AVO analysis for a single thin bed using three-layer media

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Summary

As effective criteria for hydrocarbon detection, Amplitude Versus Offset (AVO) technology has been widely used in the recent years. Zoeppritz equation, which describes the reflection and transmission of plane wave on a single interface separating two half infinite spaces, is the basis for traditional AVO analysis. This characteristic of Zoeppritz equation makes it unsuitable to analyze the propagation of wave in multi-layered media when the layers are very thin. This study derives the three-layer media equation based on multi-layer media equation by Breshkovsky in elastic regime for discussing the reflection and transmission of plane wave in thin bed. The reflection coefficient equation is a continuous function of incident angle, frequency and thin bed thickness.

It is concluded that: (1) three-layer media equation is more quantitative and precise than Zoeppritz equation to analyze the AVO responses of thin bed; (2) the influence of thin bed thinning on variations of amplitudes is equal to that of dominant frequency decreasing; (3) AVO analysis of P-S wave helps us to eliminate the problem of multi-solutions in fluids prediction; (4) With decreasing Q, the AVO curve obtained from three-layer media equation become more smooth and get closer to the curve calculated by Zoeppritz equation.

Three-layer Media Model

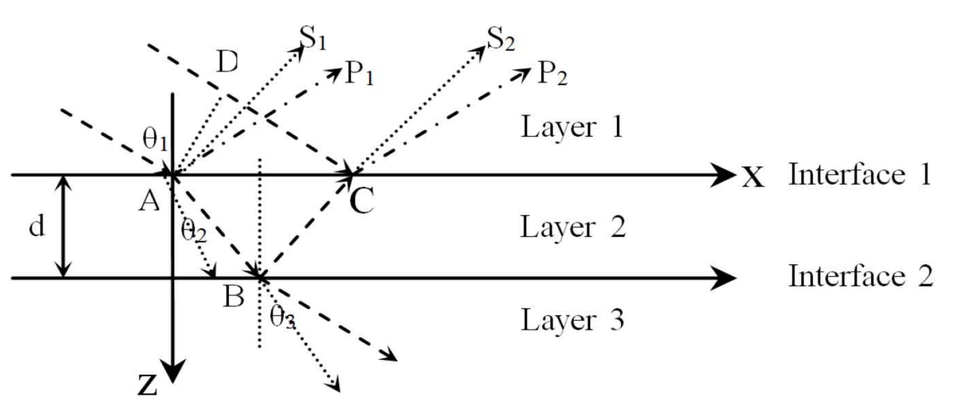

Figure 1. Three-layer media model

Figure 1 show the three-layer model used in this research. The target layer (Layer 2 shown in Figure 1) is embedded between two infinite half spaces. And a plane harmonic and compressional wave illuminates on Interface 1, which causes the reflected compressional wave (P-wave) and shear wave (only SV-wave is considered here), transmitted compressional wave and shear wave.

Theory and Algorithm

Breshkovsky (1960) analyzed the propagation of plane wave in multi-layered and elastic media and built the multi-layered media equation. Here, the multi-layer model is simplified to three-layer model. This equation connects the displacement of stress of layer 1 and layer 3 through one coefficients matrix.

$$\begin{bmatrix} u_x{}^3 \\ v_z{}^3 \\ \sigma_{zz}{}^3 \\ \tau_{zx}{}^3 \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \begin{bmatrix} u_x{}^1 \\ v_z{}^1 \\ \sigma_{zz}{}^1 \\ \tau_{zx}{}^1 \end{bmatrix}$$

Then we can get the reflection and transmission coefficients which are the functions of incident angle θ, dominant frequency f and target thin layer thickness d. It is easier for us to study the influences of frequency and thin layer thickness to amplitudes comparing with Zoeppritz equation.

$$R_{pp}(\theta,f,d)=\frac{\det V_{pp}}{\det V},\ R_{ps}(\theta,f,d)=\frac{\det V_{ps}}{\det V},\ T_{pp}(\theta,f,d)=\frac{\det V'_{pp}}{\det V},\ T_{ps}(\theta,f,d)=\frac{\det V'_{ps}}{\det V}$$

Even though, we don't derive the direct expression of reflection coefficient or its linear approximations. We can still analyze the variations of amplitudes with varying incident angle, frequency and thin bed thickness in elastic regime.

