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PREMONITORY VARIATIONS OF DYNAMIC CHARACTERISTICS OF SEISMIC WAVES IN MEDIUM OF EARTHQUAKE PREPARATION*

孕震介质中地震波动力学特性的前兆异常变化*

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摘　　要

本文从理论上与实际资料分析上入手，较系统而广泛地研究了强震及中强震前地震波的动力学特性。

首先，选取多相介质模型来模拟孕震区的含裂隙岩石。在两相介质情况下用传波理论研究了地震波动力学特性，如振幅和波形的一般变化。所得的理论结果表明，P波、S波、面波及尾波等的振幅、振动特续时间、周期或频谱等在大震前均可能出现某些前兆异常变化。

其次，借助于观测资料，本文介绍了探索地震波动力学特性前兆异常的一些有效处理方法。特别使用了对尾波和短周期瑞雷波的前兆异常的分析处理方法。除天然小震资料外，还使用了矿山人工爆破资料。作为例子，本文得到了在溧阳台（距M＝6.0震中22公里），天平山台（Δ＝190公里）和杭州台（Δ＝220公里）从马鞍山铁矿爆破源（震中西北86公里）爆破中记到的直达波和反射波的新的资料结果，从中较详细地研究了P波和S波的振幅、振幅比、初动周期偏差和尾波的某些特性（相对走时，频率变化，振幅衰减及由尾波确定的Q值）。

然后，本文利用大量的实际观测资料，具体剖析和研究了我国唐山（M＝7.8）、海城（M＝7.3）、松潘（M＝7.2）、溧阳（M＝6.0）及其它一些强震和中强震前的P波、S波、短周期面波和尾波的多种动力学特性（振幅、振幅比，初动周期偏差，波形和频谱，振动持续时间等）出现的前兆异常变化，在此基础上，初步归纳了地震波动力学特性前兆异常

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变化时空分布的一般特点，并与波速异常加以对比。

最后，对所得的结果及其在地震预报中的应用作了简要的讨论。这里要着重指出的是，大震前地震波的某些动力学特性的前兆变化能明显地观测到。因此，如果同时使用地震波的运动学和动力学特性，我们就能得到更多的地震前兆信息。

1.Introduction

The seismic wave precursors to earthquakes can be classified into 2 basic types according to the kinematic and dynamic characteristics of seismic waves。The precursors of kinematic characteristics of seismic waves, such as seismic velocity anomalies, including premonitory changes in Vp/Vs and travel-time residuals were researched for more than 20 years by many seismologists (Fedototv, S.A.et al.,1977; Feng, D.Y. and Gu, J.P., 1981; Reyners, M., 1981)。But the precursors of dynamic characteristics of seismic waves in medium of earthquake preparation, such as their amplitudes and forms were investigated not so broadly and deeply。Among them the precursory anomalies of the amplitude ratio of S—and P—waves and their application to earthquake prediction had been studied by Feng De—yi (1974), Talwani, P. (1981) and the others. A variation in the use of the amplitude ratio of P—and S—waves for esrthquake prediction had been that of Fedotov et al. (1977). they had studied changes in the parameter log(E_s/E_P), where E_s and E_P are the radiated energies of the short period S—and P—waves.

In this paper,on the basis of theoretical research of wave propagation in medium preparing earthquake and practical analysis of abundant observational data, we have investigated broadly the precursory dynamic characteristics of seismic waves before strong and moderate earthquakes. The results obtained show that the premonitory variations of some dynamic characteristics of seismic waves before large earthquakes can be observed remarkably. Therefore, these precursors must be taken into account in the earthquake prediction researches.

2.Theoertical Research on Dynamic Characteristics of Seismic Waves in Medium Perparing Earthquake

The cracked rock in a medium of earthquake preparation may be simulated by a polyphase medium。For simplicity we have investigated the wave propagation theory in the case of two—phase medium。

2.1 Basic Equations and Parameters of Medium for Propagation of Seismic Waves in Two—Phase Medium

we assume that the medium preparing earthquake consists of two phases or elements: phase 1 is the solid skeleton and phase 2 is the porous fluid or another soft element。According to Filippov, E,G, and Bachramov, B.M. (1978), the Hook's law in this case can be represnted as

$$\sigma_i^{[1]} = -\alpha_2 + \lambda_1 \operatorname{div}\vec{u}^{[1]} + 2\mu_1 \frac{\partial u_i^{(1)}}{\partial x_i} + \lambda_3 \operatorname{div}\vec{u}^{[2]}$$

$$\tau_{ij}^{[1]} = \mu_1\left(\frac{\partial u_i^{(1)}}{\partial x_j} + \frac{\partial u_j^{(1)}}{\partial x_i}\right) = \tau_{ji}^{[1]} \qquad (1)$$

for the phase 1, and

$$\sigma_i^{[2]} = \alpha_2 + \lambda_2 \operatorname{div}\vec{u}^{[2]} + \lambda_4 \operatorname{div}\vec{u}^{[1]}$$

$$\tau_{ij} = \tau_{ji} = 0 \qquad (x_i \neq x_j) \qquad (2)$$

for the phase 2, where λ_1, λ_2, λ_3, λ_4, $\mu_1$are the corresponding elastic moduli and $\alpha_2 = \lambda_3 - \lambda_4$, $u_i^{(K)}$ is the component of displacement vector u of k—th phase in the direction x_i, $\sigma_i^{(K)}$ is the normal stress of k—th phase in the directtion x_i and $\tau_{ij}^{(K)}$ is the shear stress of k—th phase in the direction x_i acting on the plane with normal direction x_j。

Representing the displacement vector $\vec{u}^{(j)}$by use of the potentials Φ and $\vec{\psi}_j(0, \psi_j^{(1)}, \psi_j^{(2)})$:

$$\vec{u}^{(j)} = \operatorname{grad}\Phi_j + \operatorname{rot}\vec{\psi}_j \qquad (j=1,2) \qquad (3)$$

the equations for propagation of P—and S—waves can be writen as:

$$A_1\Delta\phi_1 + B_1\Delta\phi_2 = \sum_{j=1}^{2}\rho_{1j}\frac{\partial^2\phi_j}{\partial t^2} + b\left(\frac{\partial\phi_1}{\partial t} - \frac{\partial\phi_2}{\partial t}\right)$$

$$B_2\Delta\phi_1 + A_2\Delta\phi_2 = \sum_{j=1}^{2}\rho_{j2}\frac{\partial^2\phi_j}{\partial t^2} - b\left(\frac{\partial\phi_1}{\partial t} - \frac{\partial\phi_2}{\partial t}\right) \qquad (4)$$

