NPTEL ONLINE CERTIFICATION COURSES



# EARTHQUAKE SEISMOLOGY

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**Module 09 : Earthquakes, focal mechanisms, moment tensors.**
**Lecture 02: Focal mechanism, First motions, Body wave radiation patterns**

# CONCEPTS COVERED



- Focal mechanism
- First motions
- P-wave radiation pattern
- Shear wave radiation pattern
- Summary

# Recap

- Elastic rebound theory states that strain accumulated in the rock is more than the rocks on the fault can withstand, and the fault slips, resulting in an earthquake.

- Preseismic stage that can be associated with small earthquakes (foreshocks).

- Earthquake itself marks the coseismic phase during which rapid motion on the fault occur and generate seismic waves

- Postseismic phase occurs after the earthquake, and aftershocks and transient afterslip occur for a period of years.

- The two different coordinate systems, ($\phi_f$, $\delta$, $\lambda$) and ($\hat{n}$, $\hat{d}$), are useful to describe the fault geometry.

# Recap

- **Unit normal vector to the fault plane is** $$\hat{n} = \begin{pmatrix} -\sin\delta\sin\phi_f \\ \sin\delta\cos\phi_f \\ \cos\delta \end{pmatrix}$$

- **Slip vector, a unit vector in the slip direction, is** $$\hat{d} = \begin{pmatrix} \cos\lambda\cos\phi_f + \sin\lambda\cos\delta\sin\phi_f \\ -\cos\lambda\sin\phi_f + \sin\lambda\cos\delta\cos\phi_f \\ \sin\lambda\sin\delta \end{pmatrix}$$

- **For pure strike-slip fault λ = 0°, the hanging wall moves to the right, and the motion is called left-lateral and for λ = 180°, right-lateral motion occurs.**

- **For pure dip-slip fault λ = 270°, the hanging wall slides downward, causing normal faulting and λ = 90°, and the hanging wall goes upward, yielding reverse, or thrust, faulting.**

# Focal mechanism:  First motions

## How to know the geometry of faulting in the subsurface from reading at surface ?

-Time series recording of an earthquake
-The earthquake recorded at various distance
-The earthquake recorded at various azimuths

**Stress release**
Faulting  with different geometry

**Seismograms**
Recording  at different distance and azimuths

**Identify focal mechanism**
Observe  the first motion or polarity of body waves



### Focal mechanism

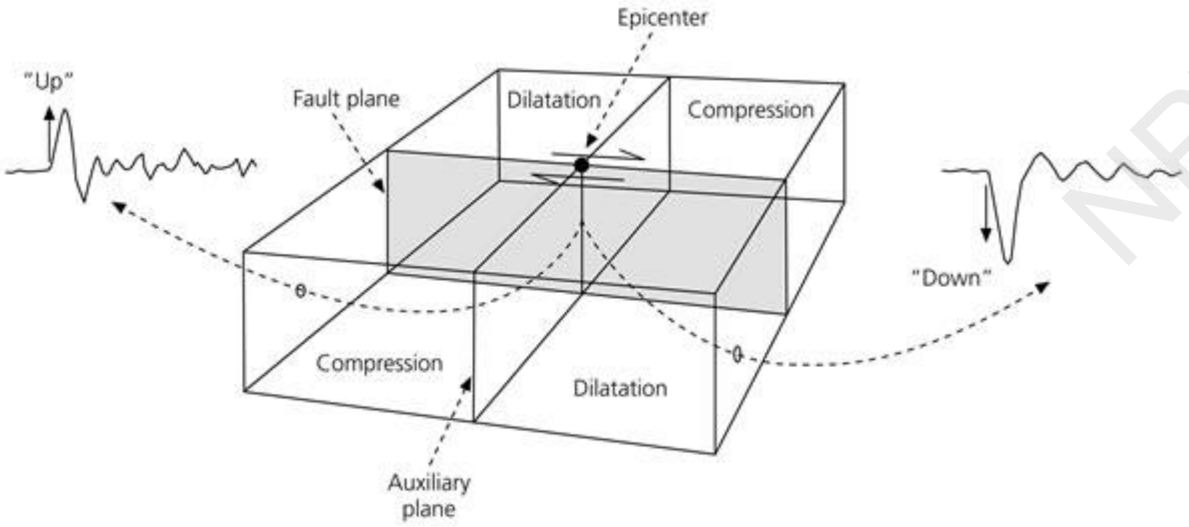
**Seismograms recorded at various distances and azimuths are used to study the  geometry of faulting during an earthquake, known as the focal mechanism**

