A Note on the Characteristics of P Coda Waves From Experimental Results

Young-Fo Chang[1] and Chao-Hui Hsieh[2]

ABSTRACT

Seismologists customarily use coda waves to study the inhomogeneous characteristics of the earth. However, P coda waves have seldom been studied due to their weak signals and short duration time when the epicenter distance is less than 100 km. In order to manifest the characteristics of the P coda, a measurement of 2-D physical modeling was made by systematically changing the scattering attenuation and the intrinsic attenuation of the medium.

Based on the experimental results, the decay rate of the P coda with elapse time is independent of the scattering attenuation; in contrast, the excitation level of the P coda is proportional to the scattering attenuation. Moreover, the amplitude decay with the elapse time of P coda waves can he satisfactorily interpreted by the model of energy transfer (Shang and Gao, 1988).

(Key words: P coda, Physical model, Scattering attenuation)

1. INTRODUCTION

The decay rate of a coda wave is independent of the distance and the path between the epicenter and a station. Similarly, it is independent of earthquake magnitude and receiver station representing an average property of the region containing the source and receiver (Aki and Chouet, 1975). Since it is easy to completely and uniformly measure the coda Q over a large area, it is convenient to use coda waves to study the source characteristics and properties of the geological structures and site effects (Herraiz and Espionsa, 1987). Aki and Chouet (1975) suggested that it is better to use the coda waves to evaluate the inhomogeneous properties of an area if the epicenter distance is less than 100 km. Essentially, the same things can be done based on the P codas. Although some of the characteristics of teleseismic P coda waves have been investigated (Basham and Ellis, 1969; Greenfield, 1971; Sato, 1984; Dainty, 1990;

---

[1] Formerly: Institute of Geophysics, National Central University, Chung-Li, Taiwan, R.O.C.; presently: Institute of Applied Geophysics, National Chung Cheng University, Ming-Hsiung, Chiayi , Taiwan, R.O.C.

[2] Institute of Geophysics, National Central University, Chung-Li, Taiwan, R.O.C.

Gupta and Wagner, 1992; Wagner and Langston, 1992), those P coda waves with an epicenter distance less than 100 km are not very often used because it is difficult to accurately identify the P coda due to the possibility of their mixing with S-waves.

To understand the scattering effect of heterogeneity and the attenuation of the medium on P coda waves, physical modeling experiments were conducted in this study.

2. EXPERIMENTS AND RESULTS

In an ultrasonic 2-D physical modeling experiment here, the characteristics of the P coda waves were observed. The detailed experimental setup and procedures are presented in Chang (1995). A plexiglass plate and a duralumin plate were individually taken as a 2-D homogeneous medium. The former was specified with a strong intrinsic attenuation coefficient, was taken as a soft and low velocity area, such as a sedimentary basin. The latter with a weak one, was taken as a harder and high velocity one, e.g., an igneous area. The physical properties and dimensions of the plates are shown in Table 1. A disk transducer PZT-4, inlaid in the plate, was like a point source and generated P-waves into the model. Chang (1995) describes the characteristics of the transducer clearly. The holes were distributed randomly in the plate and were used as scatterers in the present study.

Table 1. The properties of the plexiglass plate and duralumin plate.

Medium	Density	Velocity (m/sec)		Poisson	Attenuation coefficient (1/m)	
	(g/cm^3)	P-waves	S-waves	ration	P-waves	S-waves
Plexiglass	1.22	2300	1280	0.28	$2.71 \times 10^{-5} \times f + 0.126$*	$4.98 \times 10^{-5} \times f + 0.243$*
Duralumin	2.7	5270	3100	0.25	0.29 ± 0.04	0.46 ± 0.18

The percentages of the volume ratio (VR) of the holes to the plate for the plexiglass models were 0.5, 1, 2 and 3.3 for increasing scatterer numbers, but the VR for the duralumin models were 1.24 and 2. The dominant frequency of the source wavelet was 100 KHz and the radius of the void scatterers was 0.1 cm for the plexiglass plate. However, as for the duralumin plates, the dominant frequencies were 500 KHz, 200 KHz and 100 KHz with the radii of the scatters being 0.1 cm and 1 cm. The radiant component and transverse component are measured for analysis. The values of scattering Q (Qs) of the plexiglass plate and duralumin plate with variant scatterers could be estimated by the averaging waveform method (Hsieh and Chang, 1996).