and

$$\mu_1\Delta\Psi_1^{(1)} = \sum_{j=1}^{2}\rho_{1j}\frac{\partial^2\Psi_j^{(1)}}{\partial t^2} + b\left(\frac{\partial\psi_1^{(1)}}{\partial t} - \frac{\partial\psi_2^{(1)}}{\partial t}\right)$$

$$\sum_{j=1}^{2}\rho_{j2}\frac{\partial^2\Psi_j^{(1)}}{\partial t^2} - b\left(\frac{\partial\psi_1^{(1)}}{\partial t} - \frac{\partial\psi_2^{(1)}}{\partial t}\right) = 0 \qquad (5)$$

where

$$A_j = \lambda_j + 2\mu_j + (-1)^j\frac{\rho_2\alpha_2}{\rho}$$

$$B_j = \lambda_{j+2} + (-1)^j\frac{\rho_1\alpha_2}{\rho} \qquad (6)$$

and b is the diffusion coefficient which can be represented by using the viscosity v, permeability K and porosity φ:

$$b = \frac{v\varphi^2}{K} \qquad (7)$$

The parameters of medium may be given by the following expressions

(Li Qing—he anb Feng De—yi, 1982):

$$\lambda_1=(1-\varphi)(1-K_2\varphi)^2\lambda_s$$
$$\mu_1=(1-\varphi)(1-K_1\varphi)^2\mu_s$$
$$\lambda_2=[1-(1-\varphi)(1-K_2\varphi)^2]\lambda_f$$
$$\lambda_3=\sqrt{\lambda_1\lambda_2}-\varphi P_0$$
$$\lambda_4=\sqrt{\lambda_1\lambda_2},$$
$$\alpha_2=\lambda_3-\lambda_4=-P_0\varphi \quad (8)$$

where λ_s, μ_s and λ_f are the elastic moduli of the corresponding solid and fluid particularly。According to Sato, I. (1952), we have approximately: $K_1=0.478$, $K_2=1.348$. If the constitutive relationship for fluid is: $P=A\left(\frac{\rho}{\rho_0}\right)^n+B$, so we have: $\lambda_f=An$. The parameters ρ_i, ρ_{ij} with density dimension are determined by Biot, M.A. (1956) as

$$\rho=\rho_1+\rho_2,\qquad \rho_1=(1-\varphi)\rho_s,\qquad \rho_2=\varphi\rho_f,$$
$$\rho_1=\rho_{11}+\rho_{12},\qquad \rho_2=\rho_{12}+\rho_{22},\qquad \rho_{12}<0 \quad (9)$$

where ρ_s, ρ_f are the densities of solid and fluid particularly。

2.2 Variations of Form and Amplitude of Spherical Seismic Wave in Two—Phase Medium

In a general way we may take the formal solutions of equations for spherical P—wave (4) in the form of Fourier integral with attenuation coefficient β:

$$\phi_1(\gamma\cdot t)=\int_{-\infty}^{\infty}\frac{A(\omega)}{\gamma}e^{i\omega\left(t-\frac{r-\delta}{a}\right)+\beta r}d\omega$$
$$\phi_2(\gamma\cdot t)=\int_{-\infty}^{\infty}\frac{B(\omega)}{\gamma}e^{i\omega\left(t-\frac{r-\delta}{a}\right)+\beta r}d\omega \quad (10)$$

where δ is the radius of spherical source, a is the velocity of P—wave, ω is the angular frequency, t is the time and r is the radial distance。

By replacing (10) into (4), we can obtain the following equations for A(ω) and B(ω):

$$a_{j1}A(\omega)+a_{j2}B(\omega)=0 \qquad (j=1.2) \quad (11)$$

where a_{j1}, a_{j2} are

$$a_{jj}=A_j\left(\beta-\frac{i\omega}{a}\right)^2+\rho_{jj}\omega^2-ib\omega \qquad (i=1.2)$$
$$a_{jk}=B_j\left(\beta-\frac{i\omega}{a}\right)^2+\rho_{12}\omega^2+ib\omega \qquad (j,K=1.2,\ i\neq K)$$
$$(12)$$

From (11) we can see that for obtaining the nonzero solutions the eterninant of coefficients must be equal to zero, i,e,

$$a_{11}a_{22} - a_{12}a_{21} = 0 \tag{13}$$

and in this case we have

$$A(\omega) = -\frac{a_{12}}{a_{11}}B(\omega) = -\frac{a_{22}}{a_{21}}B(\omega) \tag{14}$$

Let us put the real and imaginary parts of left hand in the equation (13) into zero, we can obtain after simplification:

$$\begin{gathered}(x+x_0)^2 - 4(y+y_0)^2 = R_1 \\ (x+x_0)(y+y_0) = R_2\end{gathered} \tag{15}$$

where

$$x_0 = \frac{1}{2}\frac{C_2}{C_1}\omega^2, \qquad y_0 = \frac{1}{4}\frac{C_3}{C_1}b\omega$$

$$R_1 = x_0^2 - 4y_0^2 - \frac{C_4}{C_1}\omega^4$$

$$R_2 = x_0 y_0 - \frac{C_5 b}{4C_1}\omega^3 \tag{16}$$

and

$$x = \beta^2 - \frac{\omega^2}{\alpha^2}, \qquad y = \frac{\omega\beta}{\alpha} \tag{17}$$

$$\begin{gathered}C_1 = A_1A_2 - B_1B_2, \quad C_2 = A_1\rho_{22} + A_2\rho_{11} - (B_1+B_2)\rho_{12} \\ C_3 = A_1 + A_2 + B_1 + B_2, \qquad C_4 = \rho_{11}\rho_{22} + \rho_{12}^2 \\ C_5 = \rho_{11} + \rho_{22} + 2\rho_{12}\end{gathered} \tag{18}$$

From (15), (16) we can obtain the following expressions for velocities a_j and attenuation coefficients:

$$\begin{gathered}\frac{a_j}{\omega} = \sqrt{\frac{x_j + \sqrt{x_j^2 + 4y_j^2}}{2y_j^2}} \\ \beta_j = -\sqrt{\frac{x_j + \sqrt{x_j^2 + 4y_j^2}}{2}}\end{gathered} \tag{19}$$

where

$$x_j = \pm\sqrt{\frac{R_1 + \sqrt{R_1^2 + 16R_2}}{2}} - x_0$$

$$y_j = \frac{R_2}{x_j + x_0} - y_0 = \frac{R_2}{\pm\sqrt{\dfrac{R_1 + \sqrt{R_1^2 + 16R_2}}{2}}} - y_0 \tag{20}$$

From (19), (20) we can see that there are P—waves of two types with different velocities a_1, and a_2 which may be propagated in the two—phase medium and when $b \neq 0$, we have $\beta \neq 0$ and frequency—dependent velocities a_1, a_2 and attenuation coefficients β_1, β_2.