# First motions

## How the focal mechanism is useful to get geometry of the fault?

**It uses the fact that the pattern of radiated seismic waves depends on the fault geometry.**

**Figure 4.2-4: First motions in relation to fault orientation.**




**How to determine the focal mechanism ?**

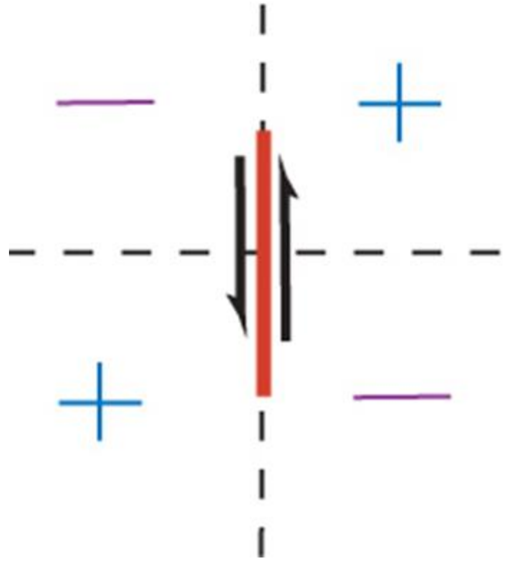
**-First motion, or polarity, of body waves**
**-waveform of body and surface waves**

**The polarity (direction) of the first P-wave arrival varies between seismic stations at different directions from an earthquake.**

# First motions

## Compression and dilatation

- = down (dilatation)
+ = up (compression)



➔ **The vertical component seismogram records upward or downward first motion, corresponding to either compression or dilatation.**

- **Compression**
  **It is observed for station located such that material near the fault moves "toward" the station.**

- **Dilatation**
  **For station located at an azimuth where material near the fault moves "away from"station.**

# First motions

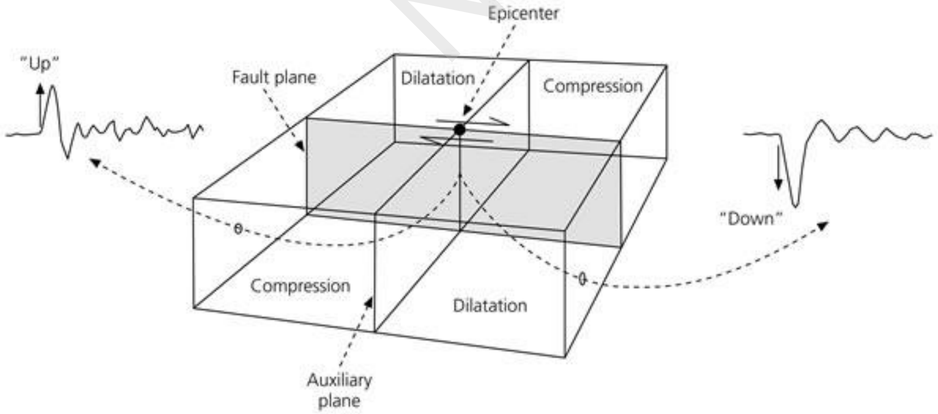
## First motion quadrants and nodal planes

- **The division between the quadrants occurs along the fault plane and a plane perpendicular to it known as Auxiliary plane.**

