Features of Wave Theory

1. Seismic waves generated are commonly classified into three main types. The first two, the P (or primary) and S (or secondary) waves, propagate within the body of the Earth, while the third, consisting of Love and Rayleigh waves, propagates along its surface.

2. The P seismic waves travel as elastic motions at the highest speeds. They are longitudinal waves that can be transmitted by both solid and liquid materials in the Earth's interior. With P waves, the particles of the medium vibrate in a manner similar to sound waves—the transmitting media is alternately compressed and expanded.

3. The slower type of body wave, the S wave, travels only through solid material. With S waves, the particle motion is transverse to the direction of travel and involves a shearing of the transmitting rock.

4. Love and Rayleigh waves are guided by the free surface of the Earth. They follow along after the P and S waves have passed through the body of the planet. Both Love and Rayleigh waves involve horizontal particle motion, but only the latter type has vertical ground displacements.
5. At all distances from the focus, mechanical properties of the rocks, such as incompressibility, rigidity, and density, play a role in the speed with which the waves travel and the shape and duration of the wave trains. The layering of the rocks and the physical properties of surface soil also affect wave characteristics.

6. When a seismic wave encounters a boundary that separates rocks of different elastic properties, it undergoes reflection and refraction. There is a special complication because conversion between the wave types usually also occurs at such a boundary: an incident P or S wave can yield reflected P and S waves and refracted P and S waves.

7. Boundaries between structural layers also give rise to diffracted and scattered waves. These additional waves are in part responsible for the complications observed in ground motion during earthquakes.

Features of Ray theory

1. Ray theory is an alternative approach in which a point on the wavefront is tracked rather than the complete wavefield
2. Ray theory is extensively used due to its simplicity, speed and applicability to a wide range of problems.
3. Ray theory is strictly valid for media whose length scale variation of λ and μ is much larger than the seismic wavelength (the high frequency assumption).
4. At low frequencies, diffraction and scattering can be significant, and ray theory is not generally valid
5. Ray theory is an integral part of many seismological techniques, including body wave tomography, migration of reflection data, and earthquake relocation.

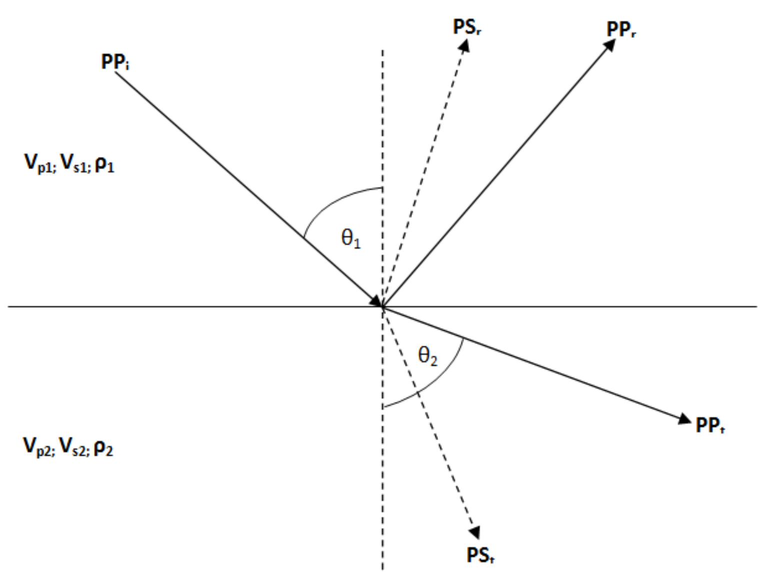
6. The ray theory belongs to the methods most frequently used in seismology and seismic exploration for forward and inverse modelling of high-frequency seismic body waves. In smoothly varying layered media, it can provide useful approximate solutions of satisfactory accuracy.

Limitations -

1. It is applicable only to smooth media, in which the characteristic dimensions of inhomogeneities are considerably larger than the prevailing wavelength of the considered waves.
2. The ray method can yield distorted results and may even fail in some special regions called singular regions.