For simplicity we take a tension—type source with the normal stress

$p=p_0 f(t)$ on the source surface, i.e. let us take the boundary conditions:

$$\sigma_r^{(1)}|_{r=\delta}=-\alpha_2+p_0(1-\varphi)f(t)$$
$$\sigma_r^{(2)}|_{r=\delta}=\alpha_1+p_0\varphi f(t) \tag{21}$$

and initial conditions:

$$u^{(1)}=u^{(2)}=0, \qquad \frac{\partial u^{(1)}}{\partial t}=\frac{\partial u^{(2)}}{\partial t}=0 \tag{22}$$

By replacing (10) into (21), we can obtain the final expressions for potential functions as

$$\phi_1(\gamma,t)=\sum_{j=1}^{2}\int_{-\infty}^{+\infty}\frac{A_j(\omega)}{\gamma}e^{i\omega\left(t-\frac{\gamma-\delta}{a_j}\right)+\beta_j\gamma}d\omega$$

$$\phi_2(\gamma,t)=\sum_{j=1}^{2}\int_{-\infty}^{+\infty}\frac{B_j(\omega)}{\gamma}e^{i\omega\left(t-\frac{\gamma-\delta}{a_j}\right)+\beta_j\gamma}d\omega \tag{23}$$

where $A_j(\omega)$, $B_j(\omega)$ are determined by

$$\sum_{j=1}^{2}\left[\alpha_{11}^{(j)}A_j(\omega)+\alpha_{12}^{(j)}B_j(\omega)\right]=F(\omega)p_0(1-\varphi)$$

$$\sum_{j=1}^{2}\left[\alpha_{21}^{(j)}A_j(\omega)+\alpha_{22}^{(j)}B_j(\omega)\right]=F(\omega)p_0\varphi \tag{24}$$

$$\alpha_{11}^{(j)}=\frac{\lambda_1}{\delta}\left(\frac{-i\omega}{a_j}+\beta_j\right)^2e^{\beta_j\delta}+2\mu_1\left[\frac{2}{\delta^3}-\frac{2}{\delta^2}\left(-\frac{i\omega}{a_j}+\beta_j\right)\right.$$
$$\left.+\frac{1}{\delta}\left(-\frac{i\omega}{a_j}+\beta_j\right)^2\right]e^{\beta_j\delta}$$

$$\alpha_{12}^{(j)}=\frac{\lambda_3}{\delta}\left(-\frac{i\omega}{a_j}+\beta_j\right)^2e^{\beta_j\delta}$$

$$\alpha_{21}^{(j)}=\frac{\lambda_2}{\delta}\left(-\frac{i\omega}{a_j}+\beta_j\right)^2e^{\beta_j\delta}$$

$$\alpha_{22}^{(j)}=\frac{\lambda_4}{\delta}\left(-\frac{i\omega}{a_j}+\beta_j\right)^2e^{\beta_j\delta}$$

$$A_j(\omega)=-\frac{a_{12}}{a_{11}}B_j(\omega) \tag{25}$$

and $F(\omega)$ is the Fourier integral of source function $f(t)$:

$$F(\omega)=\frac{1}{2\pi}\int_{-\infty}^{\infty}f(t)e^{i\omega t}dt \tag{26}$$

From $\phi_1(\gamma,t)$ $\phi_2(\gamma,t)$ we can obtain the corresponding expressions for displacement field easily. The initial conditions (22) can be satisfied automatically.

In the special case when $b=0$, from (15) we have

$$a_j=\sqrt{\frac{2C_1}{C_2\left(1\pm\sqrt{1-\frac{4C_1C_2}{C_2^{\,2}}}\right)}} \tag{27}$$

$$B_j=0$$

Obviously, the velocities a_1, a_2 in this case are independent of freguency ω。For comparison we give the corresponding approximate expression of radial displacement in the case of monophase elastic solid medium with modulus μ_0 and velocity a_0 for enough small source radius:

$$u=-\frac{p_0\delta^3}{4\mu_0}\left[\frac{1}{ra_0}f'\left(t-\frac{r}{a_0}\right)+\frac{1}{r^2}f\left(t-\frac{r}{a_0}\right)\right] \tag{28}$$

By the similar way we can obtain the corresponding expressions for displacement field of S—wave。

Figures 1, 2 show the forms of P—and S—waves in two—phase medium with porous air and porous liquid and in corresponding monophase medium for source function f(t) as a half—period sinusoid。From these figures we can see that the forms and amplitudes of seismic waves propagated in the two—phase medium may have remarkable variations in comparison with those in the corresponding monophase medium。

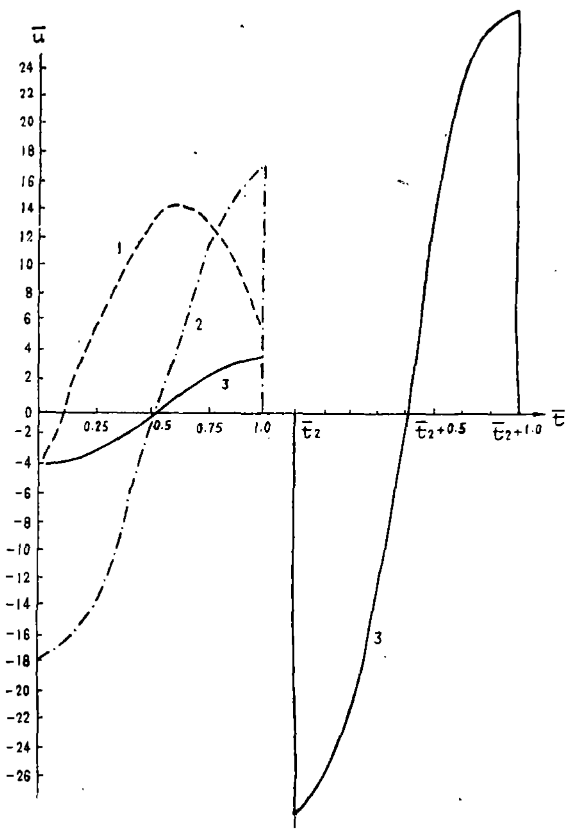

图 1　两相介质中与单相介质中 P波的理论波形。图中曲线 1 表示单相介质，曲线 2 表示孔隙为空气的两相介质，曲线 3 表示孔隙为水的两相介质。$\bar{u}$ 是相对位移，$\bar{t}=\left(t-\frac{r}{a_1}\right)/T$是相对时间且$k_0=0.1$，$\rho_{12}=0$。

