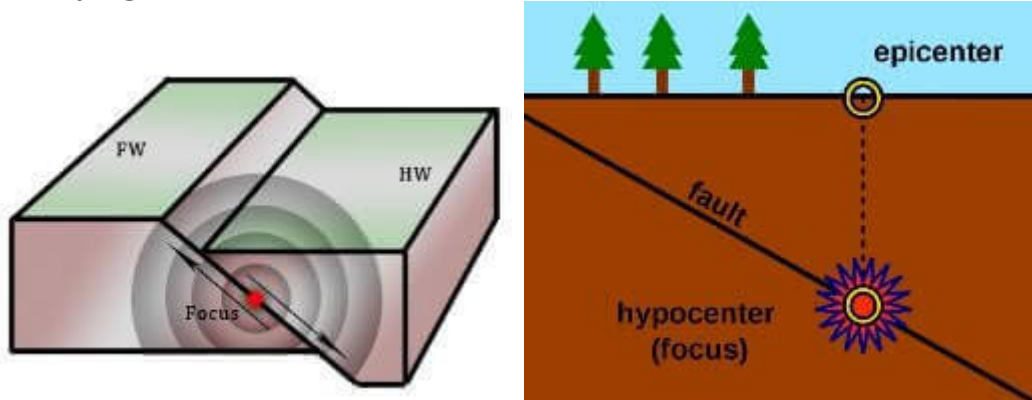


How are earthquake waves produced?

- The abrupt release of energy along a fault (sharp break in the crustal layer) causes earthquake waves.
- Rock layers along a fault tend to move in opposite directions due to the force exerted on them but are held in place by counteracting frictional force exerted by the overlying rock strata.

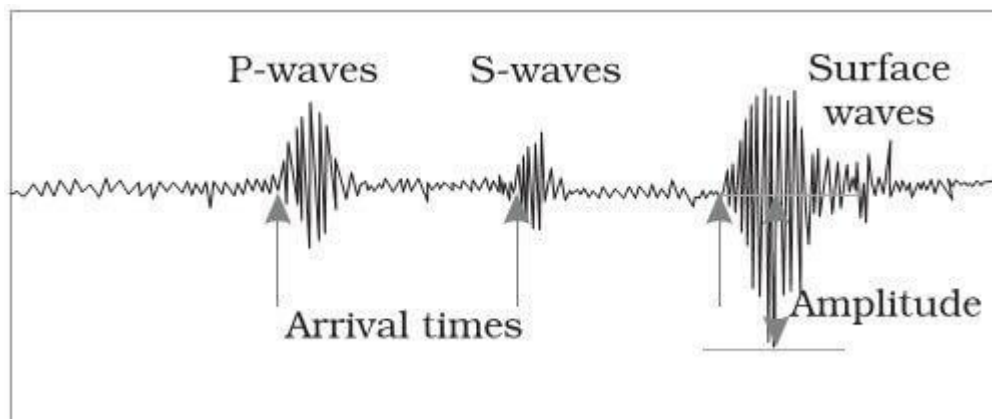


The Focus of an Earthquake ([Eround1](#)); Epicentre (AnsateSam, via [Wikimedia Commons](#))

- The pressure on the rock layers builds up over a period and overcomes the frictional force resulting in a sudden movement generating shockwaves (seismic waves) that travel in all directions.
- The point where the energy is released is called the **focus** or the **hypocentre** of an earthquake.
- The point on the surface directly above the focus is called **epicentre**.
- An instrument called 'seismograph' records the waves reaching the surface.

Types of Seismic waves or earthquake waves

- The seismic waves or earthquake waves are basically of two types — **body waves** and **surface waves**.