The seismogram of the transverse component in the plexiglass plate is shown in Figure 1, and the amplitudes in the time window, 25-250 micro seconds, are used to calculate the root-mean-square amplitude. Figure 2 shows that the root-mean-square amplitude of the transverse component in the plexiglass plate decays with the elapse time of the P coda waves for different scattering densities. The decay rates are almost similar for all cases, thus indicating that the decay rate is nearly independent of scattering attenuation. The excitation levels of the P coda waves in the plexiglass plate are shown in Figure 3, noted that the excitation level is proportional to scattering attenuation (1/Qs). Although the sources emit different energies depending on having different driving frequencies and being inlaid in different plates, the variation of the amplitudes with elapse time for several cases in the duralumin plate are very similar if not
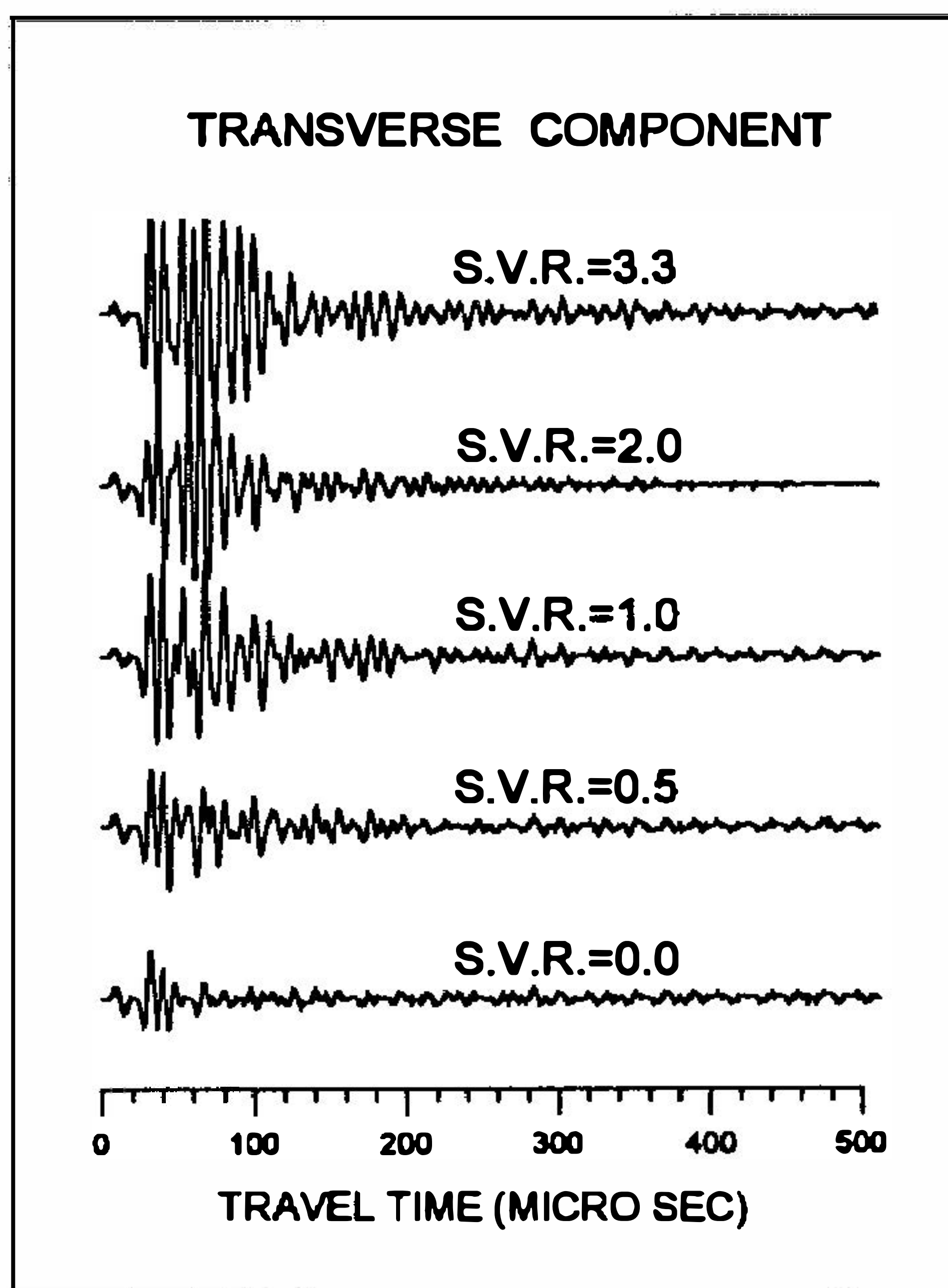
Fig. 1. The seismogram of the transverse component in the plexiglass plate. VR is the volume ratio of holes and the plate.
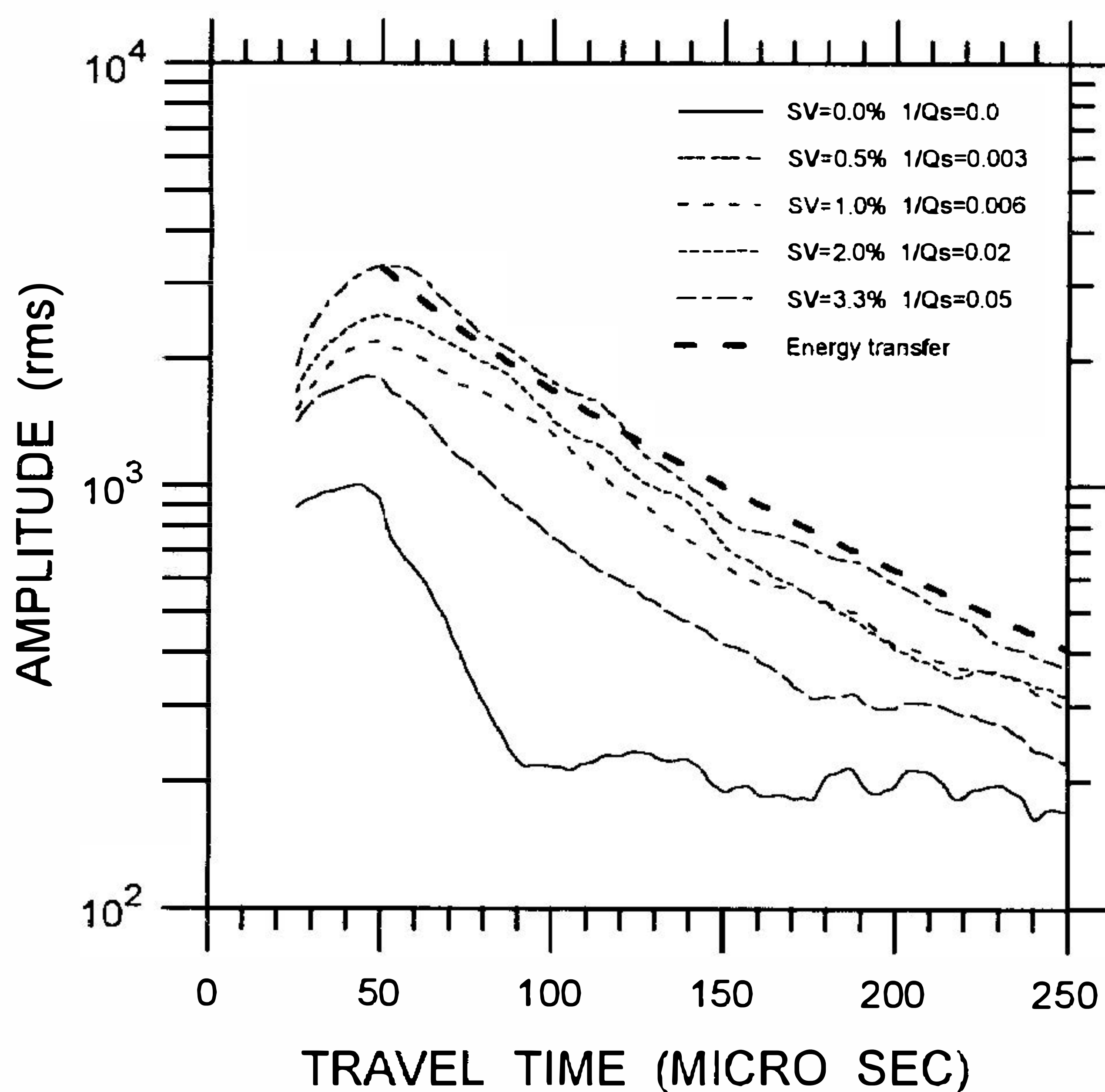