Figure 1. The theoretical waveforms of P—waves in two—phase medium with porous air (curve 2) and with porous water (curve 3) and in corresponding monophase medium (curve 1)。$\bar{u}$ is the relative displacement, $\bar{t}=\left(t-\frac{r}{a_1}\right)/T$ is the relative time, $k_0=0.1$, $\rho_{12}=0$。

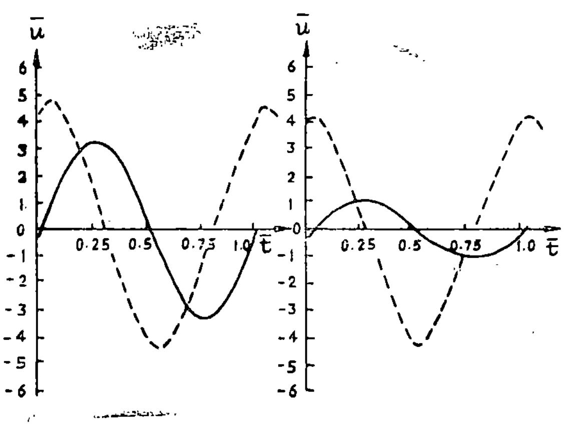

图2 两相介质中P波和S波的理论波形。图中实线表示P波，虚线表示S波，左图为孔隙为空气的两相介质，右图为孔隙为水的两相介质。

Figure 2. The theoretical waveforms of P—and S—waves in two—phase medium with porous air (left) and with porous water (right). The solid curve denot P—wave and the dashed curve denot S—wave.

2.3 Preliminary Theoretical Analysis of Premonitory Variations in Dynamic Characteristics of Seismic Waves in Medium Preparing Earthquake

According to the described above theoritical results including Figures 1, 2, we may draw the preliminary conclusion that if the crust medium preparing earthguake can be simulated by two—phase medium, so we may observe the following premonitory variations of dynamic characteristics of seismic waves。

(1). The variations of the amplitudes and amplitude ratio of P and S waves.

The above results demonstrate that the variations of P—wave amplitudes must be more obvious, then the S—wave amplitudes and, therefore, the amplitude ratio of S, P—waves also must be enough remarkable。If in the process of earthquake preparation the crust rock is microcracked at the first and then saturated, so the P—wave amplitude must be increased during the former stage and decreased during the latter stage, but the amplitude ratio of S, P—waves must decreased in the former stage and increased in the latter stage of process preparaing earthquake.

(2). The variations of form, period and spectra of P—waves.

From (23) — (25) and Figure 1 we can see thet the form, period and spectra of P—wave may have rather obvious changes in the process of earthquake preparation。For example, Fig. 1 shows that the dominant perioed or the period of first—motion of P—wave may decreased before large oarthquake。

(3). The variations of vibration duration and characteristics of seismic coda.

From Figl, 2 we see that in the process preparing earthquake, especially in the latter stage when the rock may be full of water or another liquid, the vibration duration of P—wave is often enlarged。Moreover, because the seismic coda may consist of multireflected—refracted waves, difracted waves, diffused waves and other waves in the way of superposition, some characteristics of coda must have enough remarkable variations. For example, the vibration duration of coda may be enlarged and the attenuation of coda intensity may be slow。

3 . Premonitory Variations of Dynamic Characteristics of Seismic Waves in Medium Preparing Earthquakes on the Observational Data

3.1. The Amplitude and Amplitude Ratio before and after strong and Moderate Earthquakes in Chine。

The variation of the seismic amplitude ratio from near earthquaks before and after strong and moderate earthquakes have been observed. Using the methods of dealing with maximum direct P,S—waves amplitudee ratio (As/Ap) from multi or (and) single stations, of dealing with refletive P, S—waves amplitudes ratio (Asr/Aps or Asr/As, Apr/Ap) from multi or (and) single stations, of dealhng with relation between maxmum direct P, S—waves amplitudes etc, we found the anomolous forms of the spatial and temporal characteristics of the amplitudes ratio before large earthquakes.

Fig 3 showt the variation of the amplitude ratio of S, P—waves before the Naping M5.7 earthquake November, 17, 1974 recorded at Minxian (a) and Lixian (b) stations. we can find that for several months before the earthquake the forms of the amplitude ratio in two stations tend to towards lower, of course, their forms are different slightly because the position of single station is different.

Authors had studied detaily the amplitude ratio of S, P—waves before and after the Haicheng M 7.3 earthquake February 4, 1975 (Li Qing—he, Feng De—yi 1982). The direct P, S—waves amplitudes of 607 weak earthquakes, occurred around the Haicheng earthquakes epicentre from January 1970 to July 1975 have been recorded by 20 stations, and have been made correspoding statistics. we obtained the temporal and spatlal distribution and immediate-term shock charactersitics of the large earthquake。Fig 4 is a scheme of the daily average value of S. P—waves amplitude ratio from Novemder 1, 1974 to March 31, 1975. From this scheme we can see that before December 22, 1974 M=5.2 Benxi earthquake and February 4, 1975 M=7.3 Haicheng earthquake the amplitud ratio appear all high value and the shock occurred in the process of the peak value falling。The amplitude ratio value before the main shock (M=7.3) is 15.4, it is more high than others。We alto see that the average level before shock is higher than after.

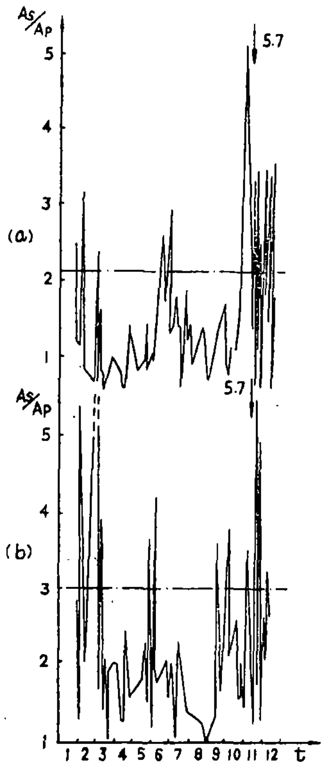

图 3 由岷县台（a）和礼县台（b）记到的1974年11月17日南坪5.7级地震前S，P波振幅比的变化。

Figure 3 The variations of amplitude ratio of S, P waves before the Naping M5.7 earthpuake, November 17,1974 recorded at Minxian (a) and Lixian (b) stations.

