INTERRELATIONS OF FAULT MECHANISMS , PHASE INCLINATIONS AND NONSTATIONARITIES OF SEISMIC WAVES

Masanori IZUMI[I], Takahide WATANABE[II], Hiroshi KATUKURA[III]

SUMMARY

Phase-information hidden in records of seismic waves is extracted, and relations between the nonstationarities of the waves and fault parameters are studied through 'phase inclinations' : tgr and fgr, which are differentiations of phase with respect to frequency and time respectively. Physical meanings of tgr and fgr have been clarified by producing nonstationary waves of various characteristics. Phase-transfer function are proposed and proved to be as important as amplitude-transfer function, and a method to simulate ensembles of nonstationary seismic waves, considering tgr of fault models and/or of recorded strong motions, is presented. The required nonstationarities are well represented in the simulated waves.

INTRODUCTION

In the study of wave analysis, information of phase has not been sufficientry used because of its complications and the lack of the method to treat it suitably.[1] However, since the phase of waves is generally related to the time, it is evident that the information is useful for the study of nonstationary natures of seismic waves. In this paper, average nature of inclination of phase are utilized for the study.

Given a wave motion, f(t), two complex functions are defined as

$$F(\omega)=A(\omega)e^{-i\phi(\omega)}=\int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt \qquad (1)$$

$$\bar{f}(t)=|\bar{f}(t)|\, e^{i\psi(t)}=\frac{1}{\pi}\int_{0}^{\infty} F(\omega)e^{i\omega t}d\omega \qquad (2)$$

where $F(\omega)$ is the Fourier transform of $f(t)$ and $\bar{f}(t)$ is the analytic signal[2][4] associated with $f(t)$. The phase inclinations, tgr and fgr, are given by [3][5]

$$tgr(\omega)=\frac{d\phi(\omega)}{d\omega}, \quad 0\leq tgr(\omega)<Td \qquad (3)$$

$$2\pi fgr(t)=\frac{d\psi(t)}{dt}, \quad 0\leq fgr(t)<f_N \qquad (4)$$

where Td is the duration of f(t) considered and f_N is the Nyquist frequency. In general, tgr and fgr of seismic waves are also random-like functions with respect to angle frequency and time respectively, and only their average natures may be important for the analysis.

Several predominant nonstationary natures can be derived from the average behavior of tgr and fgr. The mean values of tgr for certain frequency domains have a tendency to coincide with the center of gravity of time function composed of the corresponding components, and the variances of tgr have a relation with the duration of the function. On the other hand, the mean values of fgr for certain time domains have a tendency to correspond to the central frequency of the spectrum composed of the same

I Professor, Faculty of Engineering, Tohoku University, Sendai Japan
II Reseach Enginee of Simizu Construct Corporation, Tokyo Japan
III Instructor, Faculty of Engineering, Tohoku University, Sendai Japan

part of the time function and the variances of fgr have a relation with the width of the spectrum. Therefore, the information from tgr and fgr are just like nonstatinary spectra that represent the nonstationary natures of time functin.

In this paper, the relations between tgr and nonstationarities of waves and the concrete meanings of tgr and fgr are shown. The former is calculated by a simple fault model and the latter are presented by means of artificial waves which are simulated to involve their fundamental natures. Moreover a method to simulate the earthquake base motion for design purpose is proposed.

TGR SPECTRA AND SIMULATED WAVES BY FAULT MODEL

Since the purpose of simulations with fault models in this paper is not to represent the really observed wave motions but to show the average natures of wave form or duration, we shall make use of a simple fault model as shown in Fig.2 . In Fig.1 , simulated tgr and waves are shown. In the figure the fault length is set changeable. Changing aspect of the duration of motion due to the fault length is well performed in the waves which are simulated by the Fourier inverse transform with $A(\omega)=1$ and tgr calculated by the fault models. It is interesting to note that the distributing range of tgr corresponds to the domain where the wave motions are strong and exists within the range closed to rupture time which is shown by the dotted line. The larger the rupture time becomes, the more complicated and longer do tgr and simulated waves become. The fact manifestly shows that the phase has the information of nonstationarities of waves and this is clarified when we consider its inclinations. It may be possible to mention that we can predict the intensity functions of the seismic motions of forthcoming earthquakes according to the tgr by fault models, with the conception of probability; for a certain assumed fault process, a corresponding function of tgr will be obtained. Thus we can get a lot of intensity functions for the earthquakes by the fault model.