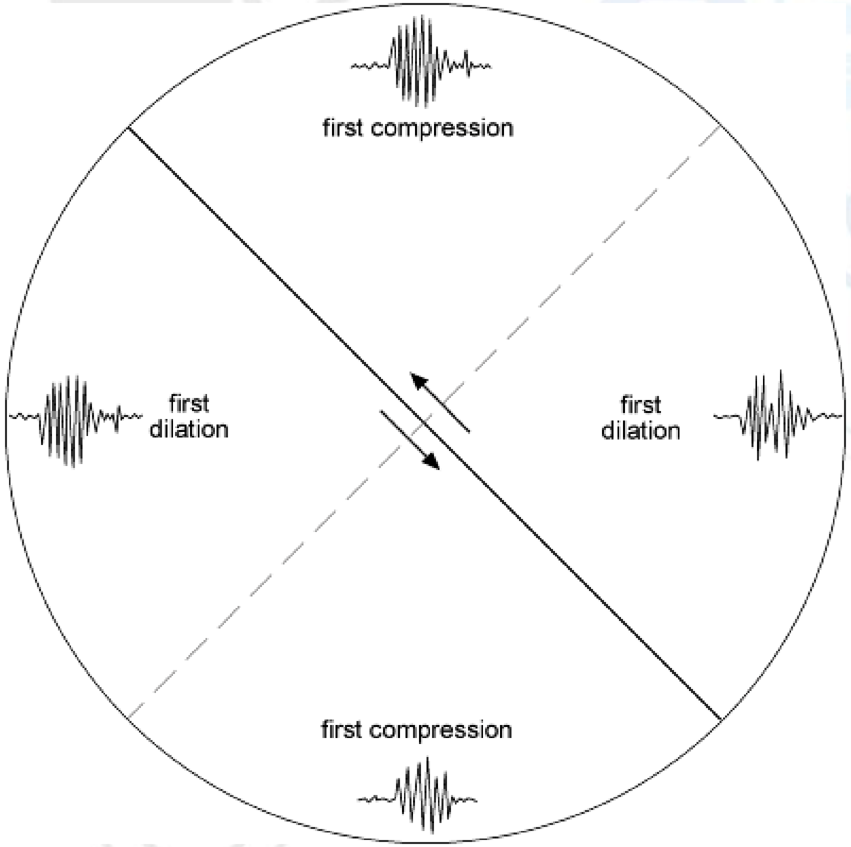
- **Seismograms show small or zero first motions right at nodal planes, separating compressional and dilatational quadrants.**

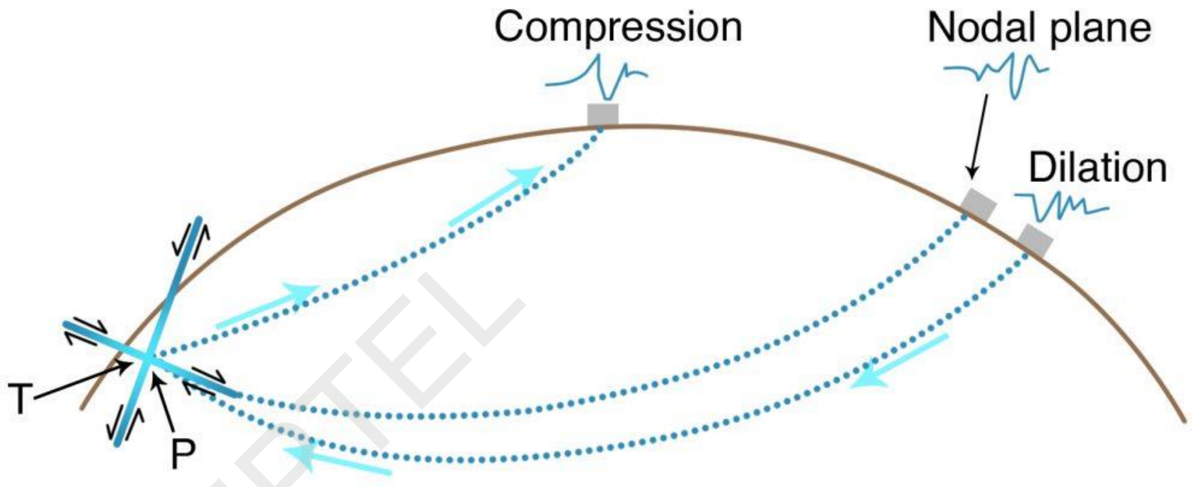
- **If the fault plane and auxiliary plane can be identified, the fault geometry is known.**

**Figure 4.2-4: First motions in relation to fault orientation.**



# First motions



# First motions

## What is ambiguity in focal mechanism using first motion ?

**There is an issue:**

- ➔ The first motions from slip on the actual fault plane and from the auxiliary plane, would be the same.
- ➔ So, the first motions alone cannot resolve which plane is the actual fault plane.