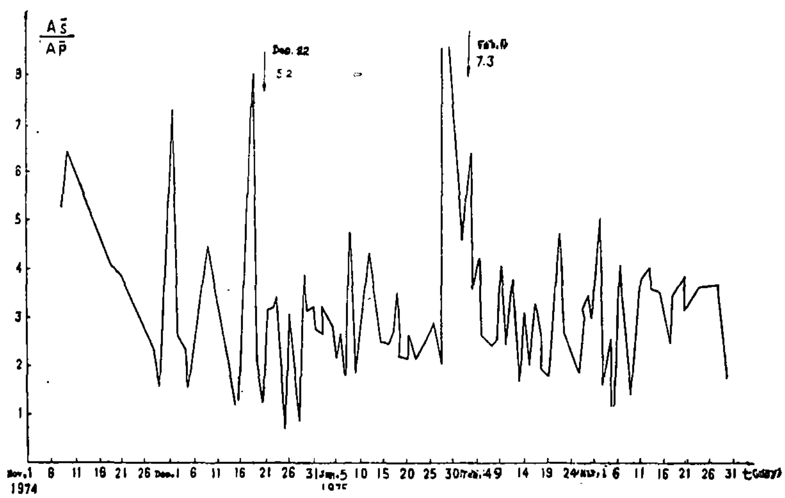

图 4 1975年海城7.3级地震前S，P波振幅比日均值的变化

Figure 4. Variation of daily average value of P—, S—wave amplitude ratio before the 1975 Haicheng M7.3 earthquake

If draw a relation between direct waves maxmum amplitude As and Ap using the earthquakes datum month out recorded by several station, we can find they have a better relativity。Make the linear fit using following formula:

$$As = a + bAp \tag{29}$$

The coefficient 'a' and 'b' may be obtained with least squares method. Fig 5 is a scheme of average 'b' value of Chengxian, Minxian and Lixian stations respect to time. One can see that before November 17, 1974 Songpan M 5.7 earthquake and August 16, 1976 Songpan M7.2 earthquake the 'b' value appear lower during former stage and then higher during latter stage.

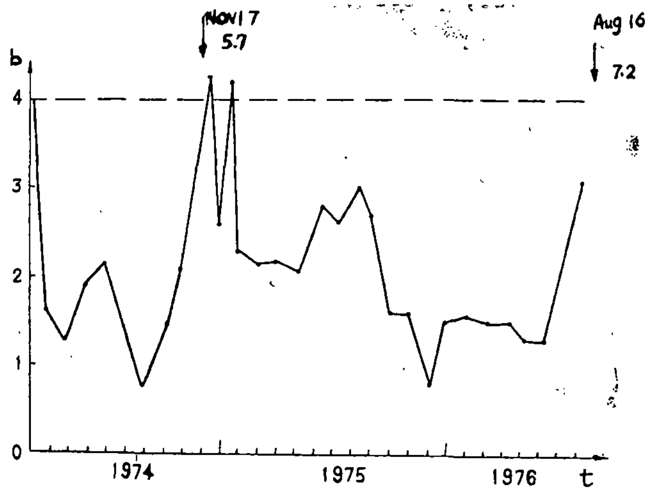

图 5　成县台、岷县台、礼县台平均 b 值随时间的变化

Figure 5. Variation of coeffficent b obtained from records at Chengxian, Minxian and Lixian stations on an average with respect to time.

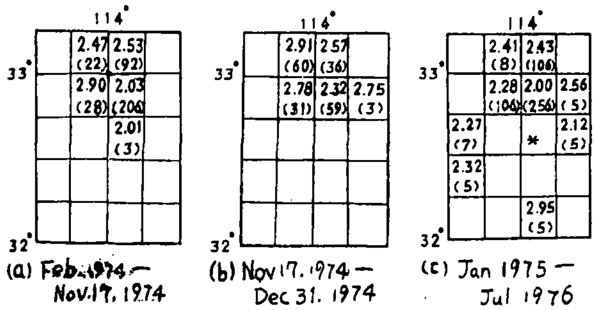

图 6　松潘地区5.7级地震前（a）和地震后（b）7.2级地震前（c）S，P波振幅比的空间分布

Figure 6. The spatial distribution of S—and P—waves amplitude ratio in Songpan region before (a) and after (b) M 5.7 earthquake before M 7.2 earthquake (c).

Fig 6 is a scheme of the spatial distribution of S and P wave amplitude ratio in Songpan region before and after M 5.7 earthqake, the number in the brackets shows the earthquake number of times and upper shows the amplitude ratio。(a) shows the stage from February 1974 to November 17, 1974, the main shok (M=5.7) occurred in the neighborhood of the boundary region of high value 2.90 and low value 2.03 and, then times ratio occuring in the two regions is large (2.06 : 28); (b) present that the grades of average amplitude ratio and events trmes in the neighborhood of the epicentre fall after the earthquake, after 1975, the grades of the two parameters rise markably and the event M=7.2 occurred in the region of large variation of the grade, presented by (c)。

Since the microquake are frequent before Haicheng M=7.3 and erery station appeares the amplitude ratio peak early or late, then the time—divergence ΔTo between appearing peak and occuring main shock baers a relationship with the epicentre distance Δ。Fig 7 is a diagram of this relation, in which the serial number 1—10 are Dalian, Chaoyang, Tieling, Dandong, Jinzhou, Heian, Yingkou, Fushun, Shenyang, Jiguanshan stations

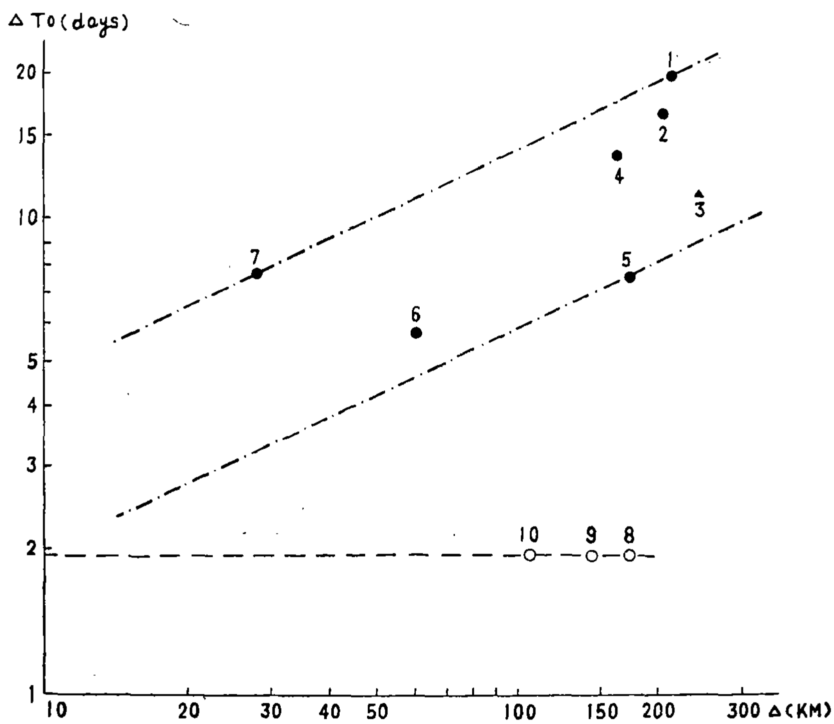

图7 海城地震临震前振幅比峰值出现的前兆时间 ΔT_o 与震中距Δ的关系。

Figure 7. The relationship between the precursor time ΔT_o of short—term peak value of amplitude ratio and epicentral distance Δ for Haicheng earthquake.

respectively。Althouth the epicentral distances of Fushun, Shenyang and Jiguanshan stations are different but ΔT_o are almost same, and they are located in the northeast of main shock region, we can consider that this phenomenon may be governed by same physical cause.

