Velocity Dispersion in Layered Media

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Summary

Velocity dispersion in stratified media depends upon the impedance contrast between contiguous layers and the ratio (*R*) of the wavelength to the layer thickness. The goal of the present work is to understand the scale dependence of propagation velocities in periodically layered media. We based our analysis in 1-D wave equation forward modeling. The numerical simulation was performed on 9 layered models with impedance contrast ranging from 1.05 to 1.99.

The analysis showed that the maximum R which RT can be used to estimate travel time is about 2, and the minimum which effective media theory is valid varies from 21 to 25. Mie and Rayleigh scattering zones are located near 4 and 5 respectively.

Introduction

One of the most important activities in seismic interpretation is well-seismic tie. This process includes synthetic trace generation from well log data. Generally, synthetic seismic traces are generated using ray theory (RT); this methodology assumes that the velocity dispersion caused by heterogeneities can be neglected. However, seismic waves propagating through layered medium experience velocity dispersion due to multiple scattering. Figure 1 shows a representation of scale dependence of propagation velocity in layered media. The area located between the point A and B is the scatter zone. Scattering varies as a function of the ratio (*R*) of the wavelength (λ) of the seismic wave to the layer thickness (d). For ratios greater than B the media behaves as non-dispersive transversally isotropic layer (Carcione, 1991) and velocities can be calculated by the effective media theory (EMT). When *R* is smaller than B, Rayleigh scattering occurs. At smaller values of R scattering varies in a complex fashion described by the Mie theory. At ratios of the order A, the laws of geometric optics begin to apply and the velocities can be estimated using the ray theory.

In the Mie (A') and Rayleigh (B') scattering zones wave velocities can be higher or smaller than the predicted by ray theory or effective media theory. Another important variable that influence velocity dispersion in layered media is the impedance contrast. Velocity dispersion increases with the impedance contrast, for small impedances contrast velocity dispersion can be neglected.

The goal of the present work is to attempt to quantify the values of A, A', B and B' for periodically layered media. We generated 9 media with impedance contrast ranging from 1.05 to 1.99. The analysis was carried out by 1-D wave equation forward modeling based on the invariant imbedding method (Kennett, 1974).

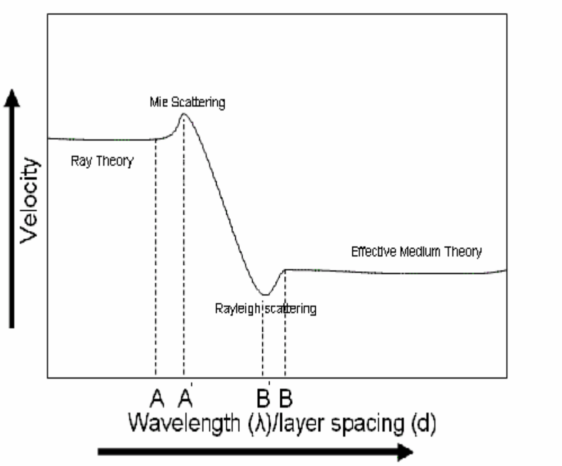

Figure 1: Representation of scale dependence of propagation velocity in layered media. (Modified from Mavko, 1998)

Velocity limits

When R is smaller than A or greater than B the media can be replaced by an equivalent medium, and the acoustic properties estimated by RT or EMT respectively. In the short wavelength limit (RT) where λ<d velocity can be estimated by:

$$\frac{1}{V_{RT}} = \sum_n \frac{f_n}{V_n}$$

When λ>>d the velocity can be calculated by:

$$\frac{1}{\rho_{ave} V_{EMT}^2} = \sum_n \frac{f_n}{\rho_n V_n^2}$$

and

$$\rho_{ave} = \sum_n f_n \rho_n$$

Forward Modeling

We performed the forward modeling over 9 layered media. The media consisted two layers staked periodically. Layers were assumed isotropic and homogeneous. The Total thickness was kept 1000 meters for all models, and the number of layers was varied from 2 to 1000 meters. Table 1 shows the acoustic properties of the 9 models used for the numerical simulation.