Zoeppritz Equations

The equations are important in geophysics because they relate the amplitude of P-wave, incident upon a plane interface, and the amplitude of reflected and refracted P- and S-waves to the angle of incidence. They are the basis for investigating the factors affecting the amplitude of a returning seismic wave when the angle of incidence is altered — also known as amplitude versus offset analysis — which is a helpful technique in the detection of petroleum reservoirs.



A P-wave (PP_i) propagating through a medium of density, ρ_1, P-wave velocity, V_{p1}, and S-wave velocity, V_{s1}, is incident upon an interface with a medium of density, ρ_2, P-wave velocity, V_{p2}, and S-wave velocity, V_{s2}, at an angle, θ_1. Mode conversions occur resulting in reflected P- and S- waves (PP_r and PS_r respectively) and transmitted (refracted) P- and S- waves (PP_t and PS_t respectively).

The Zoeppritz equations consist of four equations with four unknowns R_P, R_S, T_P, and T_S. The equation is as follows -

$$\begin{bmatrix} R_\mathrm{P} \\ R_\mathrm{S} \\ T_\mathrm{P} \\ T_\mathrm{S} \end{bmatrix} = \begin{bmatrix} -\sin\theta_1 & -\cos\phi_1 & \sin\theta_2 & \cos\phi_2 \\ \cos\theta_1 & -\sin\phi_1 & \cos\theta_2 & -\sin\phi_2 \\ \sin 2\theta_1 & \frac{V_{\mathrm{P}1}}{V_{\mathrm{S}1}}\cos 2\phi_1 & \frac{\rho_2 V_{\mathrm{S}2}^2 V_{\mathrm{P}1}}{\rho_1 V_{\mathrm{S}1}^2 V_{\mathrm{P}2}}\sin 2\theta_2 & \frac{\rho_2 V_{\mathrm{S}2} V_{\mathrm{P}1}}{\rho_1 V_{\mathrm{S}1}^2}\cos 2\phi_2 \\ -\cos 2\phi_1 & \frac{V_{\mathrm{S}1}}{V_{\mathrm{P}1}}\sin 2\phi_1 & \frac{\rho_2 V_{P2}}{\rho_1 V_{P1}}\cos 2\phi_2 & -\frac{\rho_2 V_{S2}}{\rho_1 V_{P1}}\sin 2\phi_2 \end{bmatrix}^{-1} \begin{bmatrix} \sin\theta_1 \\ \cos\theta_1 \\ \sin 2\theta_1 \\ \cos 2\phi_1 \end{bmatrix}$$

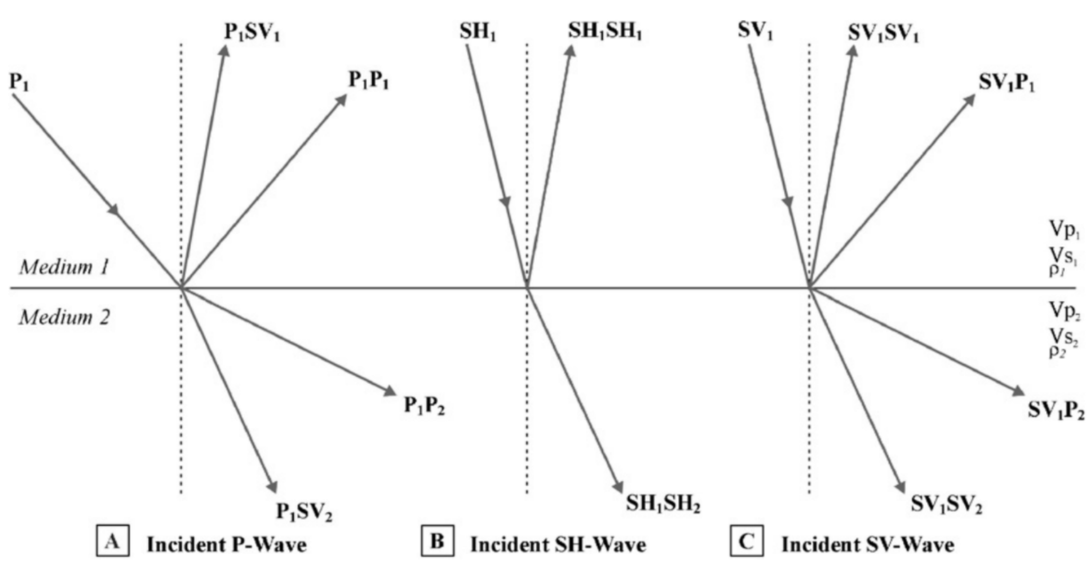
R_P, R_S, T_P, and T_S, are the reflected P, reflected S, transmitted P, and transmitted S-wave amplitude coefficients, respectively, θ_1=angle of incidence, θ_2=angle of the transmitted P-wave, Φ_1=angle of reflected S-wave and Φ_2=angle of the transmitted S-wave.

