PAPER N

A TEST ON SEISMIC ANISOTROPY AND SCALE EFFECTS IN FINELY LAYERED MEDIA

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ABSTRACT

Wave properties in a layered medium depend on the ratio of wavelength to layer thickness. If this ratio is large enough, the medium behaves as a transversely isotropic material. If the ratio is small, scattering and dispersion are present. This report gives numerical simulations using seismogram synthesis for vertically layered media, and examines the results with the theoretical formula.

INTRODUCTION

A very common rock formation is the finely layered sedimentary deposit, e.g., Devine test site. This layered formation exhibits a transversely isotropic feature if the wave length is long compared with the thicknesses of the layers. When the wave length is close to the dimensions of the layers, the layering shows a heterogeneous property, and scattering is present. The terminology *scale effect* refers to the behavior of waves in media with different wavelength to layer-thickness ratios (*R*). A model with a large *R* is calculated to study the transverse isotropy, and the averaged elasticity for long wavelength (Backus, 1962) is used to predict the anisotropic velocities. Then a model with a small *R* is simulated to test the scattering and dispersive effects. These two models have the same average material contents.

TRANSVERSE ISOTROPY AND SCATTERING

VESPA (a software of seismogram synthesis for vertically layered media) is used to simulate the transverse isotropy in finely layered media (see Figure 1). The model consists of 300 layers each with thickness of 10 cm. In this example a limestone-sandstone sediment is simulated. The ratio of wave length to layer thickness is greater than 30, which satisfies the long wave approximation. A horizontal line (Survey H) and a vertical line (Survey V) are placed in the model to study the direction-dependent properties of waves.

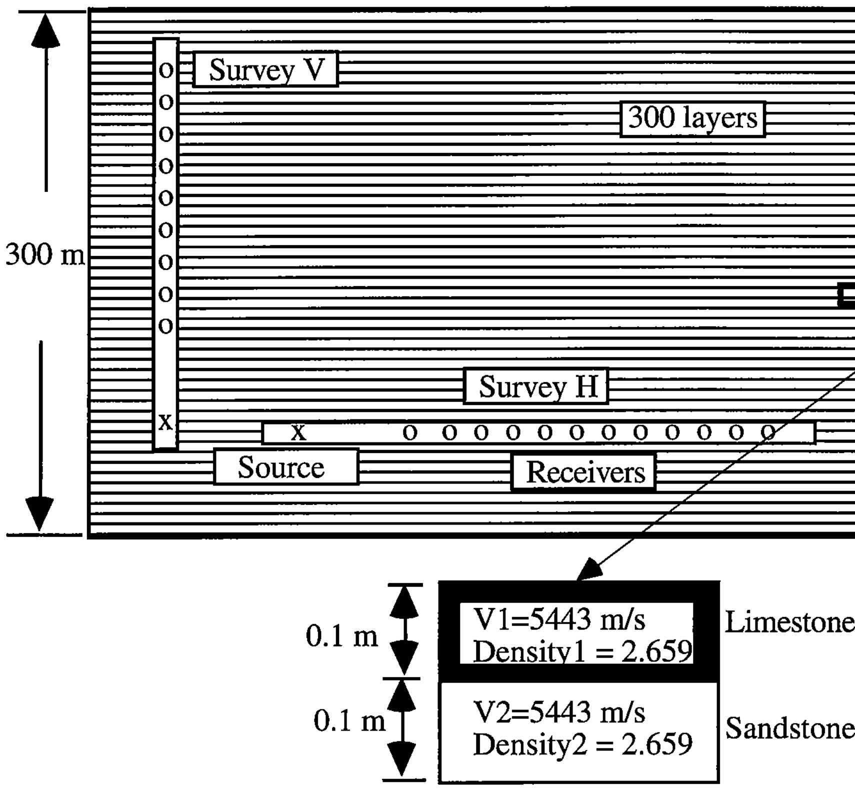
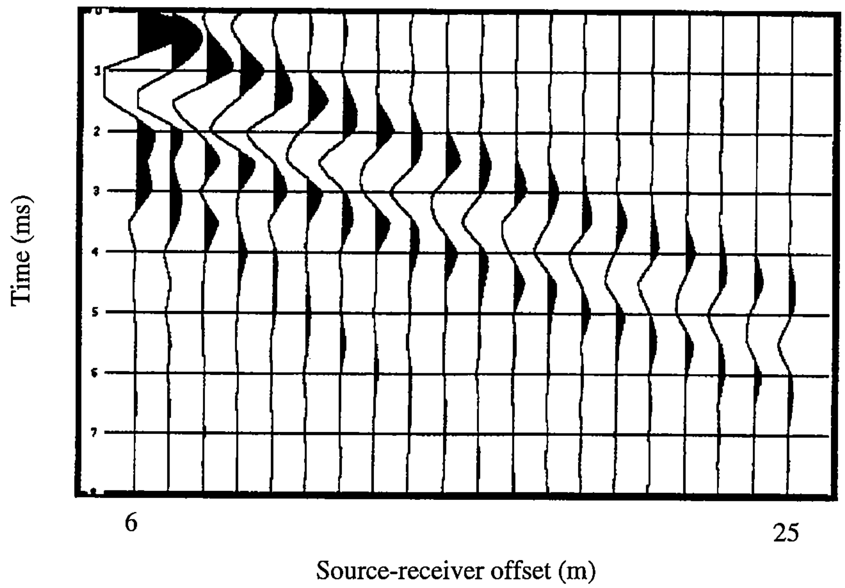
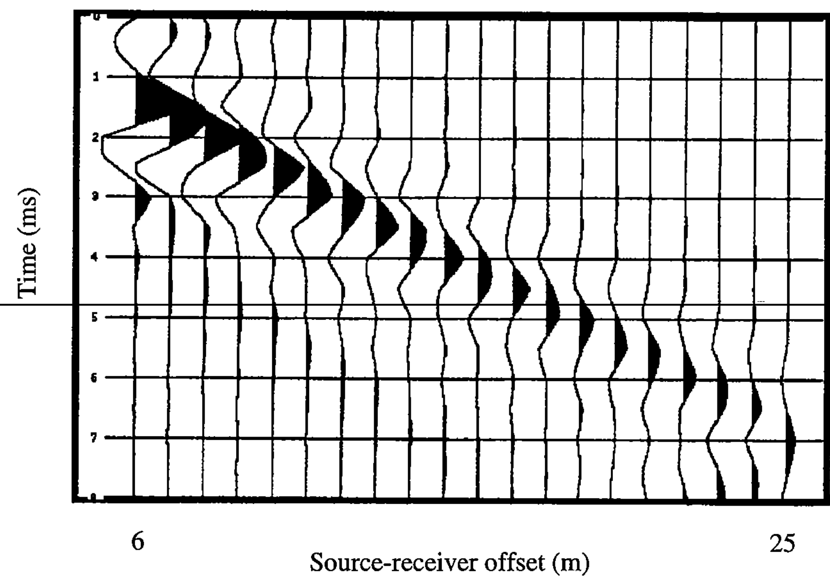