**Following information may be used to find actual fault and auxiliary plane?**

- ➔ geologic or geodetic information, such as trend of a known fault or observations of ground motion, indicates the fault plane.
- ➔ Hypocentral distribution of smaller aftershock following the earthquake, delineate the fault plane .
- ➔ For large earthquake, the finite time required for slip to progress along the fault causes variations in the waveforms observed at different directions from the fault, so the directivity effects can be used to infer the fault plane.

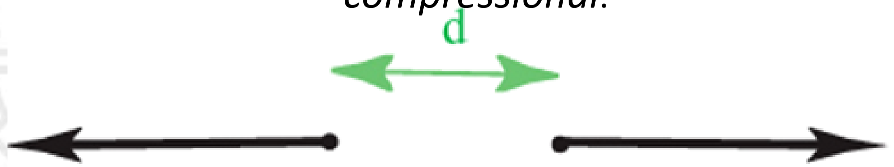
# Body wave radiation patterns

## Force couples and equivalent body forces

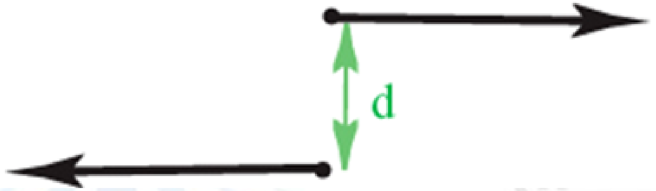
- ➔ The motions in the far field can be represented using point forces. For this we may use force couples—pairs of point sources.
- ➔ There are two conditions:

- The force couple needs to produce the observed far-field motions.
- Torque must be zero due to force couple.