Fig. 2. The root-mean-square amplitudes of the transverse components of the P coda decay with elapse time in the plexiglass plate.attenuation for the duralumin plate.
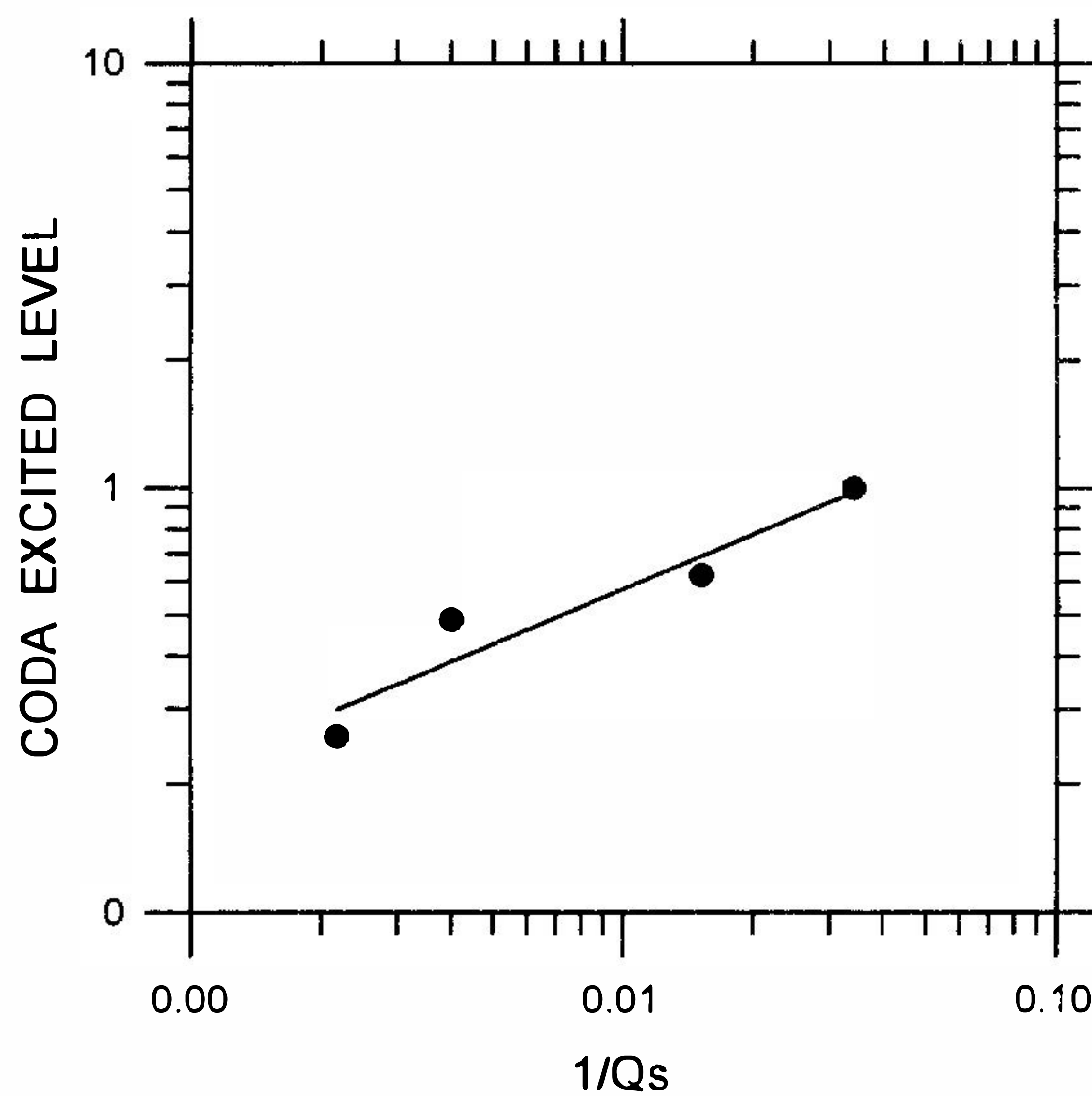
Fig. 3. The excitation level of the P codas vs. the scattering attenuation (1/Qs) in the plexiglass plate.
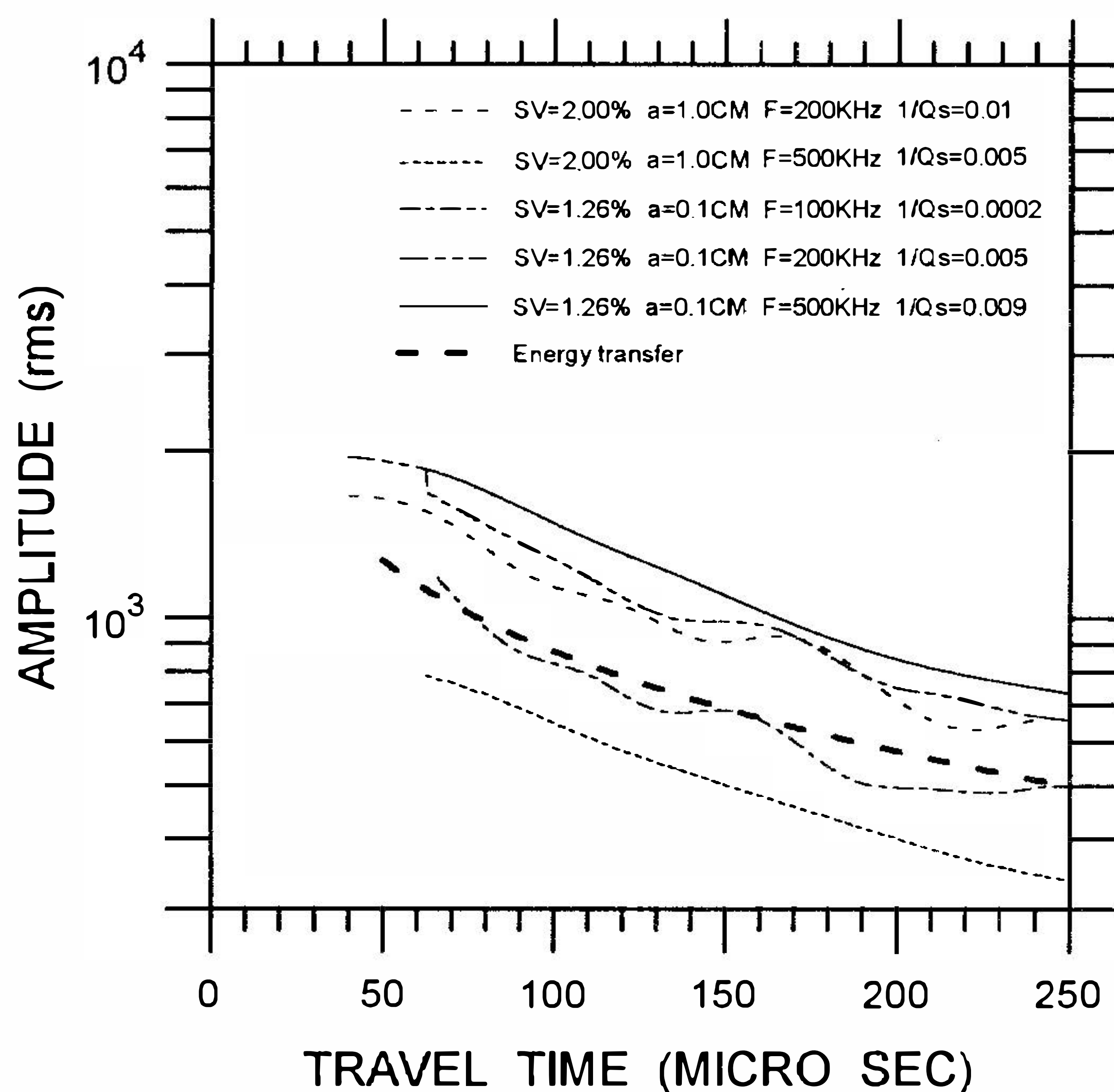