Figure 1. Model used for transversely isotropic simulation. It is made up of periodically stacked limestone and sandstone. The thickness *d* of each layer is 0.1 m. VESPA is used for forward modeling. The frequency band is 100-1000 Hz. The minimum wave length $\lambda_{min}=V_{min}/f_{min}$ = 3m. The ratio $R = \lambda_{min}/d$ = 30 meets the long wave approximation. Survey H and Survey V have the same source-receiver offsets, from 6m to 25 m.

Figure 2 shows the seismograms recorded in the two directions. I pick the travel times of P waves and show them in Figure 3. From the travel time curves, we find a horizontal velocity V_h=4514 m/s and a vertical velocity V_v=3521 m/s. The relative change $(V_h-V_v)/V_v$=28 %. The average velocity $V_m=2V_1V_2/(V_1+V_2)$, where V_1= 5443 m/s is velocity of the limestone and V_2=2949 m/s is the velocity of sandstone. Plugging in V_1 and V_2 we get V_m=3825 m/s. It can be seen that $V_v<V_m<V_h$. That means we can not use this simply averaged velocity for this medium.



(a) Waves propagating in horizontal direction recorded in survey H



(b) Waves propagating in vetical direction recorded in survey V

Figure 2. Seismograms caculated by VESPA for the model with layer thickness of 0.1 meter.