*It does not apply a net torque.  But it is all compressional.*



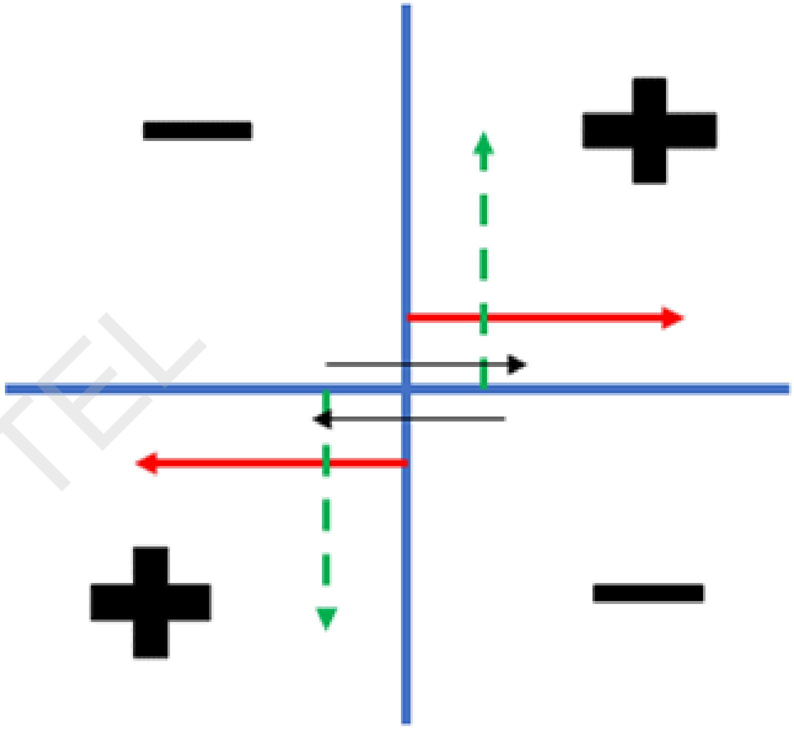

*It has a net torque.*



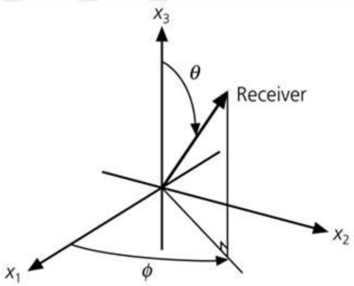
# Body wave radiation patterns

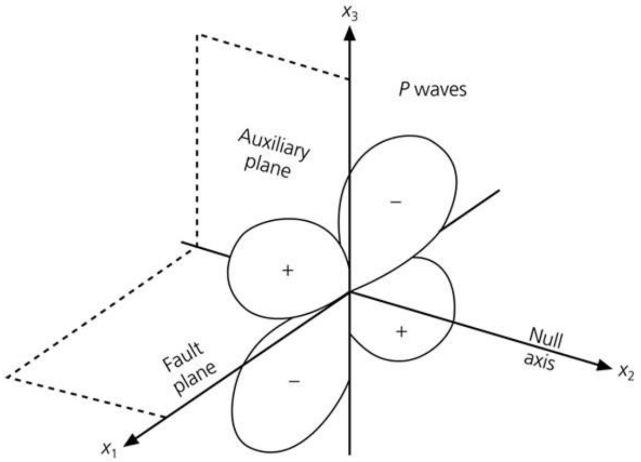
## Fault oriented coordinate system

To get the proper far-field motions, with no torque, we need a couple of couples: a double couple.



# Radiation pattern variation with direction of the receiver

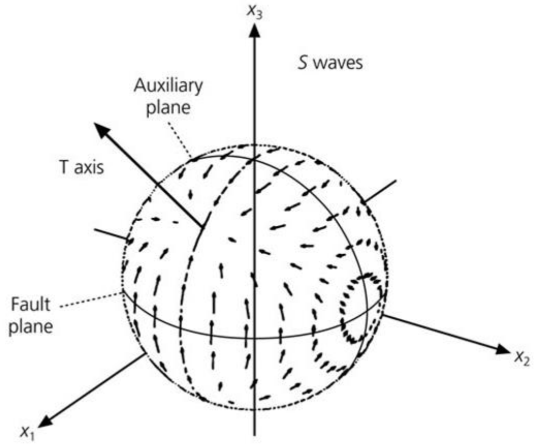



**Consider the radiation field in spherical coordinates**

**The displacement due to compressional waves, which create the radial ($\hat{e}_r$) component of the displacement ($u_r$) because their motion is along the propagation direction is**

$$u_r = \frac{1}{4\pi\rho\,\alpha^3 r} M(t - r/\alpha)\sin 2\theta\,\cos\phi$$




**The body wave radiation pattern for a double couple source has symmetry in the spherical coordinate system. θ is measured from the $x_3$ axis, the normal to the fault ($x_1 - x_2$) plane, and ϕ is measured in the fault plane.**

# Radiation pattern variation with direction of the receiver

$$u_r = \underbrace{\frac{1}{4\pi\rho\,\alpha^3 r}}\,\underbrace{\dot{M}(t - r/\alpha)}\,\underbrace{\sin 2\theta\ \cos\phi}$$

For an infinite medium

The first term is an amplitude term, which decays as 1/r.