AVO responses of P-P wave for thin bed with no attenuation

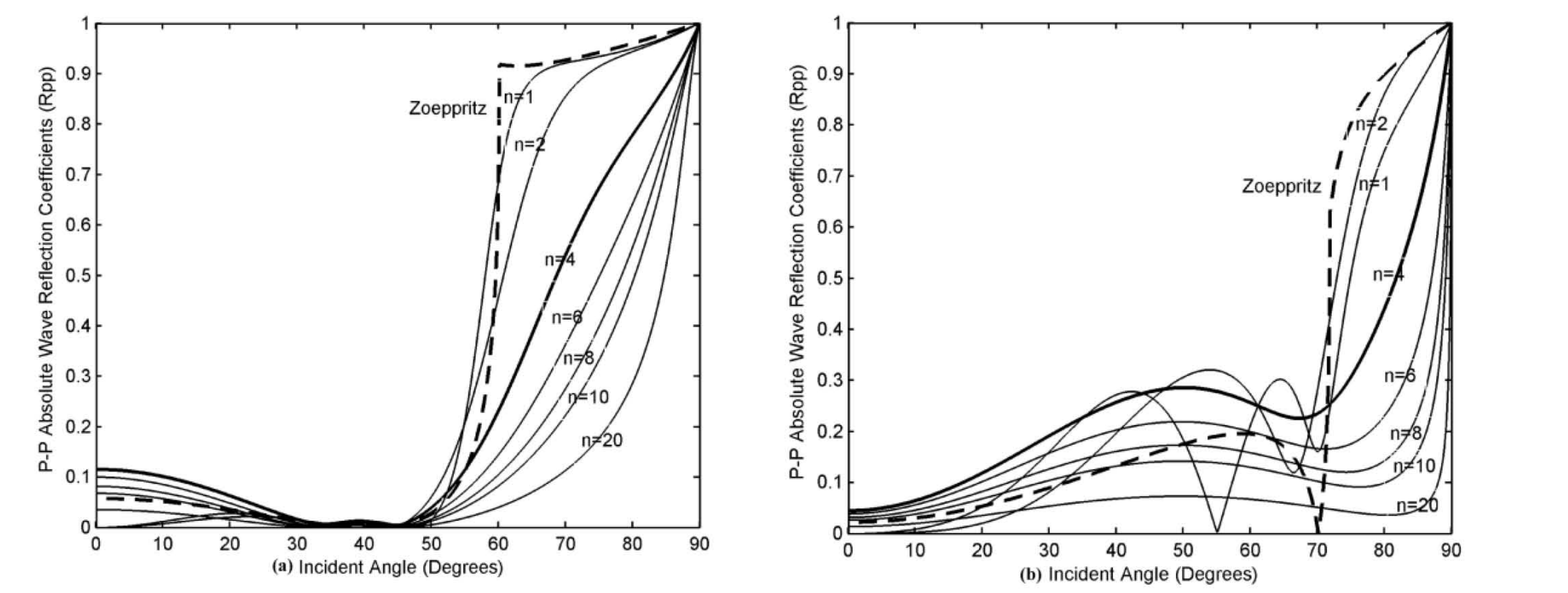

Figure 2. P-P Wave absolute reflection coefficients spectrum (frequency=30Hz) for different n = λ/d from 1 to 20 for Model I with water sand (a) and gas sand (b) at full angles. The dashed line is calculated by Zoeppritz equation and other lines are calculated by three-layer media equation.