3.2 Survey of Some Dynamic Characteristics of Seismic Waves in the Preparing Earthquake Region Utilizing man—made explosion sources

The man—made explsion souces possess knowing energy, single stimulated way, identical radial way, simple disturb etc advantages, so it is feasible.

We select Maranshan mine province Anhui as explosion point。Liyang region province Jiangshu (in which occurred M=6.0 earthquake at July 9, 1979) is a preparing earthquake region explored, Liyang station is away from explosion source about 100km and the explosion point, epicenter and station are on same line, so the seismic waves led by the explosion may pass through the preparing earthquake region and the direct and reflected waves can be received in the station。Fig 8 shows the variations of the Asr/Apr, Asr/As, Apr/Ap and travel time residual ΔT received in the Liyang station from man—made explosion before Liyang M=6.0 earthquake in comparison with the Vp/Vs of the eatthquake, in wich the Asr and Apr are the maxmum horizontal and vertical displacemnt reflected from Moho surface respectively. From this we can see that the average velue of the monthly average value of Asr/Apr is 2.02 from December 1974 to April 1977 but general tendency fall rapidly begining at the latter half of 1977 and presents obvious anomaly, its average value is 1.8, the range of anomaly is 46 percent, it is relative with the process of the preparing earthquake M=6.0 and we can see that the forms of the Asr/Apr are analogous to the Vp/Vs and ΔT。

From Asr/As, Apr/Ap we see also that, moreover, the variation of P—wave amplitude is large than S—wave, so that the amplitude ratio depend mainly on P—wave, this conclusion is same with the theoretical result (Li Qing —he) and velocity ratio result。

3.3 The Change of the Coda

The coda is caused by mutiple scattering and the overlap of body, surface and transformed waves in inhomogeneous medium, so it can carry a lot useful informations on the earthquake source region。

First, we studied the coda led by the man-made explosion in Maranshan mine before and after Liyang M=6.0 earthquake at July 9, 1979, received by Tianpingshan and Hangzhou stations。Fig 9 is a scheme of its

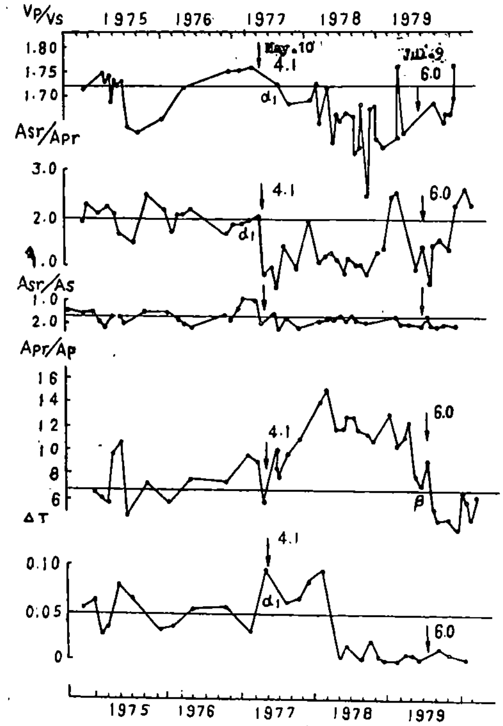

图8 1979年7月9日溧阳6.0级地震前各种地震波特性的变化

Figure 8. The changes in different seismic wave characteristics before Liyang M 6.0 earthquake on July 9, 1979。

variations。In which, (a) reprensents the variation of travel duration of coda respect to time, we can see that the duration increase gradually before shock and decrease after the shock. (b) indicates the frequency feature. The predominant frequency on every time window in the coda range is a function of time, i. e. f=F(t). According to reseach of Aki (1969), there is approximate expression:

$$f = a - Kt \tag{30}$$

and the change of the slope can reflect the relationship of 'f' and 't'.

From (b) the 'K' tending to falling can be seen in the preparing earthquake region before shock。 the shape function of the coda can be represent as following:

$$A = A_0 e^{-\bar{\alpha} t} \tag{31}$$

where A is shape function and A_0 is its maxmum scope value, α is attenuation coefficient。If we take maxmum amplitude A_i in several time window, then the following formula is represnted:

$$\alpha_i = \frac{1}{\Delta t} \ln \frac{A_i}{A_{i+1}} \tag{32}$$

and

$$\bar{\alpha} = \frac{1}{n-1} \sum_{i=1}^{n-1} \alpha_i \tag{33}$$

where $\bar{\alpha}$ is attenuation coefficient of coda as shown in Fig 9(c).we can see that α fell before and recovered after earthquake. (d) shows the quality factor 'Q' in the scattering region. Because