Fig. 4. The root-mean-square amplitudes of the transverse components of the P coda decay with elapse time in the duralumin plate, where a is the radius of the scatter and F is the dominant frequency of the source wavelet.

equivalent (see Figure 4). This indicates that the decay rate is also independent of scattering

3. DISCUSSION AND CONCLUSIONS

The decay of S coda waves with elapsed time depends only on the intrinsic attenuation (Frankel and Wennerberg, 1987; Shang and Gao, 1988; Hoshiba, 1991; Matsunami, 1991), and on the basis of this study, it may be concluded that the P coda waves are the same.

The theoretical curve of the P coda wave decay with elapse time can be computed by the energy flux method (Shang and Gao, 1988) when the source and detector are placed at the same point in the 2-D model by the following equation :

$$A_{coda}(t) \alpha \ g^s \cdot (V \cdot t)^{-1/2} \cdot e^{-g^i V t} , \tag{1}$$

where $A_{coda}(t)$ is the envelop of coda waves, gs is the scattering attenuation coefficient, gt is the intrinsic attenuation coefficient, V is the velocity of the medium, and t is the time. By using the P-wave velocity and its intrinsic attenuation coefficient of the plexiglass and duralumin plate, the theoretical decay curves (thick dashed lines) of the P coda waves depicted by Equation (1) are shown in Figures 2 and 4, respectively. These figures show that the energy flux model can describe the decay rate of the P coda very well, even though the energy flux model was originally used for the S coda waves. By comparing the decay rates of the P coda waves in Figures 2 and 4, it is noted that the decay rates in the duralumin plate are slower than those in the plexiglass plate. This might be due to the fact that the intrinsic attenuation of the duralumin plate is weaker than that of the plexiglass plate.

Figure 3 shows that the excitation level of the P coda waves is proportional to the scattering attenuation. This result is the same as that found by Matsunami (1991), Aki and Chouet (1975), Shang and Gao (1988) and Hoshiba (1991). They showed that the excitation level of the S coda is proportional to the square of the scattering attenuation when the source and detector are placed at the same point.

The present results can be applied to P coda waves generated from an artificial explosion. The P coda excitation level is related to the P-wave scattering attenuation, while the decay rate is dependent on intrinsic attenuation.

REFERENCES

Aki, K., and B. Chouet, 1975: Origin of coda waves : source, attenuation, and scattering effects. *J. Geophys. Res.*, **80**, 3322-3342.

Basham, P. W., and R. M. Ellis, 1969: The composition of the P codas using magnetic tape seismograms. *Bull. Seis. Soc. Am.*, **59**, 473-486.

Chang, Y. F., 1995: The characteristics of scattering effect : 2-D physical model results, Ph. D. dissertation, National Central Univ. (in Chinese).

Dainty, A. M., 1990: Studies of coda using array and three-component processing. *PAGEOPH*, **132**, 221-244.

Frankel, A., and L. Wennerberg, 1987: Energy-flux model of seismic coda : separation of scattering and intrinsic attenuation, *Bull. Seis. Soc. Am.*, **77**, 1223-1251.

Greenfield, R. J., 1971: Short-period P wave generation by Rayleigh wave scattering at Novaya Zemlya. *J. Geophys. Res.*, **76**, 7988-8002.

Gupta, I. N., and R. A. Wagner, 1992: Evidence for Rg-to-P scattering in teleseismic P coda of east Kazakh explosions. *Bull. Seis. Soc. Am.*, **82**, 2139-2152.

Herraiz, M., and A. F. Espionsa, 1987: Coda waves: A review. *PAGEOPH*, **125**, 499-577.

Hoshiba, M., 1991: Simulation of multiple scattered coda wave excitation based on the energy conservation law. *Phys. Earth Planet. Int.*, **67**, 123-136.

Hsieh, C. H., and Y. F. Chang, 1996: A Study of the Characteristics of Scattering Attenuation by Physical Modeling., *TAO*, **7**, 31-42.

Jorden, N. F., 1966, Short note -attenuation and dispersion of shear waves in plexiglass. *Geophysics*, **31**, 622-624.

Matsunami, K., 1991: Laboratory tests of excitation and attenuation of coda waves using 2-D models of scattering media. *Phys. Earth Planet. Int.*, **67**, 36-47.

Sato, H., 1984: Attenuation and envelope formation of three-component seismograms of small local earthquakes in randomly inhomogeneous lithosphere. *J. Geophys. Res.*, **89**, 1221-1241.

Shang, T., and L. Gao, 1988: Transportation theory of multiple scattering and its application to seismic coda waves of impulse source. *Scientia Sinica*, **31**, 1503-1514.

Wagner, G. S., and C. A. Langston, 1992: Body-to-surface wave scattered energy in teleseismic coda observed at the Noress seismic array. *Bull. Seis. Soc. Am.*, **82**, 2126-2138.