Model	V_1 [m/sec]	ρ_1 [Kg/m^3]	V_2 [m/sec]	ρ_2 [Kg/m^3]	ΔImp
1	1900	2000	1850	1950	1.05
2	2000	2050	1850	1950	1.14
3	2200	2150	1850	1950	1.31
4	2500	2160	1850	1950	1.50
5	2700	2170	1850	1950	1.62
6	2900	2180	1850	1950	1.74
7	3000	2220	1850	1950	1.85
8	3100	2230	1850	1950	1.92
9	3200	2240	1850	1950	1.99

Table 1: Models properties

The source was defined as a zero-phase richer wavelet with central frequency (Fc) of 30 Hz (figure 2). In order to avoid any undesired numerical error due to time sampling, we chose a Δt of 0.1 milliseconds.

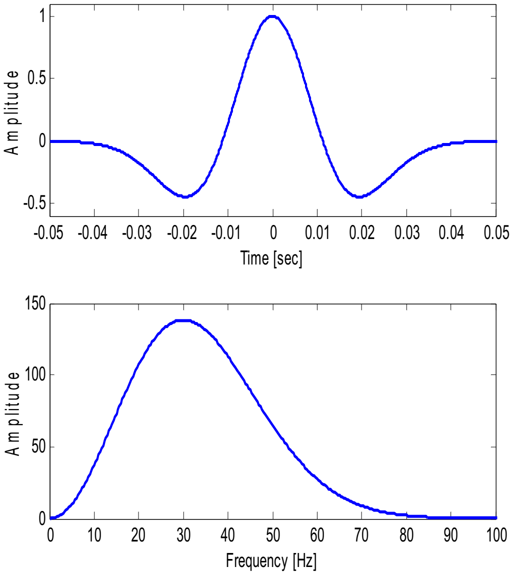

Figure 2: Seismic Sources used in the 1-D seismic modeling.

Figure 3 shows the synthetic seismograms generated from the model number 5; layer thickness were varied from 1 m to 500 m. For very thin layers the media can be described by the effective media theory and the excess travel-time is invariable for all frequencies. It means that the velocity dispersion reaches the minimum and it can be neglected. Once we start to increase the bed thickness, the media approaches to the Rayleigh scattering domain and the velocity dispersion increases. Higher frequencies arrive later producing changes in the phase and amplitude spectrum of the seismic wave. If the bed thickness grows, the media reach the Mie scattering zone and the excess travel time can be negative. Therefore, wave propagation velocities can be even faster than the velocities predicted by the ray theory. For very thick layers the velocities can be estimated by the RT and the scattering dispersion reaches the minimum again. Figure 4 shows the scale dependence of propagation velocity for model 5.

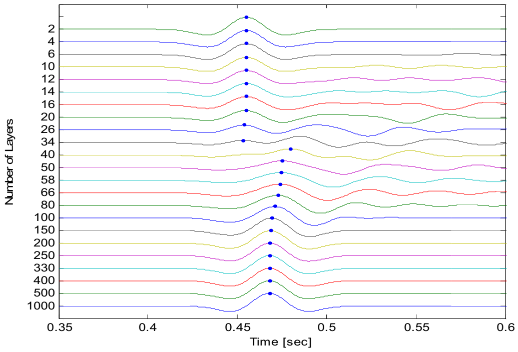

Figure 3: Synthetic seismograms of vertical displacement for model 5. Blue dots indicate the time arrival for each synthetic seismogram.

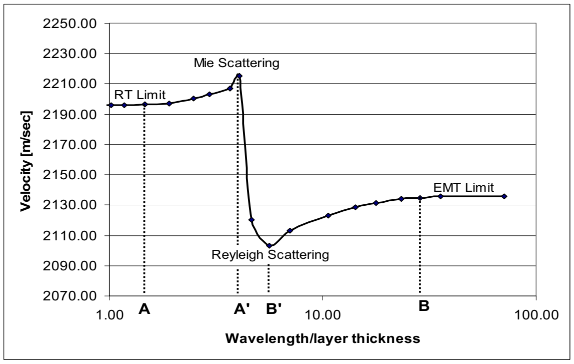

Figure 4: Scale dependence of propagation velocity for model 5.

Figures 5, 6, 7 and 8 show the values of A, A', B' and B against impedance contrast. The results of the forward modeling reveal that the Mie and Rayleigh scattering zones as well as the maximum R which RT is valid are located in narrow bands. On the other hands the minimum ratio which EMT can be used for wave velocity estimation is wider and show a linear relation with the impedance contrast; the greater the impedance contrast the greater of R.

