinistral fault (or left-lateral fault)**. Conversely, if the block moves to the right, it indicates a **dextral fault (or right-lateral fault)**.

Normal faults involve the hanging wall moving downward relative to the footwall. Conversely, reverse or thrust faults involve the hanging wall moving upward. These faults, categorized as **dip-slip faults**, result in vertical displacement of the ground.

Effective engineering solutions for ground rupture prevention are currently unavailable. Structures located on or near fault lines are vulnerable to ground rupture. The most practical approach is to refrain from constructing buildings on faults or within the recommended minimum safety distance, which should be at least 5 meters from either side of an active fault trace.

LESSON 3: LIQUEFACTION

What causes liquefaction?

Liquefaction transpires when the ground loses its solidity and takes on liquid-like characteristics due to earthquake activity. During shaking, the particles in the ground vibrate, causing **compaction** where sediments compress and fluids in pore spaces are expelled. This process reduces the gaps between particles, leading to heightened pore water pressure. When this pressure matches the weight of the material above, liquefaction takes place.

Liquefaction is influenced by various factors including the duration and intensity of shaking, distance from the fault, density of infrastructure, and geological conditions. More intense and prolonged shaking results in more significant liquefaction. When liquefaction occurs at deeper levels, it can lead to sand and water erupting from the ground, known as **sand boils**.

LESSON 4: EARTHQUAKE-INDUCED LANDSLIDES

Mass wasting, also referred to as **landslides,** involves the downward displacement of rocks or sediments due to gravity. This process occurs subsequent to weathering or the detachment of material from its original location. Landslides can be induced by various factors including intense or prolonged rainfall, steep slopes, deforestation, and seismic activity such as earthquakes.

An instance of earthquake-induced landslides occurred on July 6, 2017, following a magnitude 6.5 earthquake hitting Leyte Island. The earthquake's epicenter was approximately 15.5 km northeast of Ormoc City. This seismic event led to both liquefaction and landslides, causing damages estimated to be at least Php 271 million. This lesson will emphasize the study of landslides triggered by earthquakes.

The shaking generated by an earthquake and its subsequent aftershocks can result in the substantial movement of rock or sediment. Several factors must be taken into account for earthquakes to trigger landslides, including the earthquake's intensity, proximity to the fault, terrain, climate conditions, and the specific properties of the rock or soil.

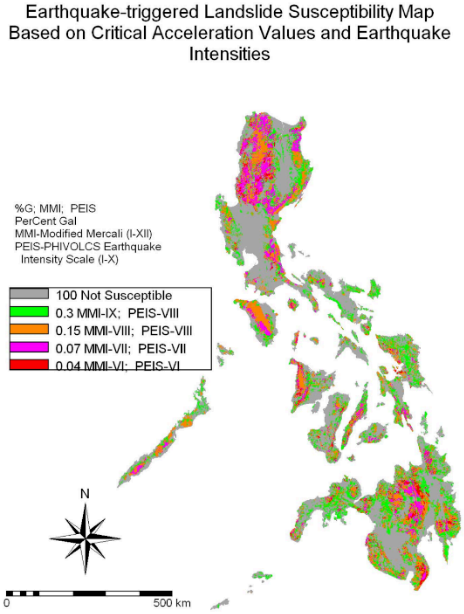
In addition to the earthquake, the landslide was influenced by heavy and sustained rainfall as well as creep. **Creep** refers to the gradual and barely noticeable downward movement of inclined rock or soil, resulting from the accumulation of considerable strain over time.

Certain terrains are more prone to earthquakes triggering landslides. These events are common in mountainous and hilly regions, particularly where slopes are excavated for road construction and other human activities. Slopes of moderate to steep inclines facilitate the movement of rock and sediment under the influence of gravity.

The geological composition of an area influences the susceptibility to earthquake-induced landslides. Aged and weathered rocks are more prone to collapse under ground shaking compared to younger, less weathered ones. Loose and unconsolidated materials are also more vulnerable to displacement than solid rock. However, even hardened rock with fractures and weak planes can succumb to earthquake-induced landslides.

The timing of landslides following an earthquake varies. Some occur suddenly, allowing little time for preparation or evacuation. However, in certain cases, there are warning signs to be aware of, including newly formed cracks or bulges in the ground, increased sediment in streams, tilting poles or walls, escalating rumbling sounds (indicating an impending landslide), and unusual noises like snapping trees or colliding rocks.

An **earthquake-induced landslide susceptibility map** is a valuable tool for identifying at-risk regions. **PHIVOLCS** has created such maps for various Philippine regions, accessible on their website. These maps account for two key factors: critical acceleration and intensity.