Elastic wave planar interface scattering

When elastic waves are incident on a planar interface separating media with an impedance contrast, scattered (reflected and/ or refracted/transmitted) waves are generated. The amplitude and energy partitioning between scattered waves is dependent on the incident wave type, the angle of incidence, and the contrast in impedance across the interface. The elastic impedance Z is defined by-

$$z= \rho v \text{ ------(1)}$$

Where: ρ = density
v= seismic velocity



In the above figure, we have -

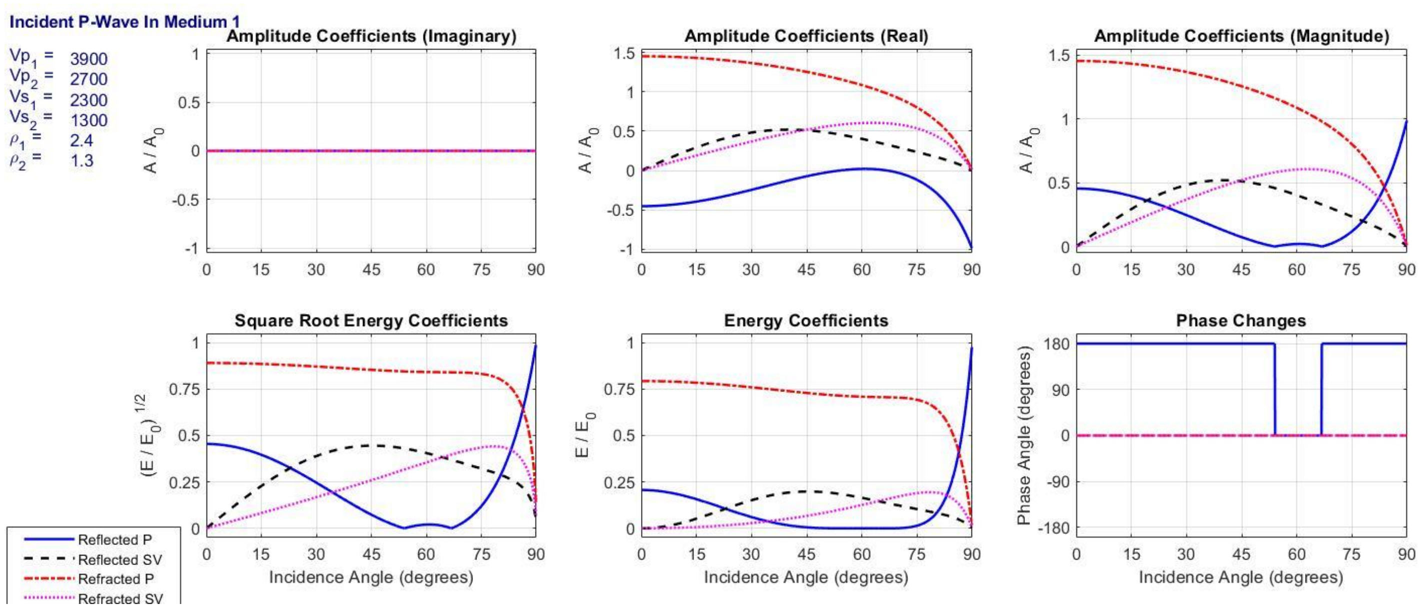
$$R = (z2-z1)/(z1+z2) \quad \text{-------}(2)$$