By many other simulations of tgr with the fault model, we obtained the following conclusions.

The average properties of tgr are determined by global rupture time, and they don't depend on the microstructures of fault process.

This shows that tgr is determined by the dimension of fault area and the rupture velocity.

The tgr is influenced by some parts of fault area such as the nearest part to the observed point and the part where the stress drop is large. This will make the wave shapes random.

MEANINGS OF TGR AND FGR FOR SEISMIC WAVES

From Fig.3 to Fig.7, we illustrate waves, their Fourier spectra, $A(\omega)$, phase inclinations, tgr and fgr, and absolute values of analytic signals, $|\bar{f}(t)|$. From these figures follows that the facts explaied in the introduction become clear, since the distributed ranges of tgr and fgr are well corresponding to the central domains of $|\bar{f}(t)|$ and $A(\omega)$ respectively. For example, in Fig.3, average values of tgr in the domain where $A(\omega)$ is large correspond to the time where the envelope is large, and average values of fgr in the domain where $|\bar{f}(t)|$ is large correspond to the frequencys where spectrum is large.

The wave in Fig.4 is calculated by $A(\omega)$ in Fig.3 and tgr that is simulated with uniform random number to have the same mean value and variance as those of tgr in Fig.3 . The resulting nonstationary nature of the simulated waves is comparably resemble to the wave in Fig.3. The wave in Fig.5 is simulated by $A(\omega)$ and $\phi(\omega)$ which are defined by uniform random number from 0 to 2π. The wave tends to have a uniform envelope function and fgr over the time corresponding to the phase property. The wave in Fig.6 is calculated by $|\bar{f}(t)|$ in Fig.3 and simulated fgr with random number to have the same mean values and variances as those of fgr in Fig.3. Changes of average frequency components through time are well simulated in the figure, and shape of $A(\omega)$ is only slightly distorted in comparison with the $A(\omega)$ in Fig.3. The wave in Fig.7 is calculated by $|\bar{f}(t)|$ in Fig.3 and $\psi(t)$ which are defined by uniform random number from 0 to 2π. The $A(\omega)$ and tgr are uniform over the frequency domain.

From these figures, the following conclusions can be obtained.

The nature of a nonstationary wave is well explained by the values, $A(\omega)$, tgr, $|\bar{f}(t)|$ and fgr.

Among these values, average values of tgr for certain frequency domain give the information of the central time where the corresponding frequency components have strong influences. On the other hand, average values of fgr for certain time domains give the information of the average frequency components in the same time region.

It seems that, for the nonstationary nature of waves like earthquake, $A(\omega)$ may perform the role of the density function which is characterized by the time variable tgr, since the shape of the wave has the tendency to be expressed by tgr where $A(\omega)$ is large.

So are $|\bar{f}(t)|$ and fgr, interchanging t and ω due to the symmetrical character of the Fourier transform.

From the average natures of tgr and fgr, we may be able to obtain the information similar to nonstationary spectra.

PHASE-TRANSFER FUNCTION OF A SYSTEM

In Fig.8, we show the examples of the phase-transfer functions expressed by the tgr for soil-structure system and one layered system. The curves are resemble to the absolute values of the transfer function and the values which depend on the damping factor and natural frequency of the systems contain the meanings of the time shifts of each frequency component for the input wave.

Therefore the phase-transfer function may also have the precious information for the system analysis similar to the amplitude-transfer functions which are usually considered.