$$\frac{1}{Q}=\frac{\alpha}{\pi f} \qquad (34)$$

so the variation of 'Q' is oppsite to α。

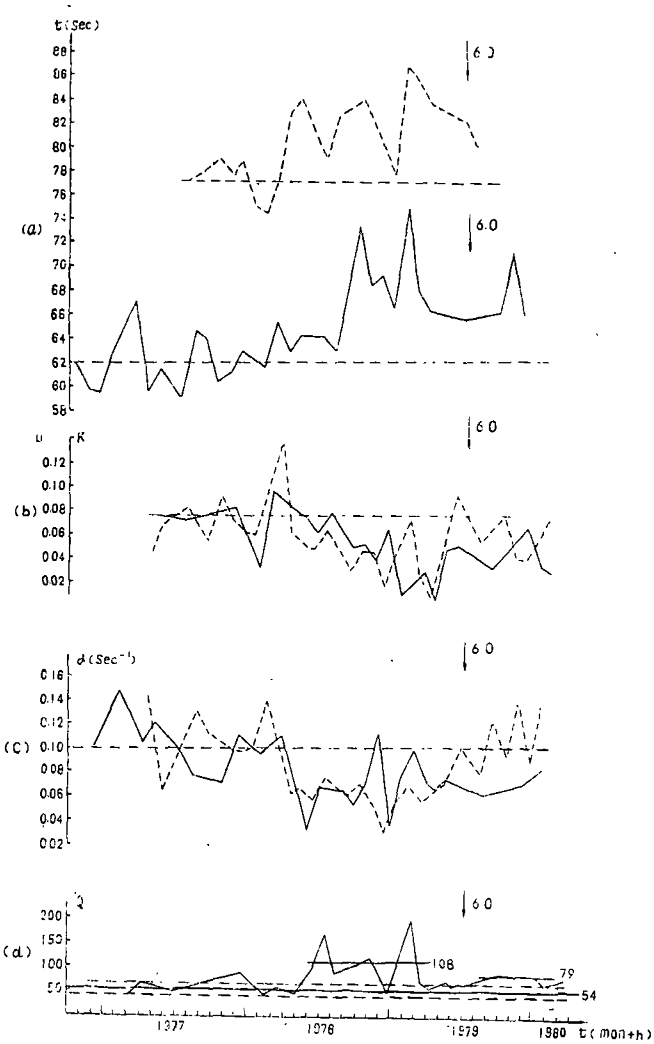

图9　1979年7月9日溧阳6.0级地震前杭州台和天平山台尾波各种参数的变化。
（a）尾波平均持续时间
（b）尾波的平均频率特性
（c）尾波振幅的衰减系数
（d）尾波的平均品质因子
图中——示天平山台……示杭州台

Figure 9. The changes of the coda different parametres respect to month before Liyang M6.0 earthquake on July 9, 1979 in Hangzhou and Tianpingshan stations.
(a).average duration of the coda;
(b).average frequency feature of the coda;
(c).average attenuation coefficient of the coda amplitude;
(d).average quality factor of the coda;
——Tianpingshan station; ……Hangzhou ttation;

Next, Fig 10 gives the scheme of 'K' and 'α' of the coda received by Gangu, Wudu and Lanzhou stations before and after Songpan M=7.2 earthquake at 1976.Not only these two parameters have more obvious change before and after the large shock, but also they present synchronons roughly variation

These four parameters τ, K, α, Q of the coda led by man—made explosion befoer Liyang earthquake present identical variation in two stations and their forms is approximate to the forms of the velocity ratio anomaly (Dong Song—sheng et al) These results show that the prepartion of large earthquake in the scattering region is a major cause controlling the attenuation feature of the coda. No matter whether the seismic rays pass through the preparing earthquake region, the variation of the attenuation feature of the coda is all corresponding to large earthquake so long as the scattering region include the preparing earthquake, this illustrates the attenuation feature is only relative to the medium characteristics in the scattering region. Moreover, the magnitudes of K, α relate to the epicentral distance, and the recovery after earthquake depend on whether the scattering region include whole preparing earthquake region.

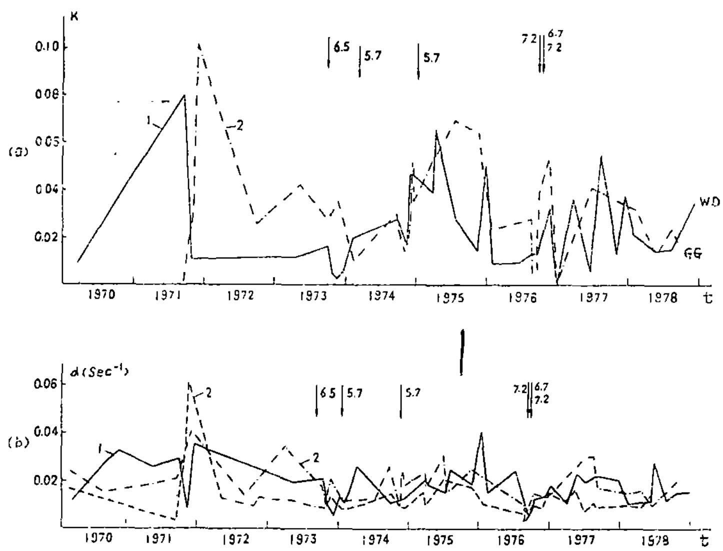

图10 松潘7.2级地震前后武都、甘谷、兰州台尾波各种参数的变化
上图是武都、甘谷台尾波的平均频率特性。
下图是甘谷、兰州台尾振幅的平均衰减系数。

Figure 10. The changes of the coda different parametes before and after Songpan M 7.2 earthquake in Wudu, Gangu and Lanzhou stations.
the upper diagram is the average frequency feature of the coda respect with month in wudu and Gangu stations;
the lower diagram is the average attenuation coefficient of the coda amplitude respect with month in Gangu and Lanzhou station;

3.4. The Precursor Anomalous Variation of the Dynamical Characteristics of Short—Period Rayleigh Wave before large Earthquake。

From former theoretical analysis we can infer that the velocity and spectra of short—period Rayleigh surface wave before large earthquake may happen more obvious changes.

we collected short—period Rayleigh surface wave datum of some large earthquake occurred in the west Sichuan province and Yunnan province since 1976, received by Chengdu, Kangding, Luzhou and Lanzhou stations using Kilnoss seismographs and analysed the velocities, spectrum and forms of Rayleigh wave。These feature all have obvious anomalies. Here we would introduce the spectral variation in particular。Draw the dealt with spectrum of every earthquake into a same diagram to comparison。Here we use maxmum amplitude Amax to dealt, we drawa a scheme of the variatioe of $s=\overline{s}/Amax$ respect to frequency f, and draw a scheme of the relative change rate of the spectrum $\tilde{s}=\frac{ds}{sdf}$ respect with f, ds, df may be replaced with difference. Fig 11 is a diagram of the relation of $|\overline{S}|$ and f。Fig 12 is a diagram of relation of $|\tilde{S}|$ and f。'A' and f are taken from several earthquakes occurred in the west Sichuan province,