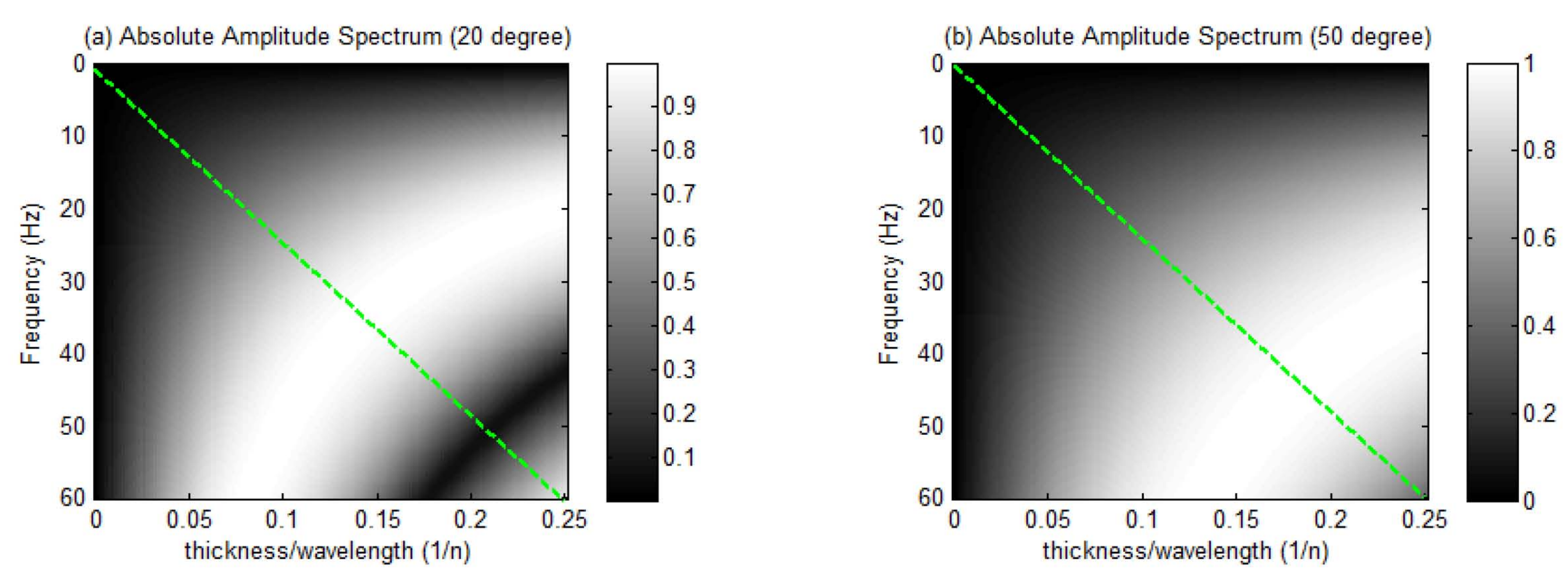

Figure 3. P-P Wave absolute amplitude spectrum with varying frequency and at fixed incident angle 20 degree (a) and 50 degree (b) for Model 1. The color represents the normalized and absolute amplitudes.