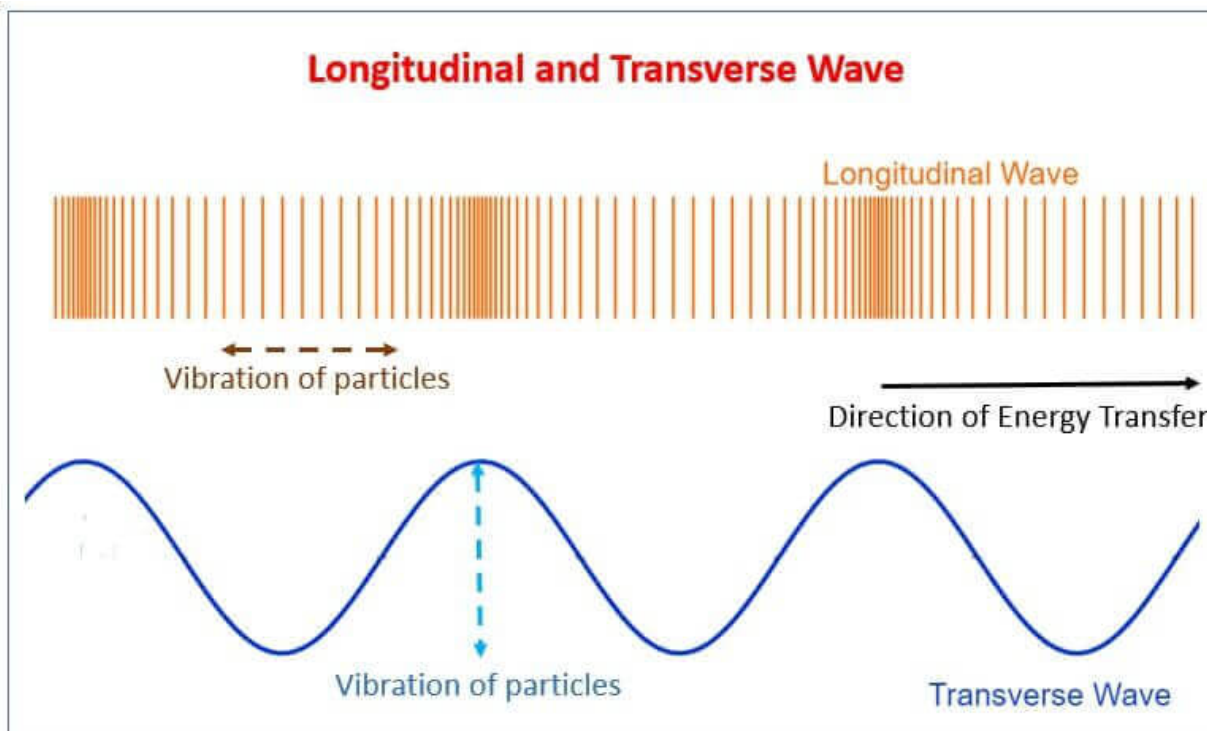


Body waves

- Body waves are generated due to the release of energy at the focus and **move in all directions** travelling through the interior of the earth. Hence, the name body waves.
- There are two types of body waves:
- the **P-waves or primary waves (longitudinal** in nature — wave propagation is similar to sound waves), and
- the **S-waves or secondary waves (transverse** in nature — wave propagation is similar to ripples on the surface of the water).

Primary Waves (P-waves)

- Primary waves are called so because they are the **fastest** among the seismic waves and hence are **recorded first on the seismograph**.
- P-waves are also called as the
- **longitudinal waves** because the displacement of the medium is in the same direction as, or the opposite direction to, (parallel to) the direction of propagation of the wave; or
- **compressional waves** because they produce compression and rarefaction when travelling through a medium; or
- **pressure waves** because they produce increases and decreases in pressure in the medium.
- P-waves creates density differences in the material leading to stretching (rarefaction) and squeezing (compression) of the material.



The vibration of particles in Longitudinal wave and Transverse wave ([Source](#))

- These waves are of relatively high frequency and are the **least destructive** among the earthquake waves.
- The trembling on the earth's surface caused due to these waves is in the **up-down direction (vertical)**.
- **They can travel in all mediums**, and their velocity depends on **shear strength (elasticity)** of the medium.
- Hence, the velocity of the P-waves in **Solids > Liquids > Gases**.
- These waves take the form of **sound waves** when they enter the atmosphere.
- P-wave velocity in earthquakes is in the range 5 to 8 km/s.
- The precise speed varies according to the region of the Earth's interior, from less than 6 km/s in the Earth's crust to 13.5 km/s in the lower mantle, and 11 km/s through the inner core.

*We usually say that the speed of sound waves depends on density. But there are few exceptions — **mercury is denser than iron**, but it is less elastic; hence the **speed of sound in iron is greater than that in mercury***

Why do P-waves travel faster than S-waves?