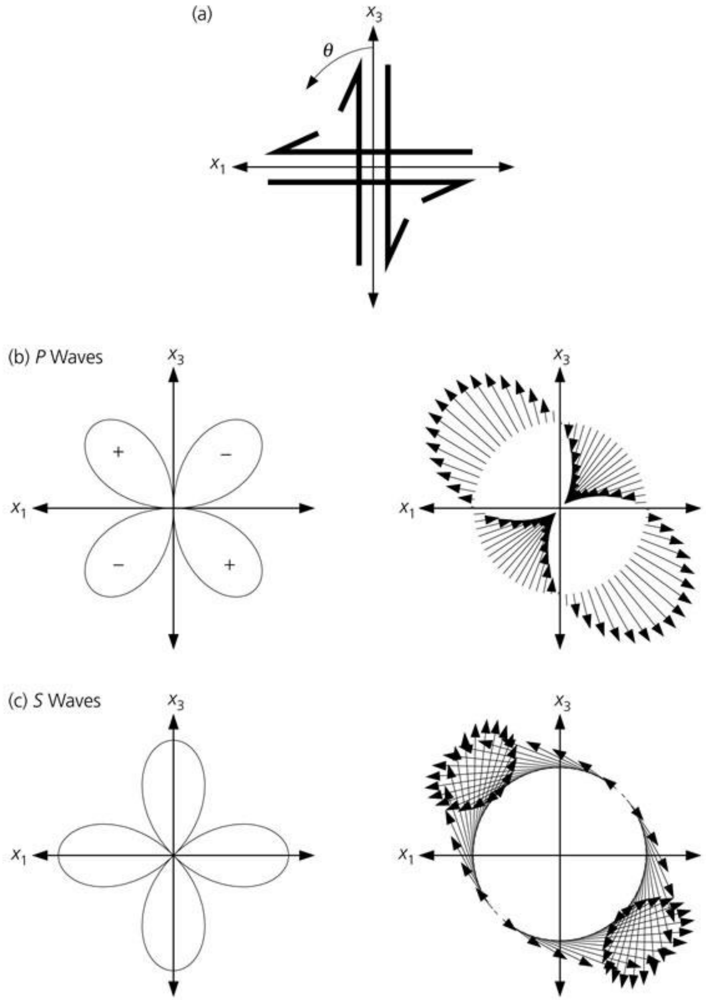
The second term reflects the pulse radiated from the fault, $\dot{M}(t)$ , which propagates away at P-wave speed $\alpha$ and arrives at a distance r at time (t-r/$\alpha$ ).

$\dot{M}(t)$ is called the seismic moment rate function or source time function. It is the time derivative of the seismic moment function.

$$M(t) = \mu D(t) S(t)$$

It describes the faulting process in terms of rigidity of the material and history of the slip D(t) and fault area S(t).

**Figure 4.2-7: *P* and *S* radiation amplitude patterns.**




**The best measure of earthquake size and energy release is the static ( or scalar) seismic moment.**

$$M_0 = \mu \bar{D} S$$

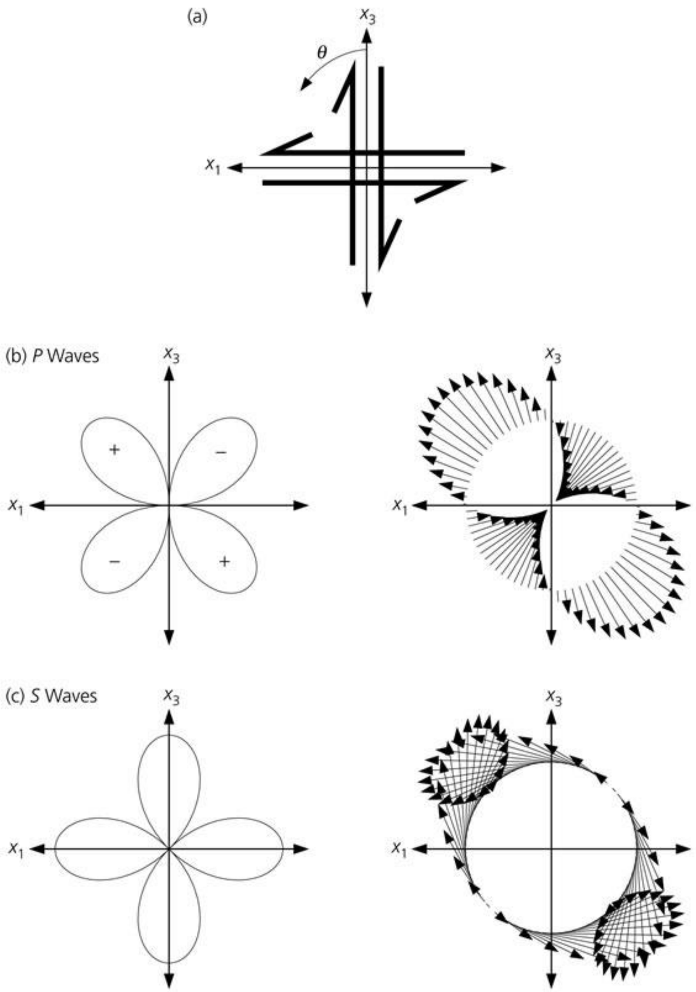
$\bar{D}$ **Average slip (or dislocation) on the fault with area S**

**We often use the seismic moment as a scale factor, so the seismic moment can be written as**

$$M(t) = M_0 x(t),\ where\, x(t)\, is\, the\, source\, time\, function$$

# P-wave radiation pattern

Figure 4.2-7: *P* and *S* radiation amplitude patterns.