(where z1 and z2 are the impedances for the first and second layer respectively)

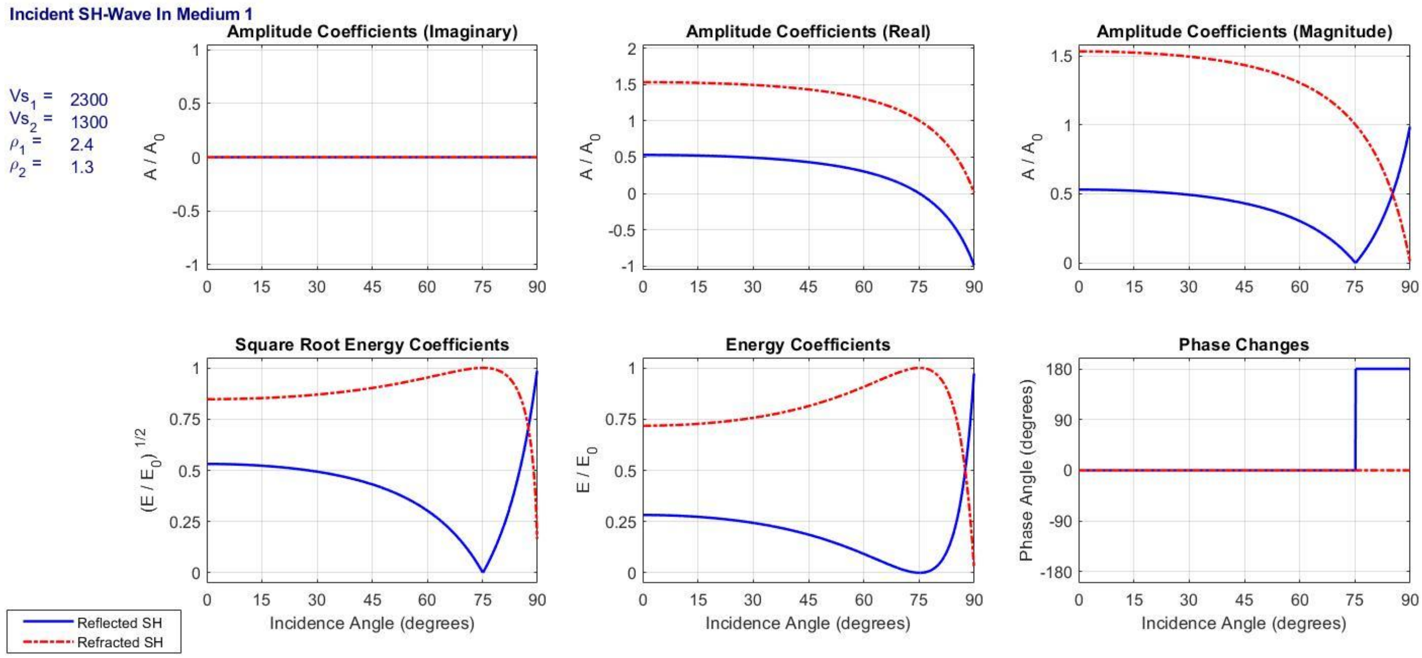
<u>Plots generated using PSHSV program</u>

These are the plots generated using PSHSV program showing amplitude coefficients, square root energy coefficients, energy coefficients, and phase changes as a function of incidence angle for elastic waves incident on a shale (medium 1) and coal (medium 2) interface: (A) P-wave, (B) SH-wave, and (C) SV-wave. Density (units of g/cm3) and velocity (units of m/s) values used are plotted on figures.