- **P-waves are about 1.7 times faster than the S-waves.**
- P-waves are compression waves that apply a force in the direction of propagation and hence transmit their energy quite easily through the medium and thus travel quickly.

- On the other hand, S-waves are **transverse waves** or **shear waves** (motion of the medium is perpendicular to the direction of propagation of the wave) and are hence less easily transmitted through the medium.

P-waves as an earthquake warning

- Advance earthquake warning is possible by detecting the non-destructive primary waves that travel more quickly through the Earth's crust than do the destructive secondary and surface waves.
- Depending on the depth of focus of the earthquake, the delay between the arrival of the P-wave and other destructive waves could be up to about 60 to 90 seconds (depends of the depth of the focus).

Secondary Waves (S-waves)

- Secondary waves (secondary they are recorded second on the seismograph) or S-waves are also called as **transverse waves or shear waves or distortional waves**.
- They are analogous to water ripples or light waves.
- **Transverse waves or shear waves** mean that the direction of vibrations of the particles in the medium is perpendicular to the direction of propagation of the wave. Hence, they create **troughs** and **crests** in the material through which they pass (they distort the medium).
- S-waves arrive at the surface after the P-waves.
- These waves are of high frequency and possess **slightly higher destructive power** compared to P-waves.
- The trembling on the earth's surface caused due to these waves is from **side to side (horizontal)**.
- S-waves **cannot pass through fluids (liquids and gases)** as fluids do not support **shear stresses**.
- They travel at varying velocities (proportional to shear strength) through the solid part of the Earth.

Surface waves (L-Waves)

- The body waves **interact with the surface rocks and generate new set of waves called surface waves** (long or L-waves). **These waves move only along the surface**.
- Surface Waves are also called long period waves because of their **long wavelength**.
- They are **low-frequency transverse waves (shear waves)**.

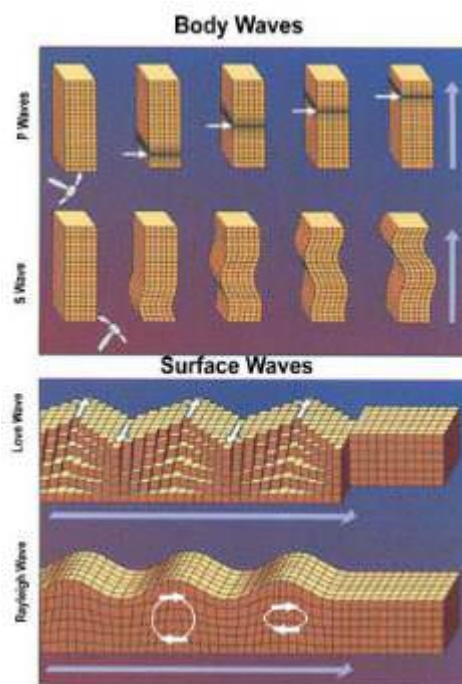
- They develop in the **immediate neighbourhood of the epicentre** and affect only the surface of the earth and die out at smaller depth.
- **They lose energy more slowly with distance than the body waves** because they travel only across the surface unlike the body waves which travel in all directions.
- **Particle motion of surface waves (amplitude) is larger than that of body waves**, so surface waves are the **most destructive** among the earthquake waves.
- They are **slowest** among the earthquake waves and are recorded last on the seismograph.

Love waves

- It's the fastest surface wave and moves the ground from side-to-side.

Rayleigh waves

- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- Because it rolls, it moves the ground **up and down and side-to-side** in the same direction that the wave is moving.
- **Most of the shaking and damage** from an earthquake is due to the **Rayleigh wave**.