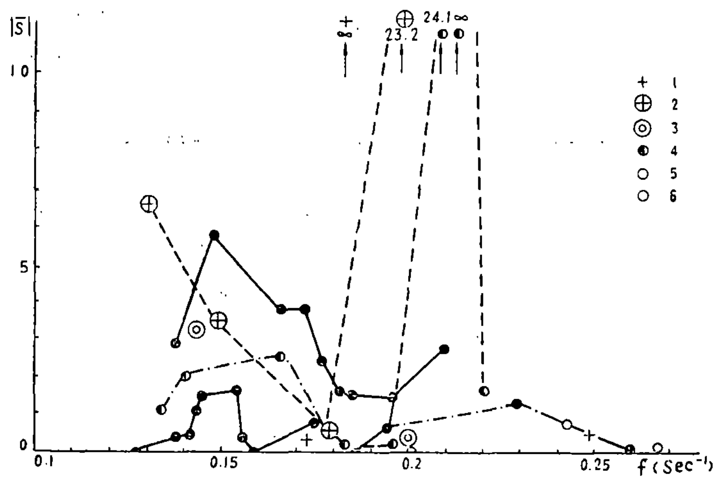

图11　泸州台记到的四川西部地震中相对频谱 $|\overline{S}|$ 对于频率f的变化。
（异常点对应于M≥5.8的地震过程）

Figure 11. The variation of the relative spectra $|\overline{S}|$ respect with frequency f in the earthquakes occurred at the west Sichuan province recorded by Luzhou station。
(the anomalous point is relative with the process of M≥5.8 earthquakes)。

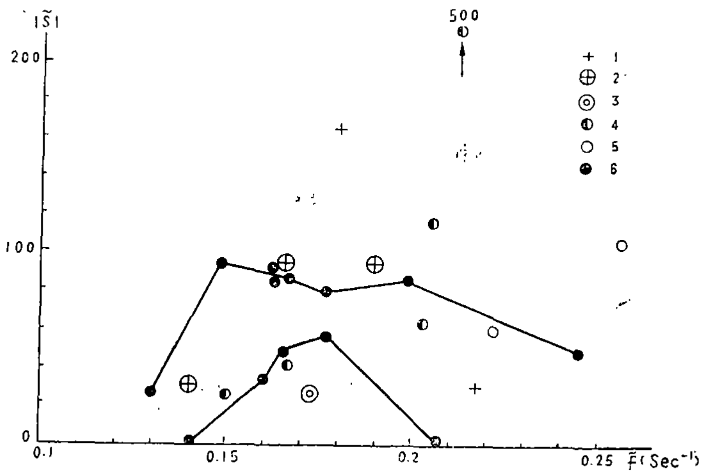

图12 泸州台记到的四川西部地震中频谱
的相对变化率|$\tilde{S}$|对频率f的变化
(异常点对应于M≥5.8的地震过程)

Figure 12. The variation of the relative change rate of spectra |$\tilde{S}$| respect with frequency f tof he earthquakes occurred at the west Sichuan province recorded by Luzhou station. (the anomalous point is relative to the process of M≥5.8 earthquakes).

recorved by Luzhou station. These results illustrate that the spectrum and its relative change rate may happen obvions anomalous variations before M≥6.0 earthquakes, and they are basically agree with the anomalous variations of the group and phase velocity, etc.

4. Preliminary Conclusions

Based on above—mentioned theoretical and practical results we can obtain foffowing preliminary conclusions:

(1). The cracked rock in a medium of earthquake preparation may be simulated by a poly—phase medium. When seismic waves propagate through in this medium their forms, amplitudes would change, so that it provide theoretical foundation for practical observation.

(2). Many instances state the ampliture, amplitude ratio, period of first—motion of the body wave, feature of coda and some dynamic characteristics of short—period Rayleigh wave would appear relevantly variations when seismic wave pass through the cracked medium. They possess some general marks, such as anomalous form, range, duration, temporal and spatial distribution, etc. This is meaningful for earthqkake predication, (3). Since explosion source has a advantage of simple source, fixed position, we applied these man—made explosion datum to study many dynamic characteristics and get pleased result, so a serial explosion datum before Liyang M=6.0 earthquake are rare useful datum.

(4).Many precursor anomalous variation of dynamic parametres are agree with velocity anomalous variation, this states the seismic dynamic and kinematic variation may be governed by a uniform physical cause, such as microcracked appearing and water permeating.

(5).The amplitude ratio of Haicheng and others earthquakes possess more odvious anomalous information for short—immediate forecast, these retults provide a possible way for short—immediate forecast.

we take note of that incomplete observation and absent special instruments are major influence on our further improte, if we should apply special instruments such as controlled sources and make seismic—roentgenoscopy to source region,then reseach for seismic dynamic characteristics would make new progress.

REFERENCES

〔1〕. Aki Keiiti, Analysis of the Seismic Coda of Local Earthquake of Scattered Waves, J.G.R., Vol.74, No.2, 1969.

〔2〕. Biot.M.A, Theory of Propagation of Elastic Waves in a Fluid—Saturated Solid, J. Acoust. Soc. Am., Vol.28, p162, 1956.

〔3〕. Dong Song—sheng、HuangCai—zhong、et al., Precursory Velocity Variations by Artificial wave Sources—Temporal Changs of Apparent Velocity—Ratio Prior to the Liyang, Jiangsu Earthquake of July 9, 1979,Acta Seismologica Sinica, Vol. 4, No.1, 1982.

〔4〕. Feng De—yi、GuJin—ping,Temporal and Spatial Characteristics of the Variations of Seismic Velocity Ratio Anomalies, Earthquake Prediction—An International Review Maurice Ewing Series 4.

〔5〕. Feng De—yi, Anomalies of Amplitude Ratio of $\overline{S}$ and $\overline{P}$ Waves from Near Earthquakes and Earthquakes Prediction, Acta Geophysica Sinica, Vol.17, No.3, 1974(English Translation in Chinese Geophysics 1.1—15. 1978).

〔6〕. Fedotov.S.A.,G.A.Sobolev at al.,Long—and Short—Term Earthquake Prediction in Kanchatka, Tectonophysics, Vol.37, 305—321, 1977.

〔7〕. Filippov E.G., Bachramov. B.M., Waves in a Homogenous and Inhomogenous Elastic Medium, 〈F.A.N〉, Tashigan, 1978.

〔8〕, Li Qing—he. A Theoretical and Practical Study on the Amplitude

Characteristics of Seismic Waves in the Preparing Earthquake Medium. the Thesis of Master's Degree, Lanzhou, Seismological Institute 1982.

〔9〕. Li Qing—he, Feng Deyi, A Theoretical and Practical Study on the Amplitude Characteristics of Seismic Waves in the Developing Earthquake Medium, Northwestern Seismological Journal, Vol. 4, No. 1, 1982.

〔10〕. Reyners, Martin, Long—and Intermediate—Term Seismic Precursors to Earthquakes State of the Art, 333—347.

〔11〕. Talwani Pradeep, Earthquake Studies in South Carolina, 381—393.

〔12〕. Sato. I., Velocity of Elastic Waves Propagated in Media with Small Holes, Bull. Tokyo. Univ. Earthquake. Res. Inst. Vol.30, No. 3, 1952.