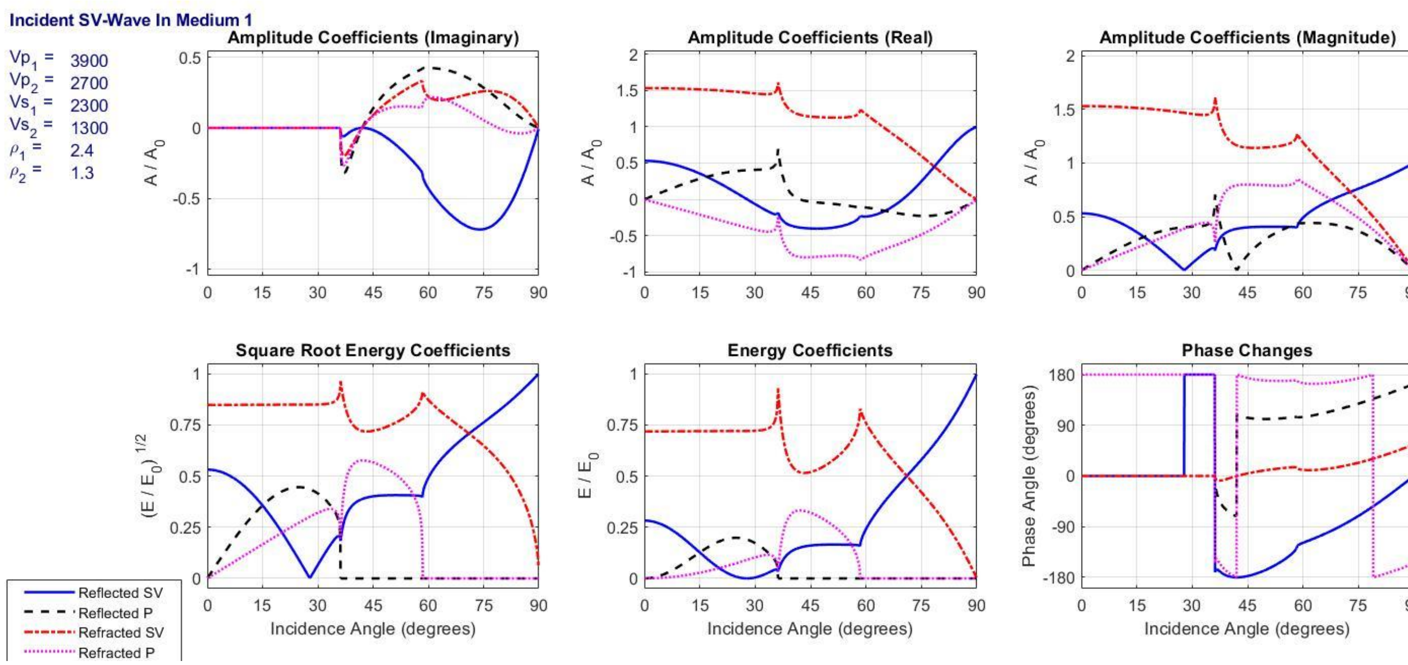
a) Incident P-Wave in Medium-1



b) Incident SH-Wave in Medium 1



c) Incident SV-Wave in Medium 1



Each incident wave type figure generated contains six subplots that show how calculated amplitude coefficients, square root energy ratios, energy coefficients, and phase angles change as a function of incident angle, for each wave type generated at the interface. For elastic wave cases (Fig. 3), the amplitude coefficient curves represent the ratio of the maximum amplitude particle displacement of reflected or refracted waves to that of the incident wave (exact Zoeppritz solutions are plotted). For electromagnetic wave cases (Fig. 4), the amplitude coefficient curves.