Earthquake-induced landslide susceptibility map of the Philippines
Image from https://www.phivolcs.dost.gov.ph/index.php/news/2-uncategorised/281-earthquake-hazard-maps-2

Intensity	Description
I	**Scarcely Perceptible** - Perceptible to people under favorable circumstances. Delicately balanced objects are disturbed slightly. Still Water in containers oscillates slowly.
II	**Slightly Felt** - Felt by few individuals at rest indoors. Hanging objects swing slightly. Still Water in containers oscillates noticeably.
III	**Weak** - Felt by many people indoors especially in upper floors of buildings. Vibration is felt like one passing of a light truck. Dizziness and nausea are experienced by some people. Hanging objects swing moderately. Still water in containers oscillates moderately.
IV	**Moderately Strong** - Felt generally by people indoors and by some people outdoors. Light sleepers are awakened. Vibration is felt like a passing of heavy truck. Hanging objects swing considerably. Dinner, plates, glasses, windows and doors rattle. Floors and walls of wood framed buildings creak. Standing motor cars may rock slightly. Liquids in containers are slightly disturbed. Water in containers oscillate strongly. Rumbling sound may sometimes be heard.
V	**Strong** - Generally felt by most people indoors and outdoors. Many sleeping people are awakened. Some are frightened, some run outdoors. Strong shaking and rocking felt throughout building. Hanging objects swing violently. Dining utensils clatter and clink; some are broken. Small, light and unstable objects may fall or overturn. Liquids spill from filled open containers. Standing vehicles rock noticeably. Shaking of leaves and twigs of trees are noticeable.
VI	**Very Strong** - Many people are frightened; many run outdoors. Some people lose their balance. motorists feel like driving in flat tires. Heavy objects or furniture move or may be shifted. Small church bells may ring. Wall plaster may crack. Very old or poorly built houses and man-made structures are slightly damaged though well-built structures are not affected. Limited rockfalls and rolling boulders occur in hilly to mountainous areas and escarpments. Trees are noticeably shaken.
VII	**Destructive** - Most people are frightened and run outdoors. People find it difficult to stand in upper floors. Heavy objects and furniture overturn or topple. Big church bells may ring. Old or poorly-built structures suffer considerably damage. Some well-built structures are slightly damaged. Some cracks may appear on dikes, fish ponds, road surface, or concrete hollow block walls. Limited liquefaction, lateral spreading and landslides are observed. Trees are shaken strongly. (Liquefaction is a process by which loose saturated sand lose strength during an earthquake and behave like liquid).
VIII	**Very Destructive** - People panicky. People find it difficult to stand even outdoors. Many well-built buildings are considerably damaged. Concrete dikes and foundation of bridges are destroyed by ground settling or toppling. Railway tracks are bent or broken. Tombstones may be displaced, twisted or overturned. Utility posts, towers and monuments mat tilt or topple. Water and sewer pipes may be bent, twisted or broken. Liquefaction and lateral spreading cause man- made structure to sink, tilt or topple. Numerous landslides and rockfalls occur in mountainous and hilly areas. Boulders are thrown out from their positions particularly near the epicenter. Fissures and faults rapture may be observed. Trees are violently shaken. Water splash or stop over dikes or banks of rivers.
IX	**Devastating** - People are forcibly thrown to ground. Many cry and shake with fear. Most buildings are totally damaged. bridges and elevated concrete structures are toppled or destroyed. Numerous utility posts, towers and monument are tilted, toppled or broken. Water sewer pipes are bent, twisted or broken. Landslides and liquefaction with lateral spreadings and sand boils are widespread. the ground is distorted into undulations. Trees are shaken very violently with some toppled or broken. Boulders are commonly thrown out. River water splashes violently on slopes over dikes and banks.
X	**Completely Devastating** - Practically all man-made structures are destroyed. Massive landslides and liquefaction, large scale subsidence and uplifting of land forms and many ground fissures are observed. Changes in river courses and destructive seiches in large lakes occur. Many trees are toppled, broken and uprooted.

PhIVOLCS Earthquake Intensity Scale (PEIS)

Image from http://www.phivolcs.dost.gov.ph/index.php?option=com_content&task=view&id=45&Itemid=100

LESSON 5: TSUNAMI

A **tsunami** is a sequence of waves resulting from significant displacements of water, often triggered by earthquakes or large underwater landslides. Originating from the Japanese words "tsu" meaning "harbor" and "nami" meaning "wave," it literally translates to "harbor wave."

When an earthquake occurs beneath the ocean, it forces the water above to move upward, generating tsunamis. Initially, these waves are small, but they grow as they move into shallower waters, a phenomenon known as **wave shoaling,** as they approach the coastline. Similar to seismic waves transitioning from harder to softer materials, tsunamis decrease in speed as they move into shallower waters. This decrease in velocity is offset by an increase in wave amplitude or height.

Tsunamis typically arise from earthquakes in **subduction zones**, which are locations at **converging tectonic plate boundaries**. In these zones, one plate descends **(subducts)** beneath another. This downward movement of the **subducting plate** is influenced by temperature, as the colder lithosphere is denser and thus sinks below the warmer lithosphere.

A tsunami can be **local** or **regional**. Local tsunamis are from a nearby source. They are confined to coasts within 100 km or the distance they travel within less than an hour. Regional tsunamis affect a wide geographical area, typically within 1,000 km or 1-3 hours of the wave travel time.

Tsunamis are monitored using open-ocean buoys and tide gauges, which track changes in sea level. A magnitude 7.5 earthquake is sufficient to trigger a tsunami watch. If a tsunami is confirmed by tide stations, a warning is issued, and evacuation procedures are enacted.
There are natural indicators of an approaching tsunami:

- Prolonged, intense ground shaking
- Sudden recession of sea levels, exposing ocean floor features
- Loud, rumbling noises resembling a freight train or aircraft
- A massive incoming wall of water

In such situations, immediate evacuation to higher ground is imperative. It's crucial to avoid low-lying or coastal areas even after the initial wave, as tsunamis often arrive in multiple waves, sometimes hours apart.