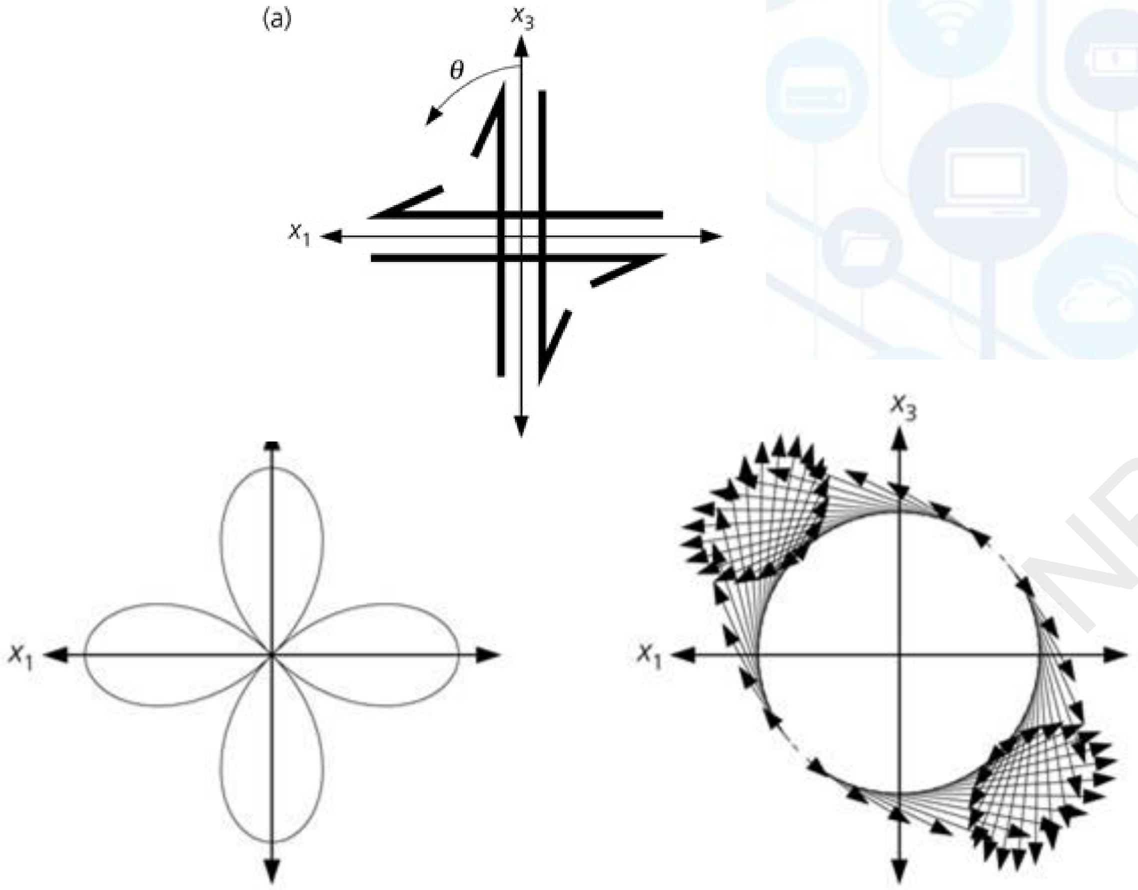



$$u_r = \frac{1}{4\pi\rho\,\alpha^3 r}\dot{M}(t - r/\alpha)\sin 2\theta\,\cos\phi$$

- ➔ The term, $\sin 2\theta\,\cos\phi$ shows the P-wave radiation pattern.
- ➔ It is four lobed, with two positive compressional lobes and two negative dilatational lobes.
- ➔ The fault plane (θ=90⁰) and auxiliary plane ($\phi$=90⁰) have zero displacement.
- ➔ The maximum displacements are between the two nodal planes.