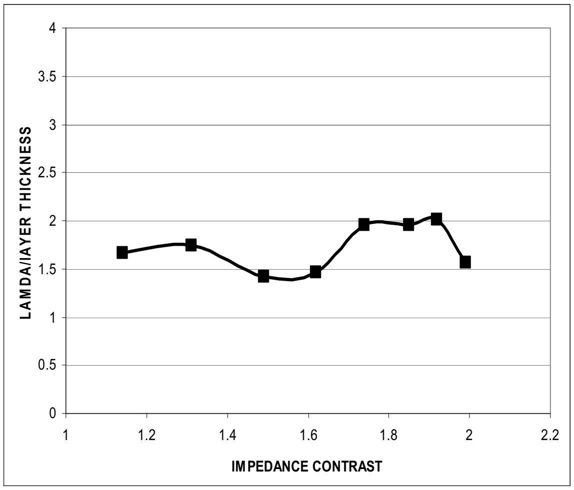

Figure 5: Maximum ratio of wavelength to layer thickness which RT is valid.

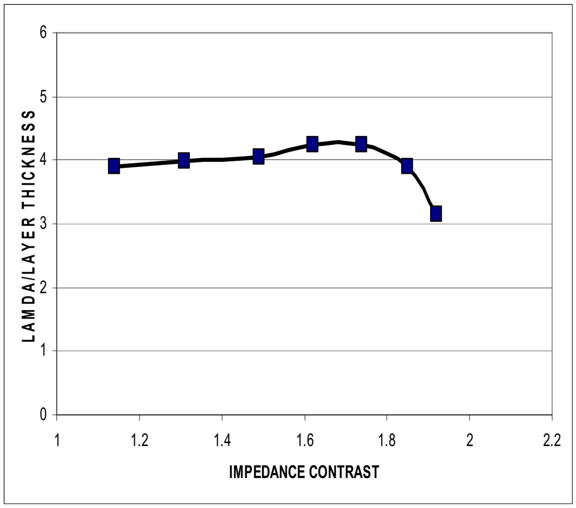

Figure 6: Mie Scattering versus Impedance contrast.

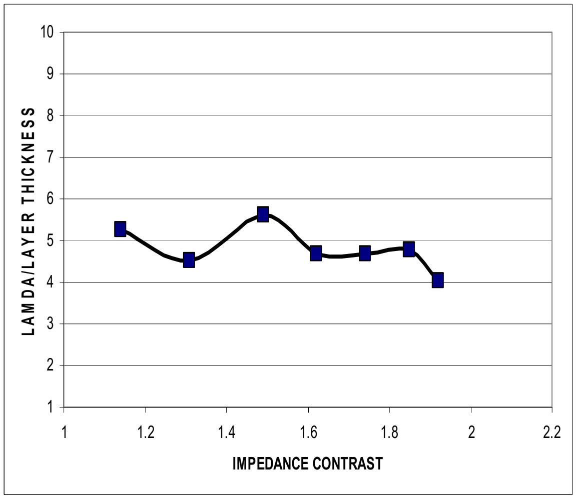

Figure 6: Rayleigh Scattering versus Impedance contrast.

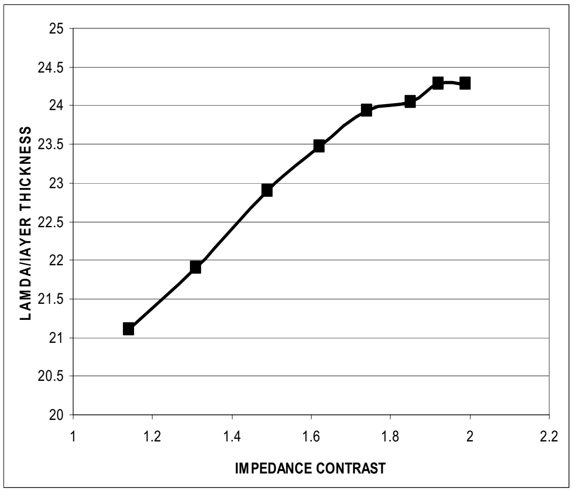

Figure 7: Minimum ratio of wavelength to layer thickness which EMT is valid.

Conclusions

1. - The maximum ratio of wavelength to layer thickness which RT is valid is located in a narrow band that range from 1.4 to 2.

2. - The Mie scattering zone is located between 3 to 4.25.

3. - The Rayleigh scattering zone range from 4 to 5.6.

4. - The minimum ratio of wavelength to layer thickness which EMT can be used for velocity estimation show a linear trend that increase with the impedance contrast. It varies from 21 to 24.5.

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EDITED REFERENCES

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