SIMULATED EARTHQUAKE BY PHASE INCLINATION

In Fig.9, we show a flow chart to simulated earthquake base motion with nonstationary properties introduced by means of the information of the phase inclination. In the flow, since the wave is calculated by the Fourier inverse transform, we must give the information both of amplitude and of phase. As for the phase, we determine the properties of tgr from assumed fault model and/or observed earthquake strong motions on rock sites, and then, we can set the real phase $\phi(\omega)$ with the properties by the random number. As for the amplitude spectrum, we use the one which is statistically obtained, since it is impossible to deduce the spectrum by fault models now.

In Fig.10, a simulated earthquake is illustrated, in which the phase properties shown in Fig.11 are assumed. In Fig.11, mean values and standard deviations are assumed for frequency ranges, $\omega 1, \ldots, \omega 5$, and amplitude spectrum levels, $A1, \ldots, A5$, where $0<\omega 1<1.0Hz, \ldots, 4Hz<\omega 5<5Hz$ and $A1>A2>A3>A4>A5$. Each value of tgr (a) was determined through the medium of uniformly distributed amplitude spectrum (b) simulated by the method similar to Fig.7. In the figure, simulated wave (d) which is calculated from the tgr and $A(\omega)=1.0$ was also shown, in addition to the real wave (c). In the simulated wave, predominant nonstationary natures, which are assumed in Fig.11 , such as peaks at about 12 sec. and long-period components at about 20 sec. are well represented. As the result of these simulations, it seems that the metod using phase inclinations may be good so far as to introduce the nonstationary properties for simulated earthquakes.

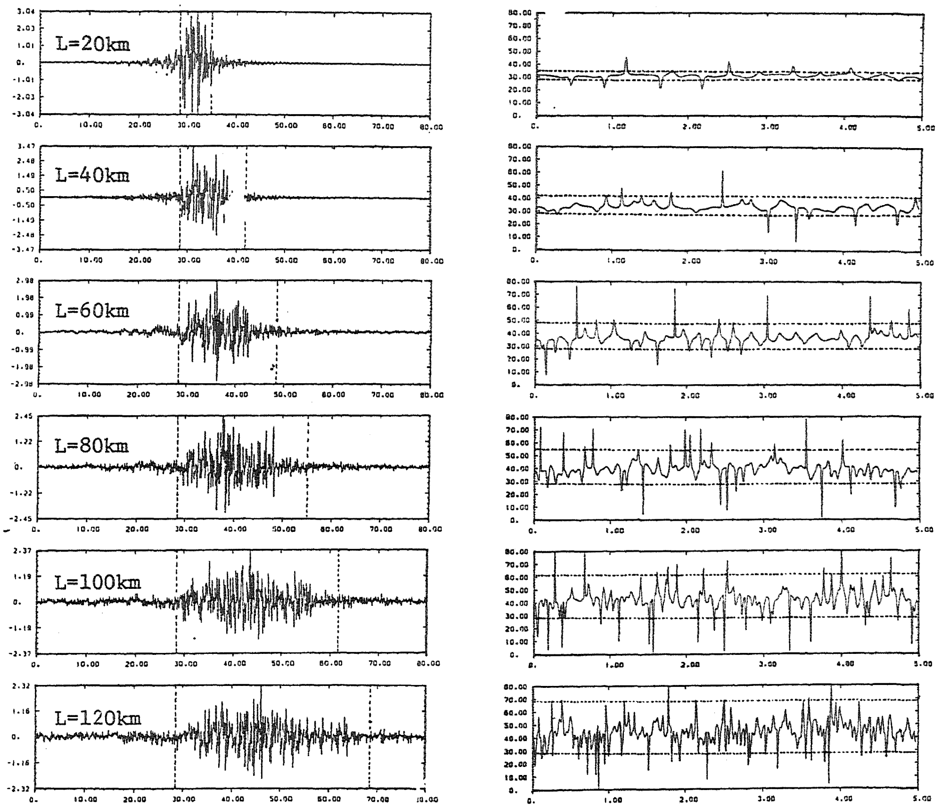
Since the wave calculated by the Fourier inverse transform only have the information of wave shape, in order to give the real base motion, it is necessary to determine the maximum value of the wave again (Fig.9). Furthermore, if required, we can also introduce a deterministic function.