# Shear wave radiation pattern

Figure 4.2-7: *P* and *S* radiation amplitude patterns.




The shear wave has two components

$$u_\theta \hat{e}_\theta + u_\phi \hat{e}_\phi \ , \ where$$

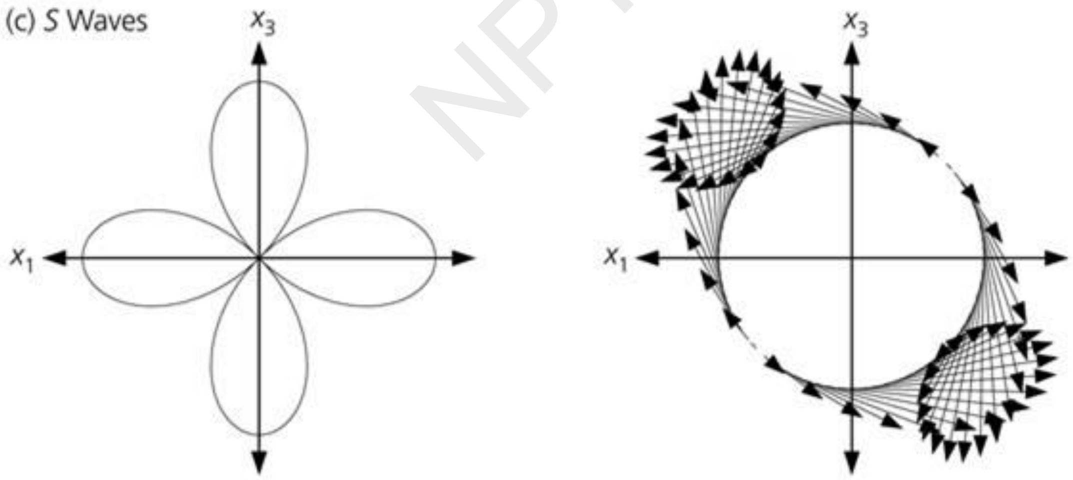
$$u_\theta = \frac{1}{4\pi\rho\beta^3 r}\dot{M}(t - r/\beta)\cos 2\theta \cos\phi$$

$$u_\phi = \frac{1}{4\pi\rho\beta^3 r}\dot{M}(t - r/\beta)(-\cos\theta \sin\phi)$$

The term involving $\dot{M}(t)$ corresponds to waves propagating at S-wave speed $\beta$.

# Shear wave radiation pattern

- ➔ It does not have nodal planes. but it is perpendicular to the P-wave nodal planes and is zero on the null axis.
- ➔ It converges toward the center of the compressional quadrants, which, as we will see shortly, is the location of the T, or least compressive stress, axis.
- ➔ It also diverges from the centers of the dilatation quadrants, known as the P, or most compressive stress, axis.



# Summary

- Seismograms recorded at various distances and azimuths are used to study the geometry of faulting during an earthquake, known as the focal mechanism. It uses the fact that the pattern of radiated seismic waves depends on the fault geometry.

- The first motion observed at different azimuths define four quadrants, two compressional and two dilatational. These quadrants are separated by the fault plane and auxiliary plane.

- The elastic radiation can be described as resulting from double couple of forces, these forces are known as equivalent body forces for the fault slip.

# Summary

**Radiation pattern for P-wave and S-wave is given by**

$$u_\theta \hat{e}_\theta + u_\phi \hat{e}_\phi \text{ , } where$$

$$u_r = \frac{1}{4\pi\rho\,\alpha^3 r}\dot{M}(t - r/\alpha)\sin 2\theta\,\cos\phi$$

$$u_\theta = \frac{1}{4\pi\rho\beta^3 r}\dot{M}(t - r/\beta)\cos 2\theta\cos\phi$$

$$u_\phi = \frac{1}{4\pi\rho\beta^3 r}\dot{M}(t - r/\beta)(-\cos\theta\sin\phi)$$

# REFERENCES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# THANK YOU !