AVO responses for thin bed with attenuation

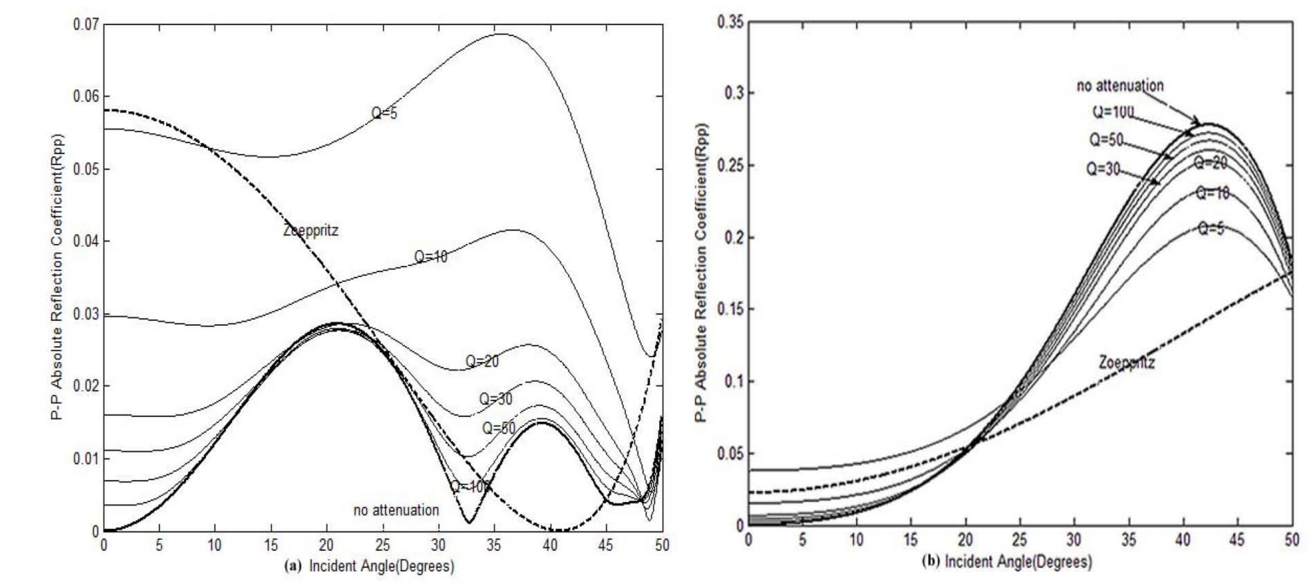

Figure 5. P-P Wave absolute reflection coefficients spectrum (n = 6) for different Q (5,10,20,30,50,100) for Model I with water sand (a) and gas sand (b) in Layer 2.

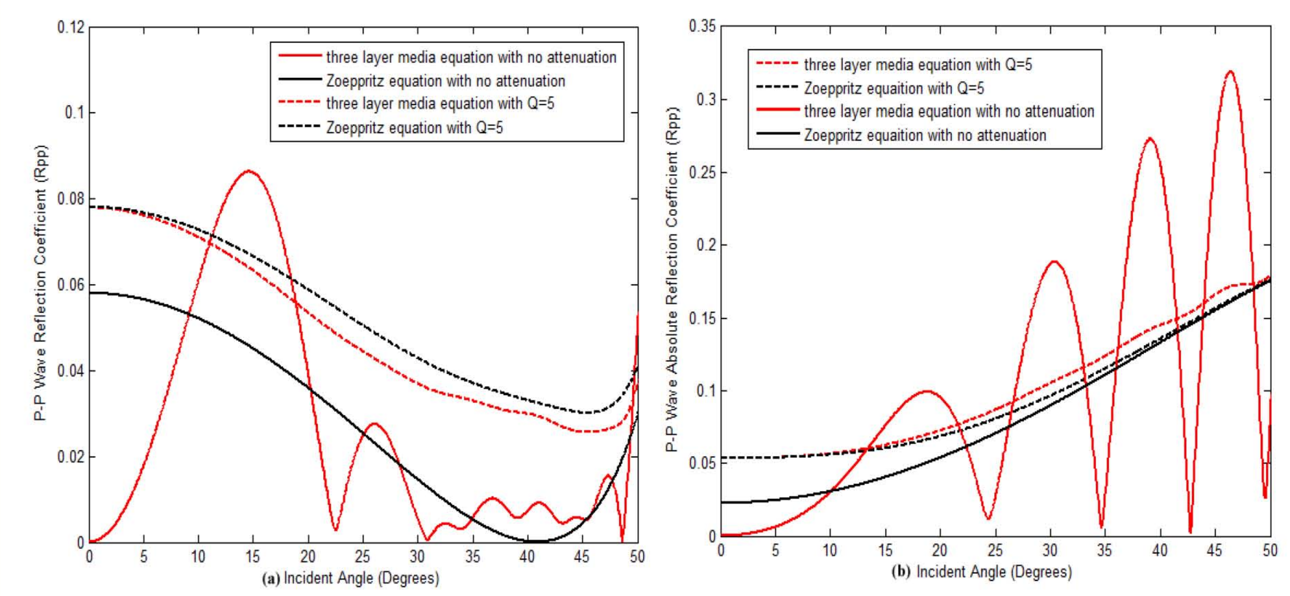

Figure 6. P-P Wave absolute reflection coefficients curves comparison (n = 0.2) for Model I with water sand (a) and gas sand (b) in Layer 2.