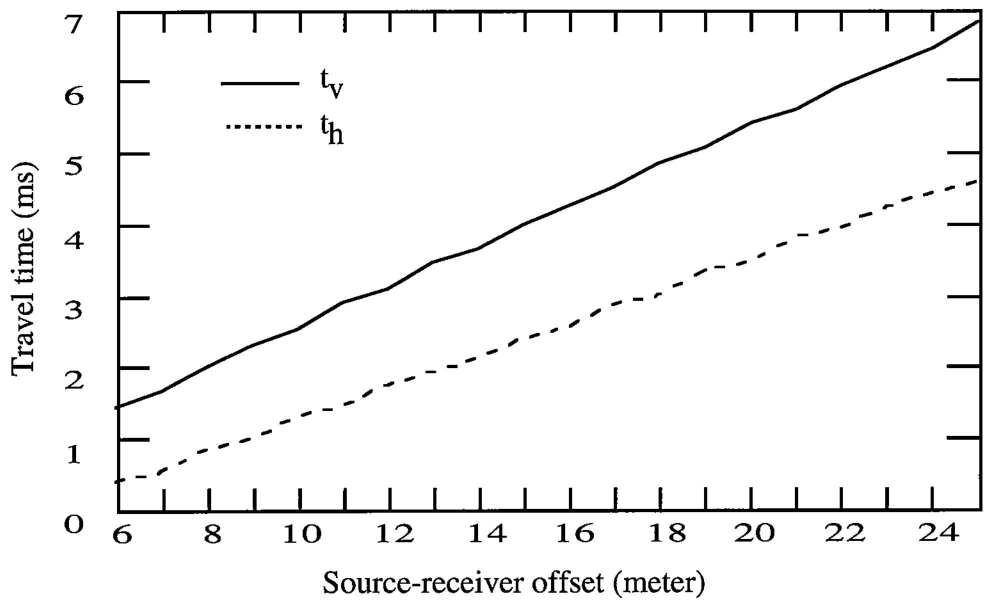


Figure 3. Travel times of waves in vertical direction (t_V) and horizontal direction (t_h), which correspond to the Survey V and Survey H shown in Figure 1. From these travel times we obtain the vertical velocity V_V=3521 m/s, and V_h=4514 m/s. Here, $(V_h-V_V)/V_V$=28%. Note that the medium used consists of limestone with V1=5443 m/s and sandstone with V_2=2949 m/s.

We can theoretically predict V_h and V_v from the averaged elastic modulus for the long-wave approximation (Backus, 1962; Carcione et al., 1991). Let M be a modulus. The averaged modulus $\overline{M}$ in the horizontal direction (see Figure 4) is given by

$$\overline{M} = \frac{1}{2}(M_1 + M_2). \tag{1}$$

The averaged density is

$$\overline{\rho} = \frac{1}{2}(\rho_1 + \rho_2). \tag{2}$$

The averaged velocity can be calculated by

$$\overline{V}_h = \sqrt{\frac{\overline{M}}{\overline{\rho}}} = \sqrt{\frac{\rho_1 V_1^2 + \rho_2 V_2^2}{\rho_1 + \rho_2}}. \tag{3}$$

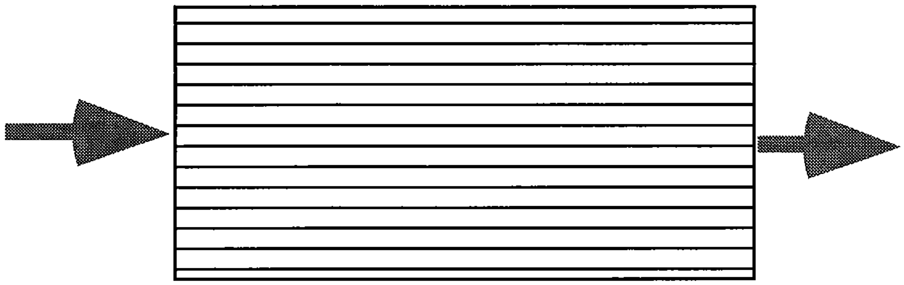


Figure 4. Waves in horizontal direction

The averaged modulus in the vertical direction (see Figure 5) is given by

$$\overline{M} = \frac{2M_1M_2}{M_1 + M_2},, \tag{4}$$

$$\overline{\rho} = \frac{1}{2}(\rho_1 + \rho_2). \tag{5}$$

and

$$\overline{V}_v = \sqrt{\frac{\overline{M}}{\overline{\rho}}} = \sqrt{\frac{2}{\rho_1 + \rho_2}\frac{2\rho_1 V_1{}^2 \rho_2 V_2{}^2}{\rho_1 + \rho_2}} \tag{6}$$