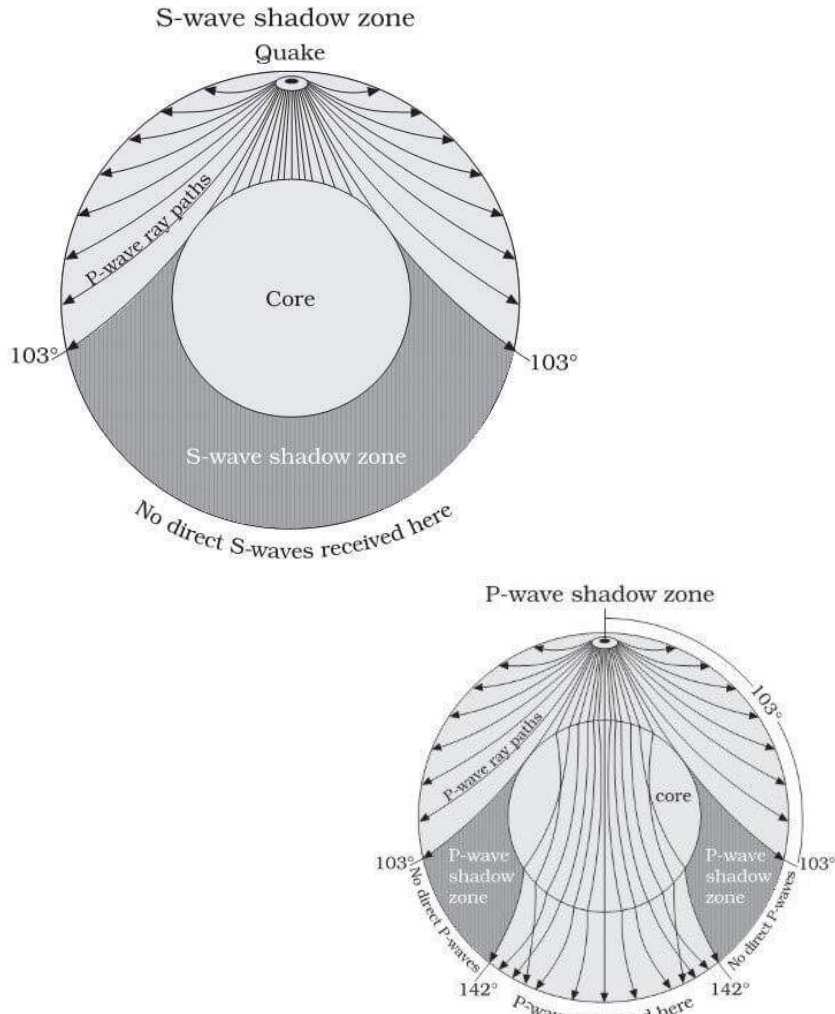
Types of earthquake waves

How do seismic waves help in understanding the earth's interior?

- Seismic waves get recorded in seismographs located at far off locations.
- Differences in arrival times, waves taking different paths than expected (due to refraction) and absence of the seismic waves in certain regions called as shadow zones, allow mapping of the Earth's interior.
- Discontinuities in velocity as a function of depth are indicative of changes in composition and density.
- That's is, by observing the changes in velocity, the density and composition of the earth's interior can be estimated (change in densities greatly varies the wave velocity).
- Discontinuities in wave motion as a function of depth are indicative of changes in phase.
- That is, by observing the changes in the direction of the waves, the emergence of shadow zones, different layers can be identified.

The emergence of Shadow Zone of P-waves and S-waves

- S-waves do not travel through liquids (they are **attenuated**).
- The entire zone beyond 103° does not receive S-waves, and hence this zone is identified as the shadow zone of S-waves. This observation led to the discovery of the **liquid outer core**.
- The shadow zone of P-waves appears as a band around the earth between 103° and 142° away from the epicentre.
- This is because P-waves are refracted when they pass through the transition between the semisolid mantle and the liquid outer core.
- However, the seismographs located beyond 142° from the epicentre, record the arrival of P-waves, but not that of S-waves. This gives clues about the **solid inner core**.
- Thus, a zone between **103° and 142°** from epicentre was identified as the **shadow zone for both the types of waves**.



Shadow Zone of P-waves and S-waves

- The seismographs located at any distance within 103° from the epicentre, recorded the arrival of both P and S-waves.

Why do sound waves travel faster in a denser medium whereas light travels slower?

The sound is a mechanical wave and travels by compression and rarefaction of the medium.

A higher density leads to more elasticity in the medium and hence the ease by which compression and rarefaction can take place. This way the velocity of sound increases with an increase in density.

Light, on the other hand, is a transverse electromagnetic wave.

An increase in the density increases effective path length, and hence it leads to higher refractive index and lower velocity.

- The span of the shadow zone of the P-Waves = 78° [$2 \times (142^\circ - 103^\circ)$]
- The span of the shadow zone of the S-Waves = 154° [$360^\circ - (103^\circ + 103^\circ)$]

- The span of the shadow zone common for both the waves = 78°