Comparison of AVO responses for thin bed in elastic and acoustic regime

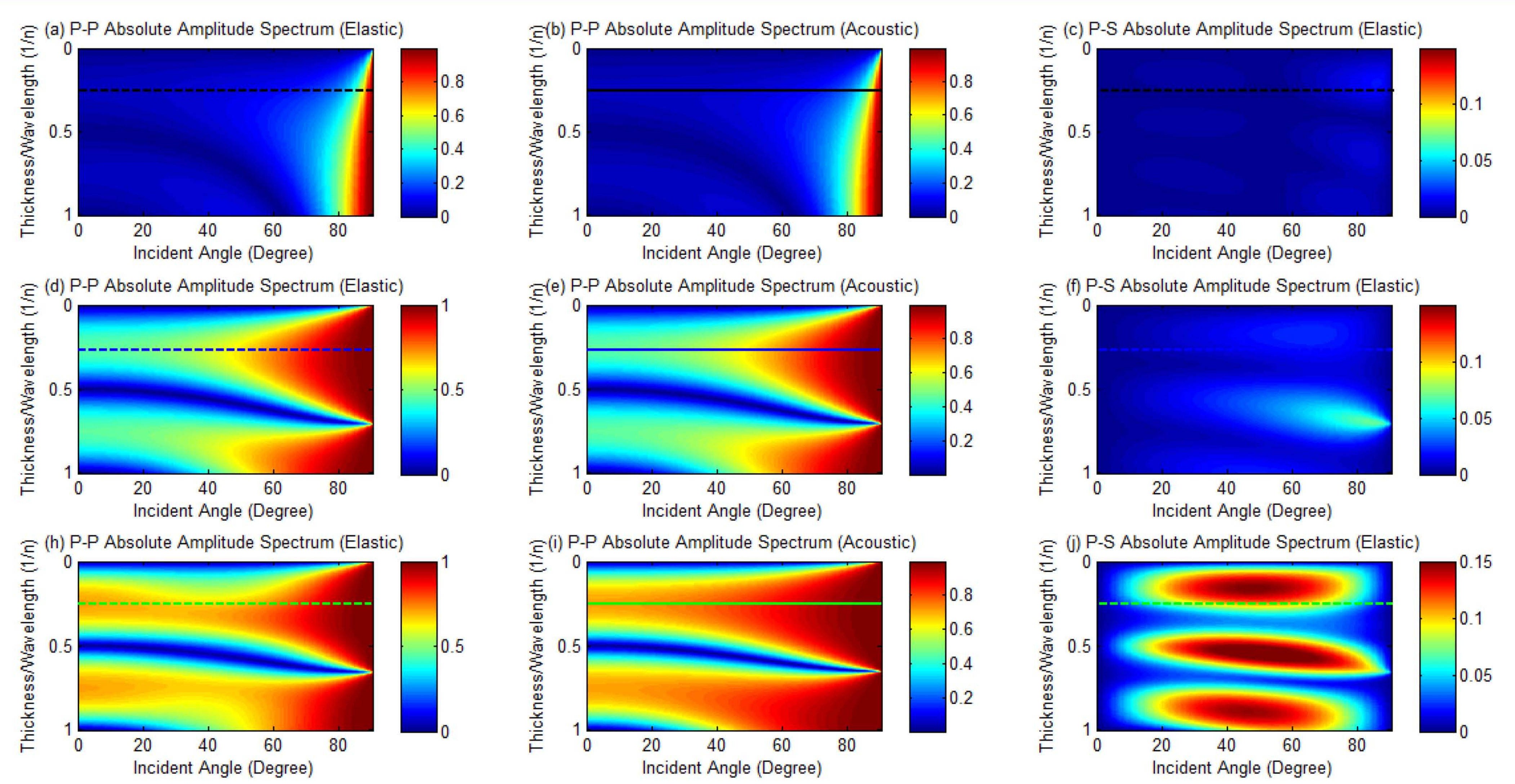

Figure 4. P-P and P-S wave absolute amplitude spectrums with varying incident angle and thickness/wavelength (1/n) at fixed frequency (30Hz) for Model II with water sand ((a), (b), (c)), gas sand ((d), (e), (f)) and coal (h), (i), (j)) in Layer 2 in elastic regime and acoustic regime respectively. The color represents normalized amplitude.

Conclusion

The three-layer media equation derived in this study describes the propagation of seismic wave in layered-media. Even though, we don't derive the direct expression of reflection coefficients or its linear approximations, this equation is still more suitable and precise than Zoeppritz equation to analyze the AVO responses of thin bed with varying the incident angle, frequency and thin bed thickness in elastic regime.

Acknowledgement

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