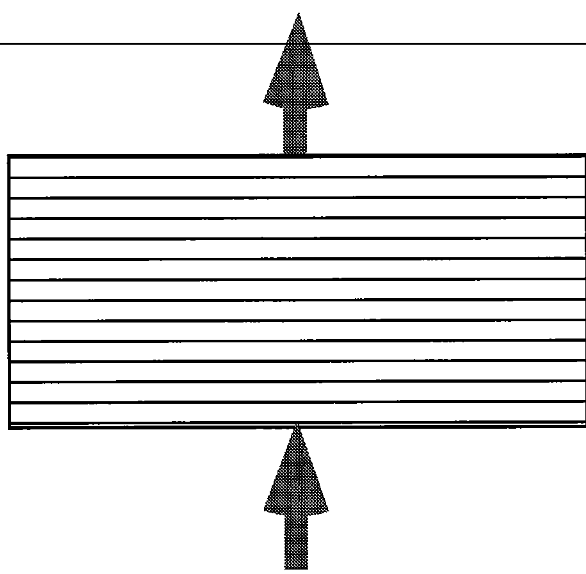


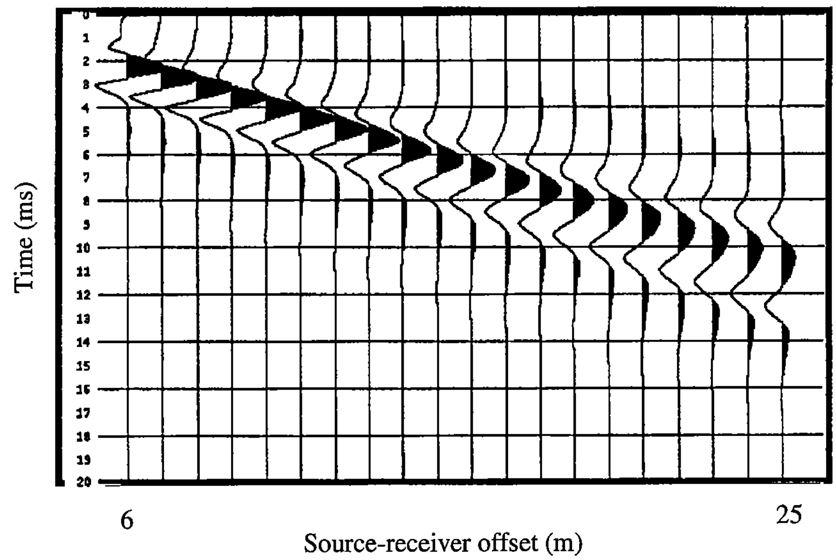
Figure 5. Waves in vertical direction.

Applying Eqns (3) and (6) to Survey H and Survey V we can obtain the theoretical velocities in horizontal and vertical directions. The theoretical prediction and the numerical result shown in Figure 6 are very close.

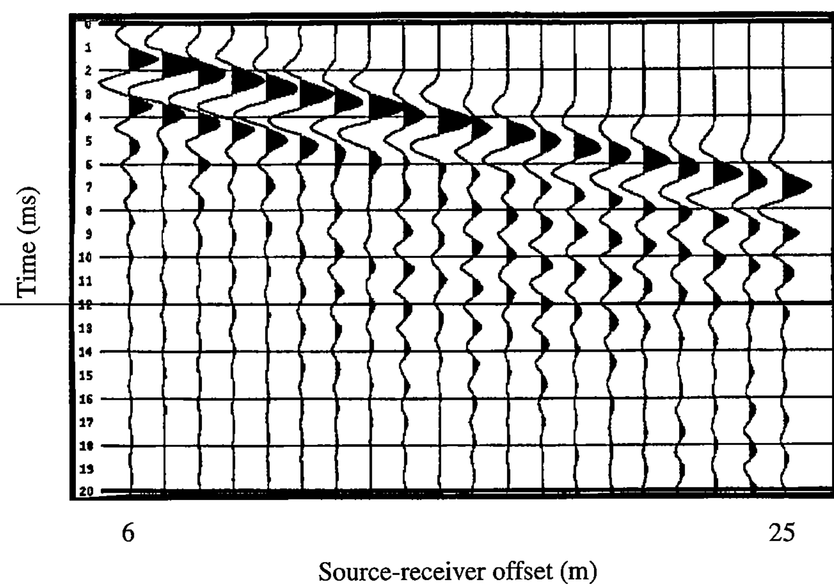
Theoretical Prediction:	Numerical Result:
V_h = 4468 m/sec	V_h = 4514 m/sec
V_v = 3582 m/sec	V_v = 3521 m/sec

Figure 6. Comparison of theoretical and numerical anisotropic velocities in finely layered medium under the condition of long wave approximation.

For the purpose to examine the scale effects I only change the layer thickness from 0.1 meter to 1.0 meter and re-calculate the seismograms for Survey H and Survey V. This does not change the average material contents of the medium. But the wavelength to layer-thickness ratio R is changed from 30 to 3. The calculated seismograms for $R = 3$ are shown in Figure 7. It can be seen that strong dispersion appears in Figure 7a. The scattering in the form of coda waves is present in Figure 7b. Comparing Figure 7 with Figure 2 we can see that these waves exhibit very different features for large R and small R. In the case of small R we can not use Eqns (3) and (6), since the condition of the long wavelength is not satisfied.



(a) Waves propagating in horizontal direction recorded in survey H



(b) Waves propagating in vetical direction recorded in survey V

Figure 7. Seismograms caculated by VESPA for the model with layer thickness of 1 meter.

CONCLUSIONS

The scale effects of waves in finely layered media are evident. The wave behavior is controlled by the ratio of wavelength to layer-thickness (or more generally, the period of the media). If this ratio (*R*) is large enough (for instance, $R > 20$), the medium behaves as a transversely isotropic material, and the vertical and horizontal velocity can be found by simple formulas which are based on the long wave average. If the ratio *R* is small (for instance, $R < 5$) strong scattering will be present, and the medium behaves as a heterogeneous dispersive material.

ACKNOWLEDGMENT

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