CONCLUSION

Several phase properties are considered by means of their inclinations, tgr and fgr, and prominent relationships with nonstationarities of seismic waves are obtained. As the results, it seems that there may be certain important information also in the phases of seismic wave and that the importance becomes clear only if we treat the values with their inclinations such as tgr and fgr. For earthquake engineering, the phase-transfer function to consider the properties due to the time of a system and a method of earthquake simulation with nonstationarities have been proposed, and predominant usefulness has been showm.

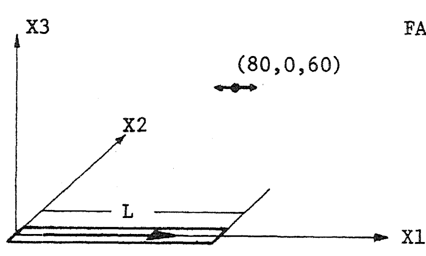
REFFERENCES

1) H.Katukura,T.Watanabe and M.Izumi;" A Study on the Phase Properties of Seismic waves," 5th Japan Earthquake Engineering Sympo. 1978
2) A.Papoulis;"Probability,Random Variables,and Stochastic Processes", McGRAW-Hill, 1965
3) A.M.Dziewonski and A.L.Hales;"Numerical Analysis of Dispersed Seismic Waves",Method in Computational Physics, Academic Press, 1972
4) J.S.Farnbach;" The Complex Envelope in Seismic Signal Analysis", B.S.S.A Vol.65 , 1975
5) A.Papoulis;" The Fourier Integral and Its Applications", McGRAW-Hill, 1962



(a) SIMULATED WAVES(SEC) (b) TGR (HZ)

Fig 1 TGR AND SIMULATED WAVES BY FAULT MODEL



FAULT PARAMETERS
RUPTURE VELOCITY
3.0km/sec
RISE TIME
2.0sec
S-WAVE VELOCITY
3.5km/sec

FIG.2 FAULT MODEL

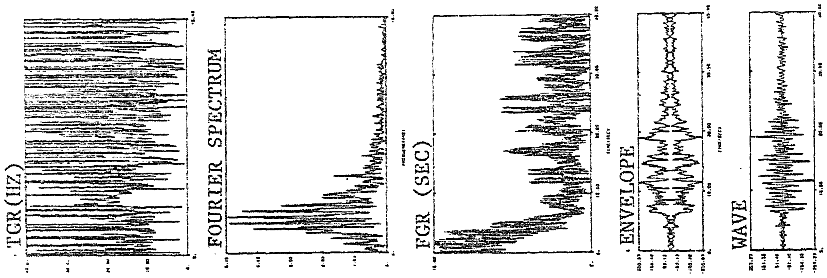


Fig.6

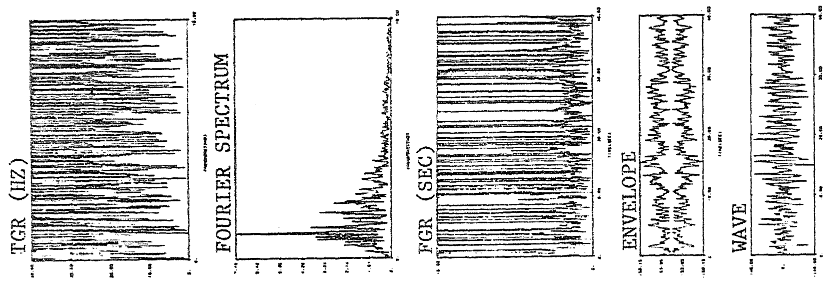


Fig.5

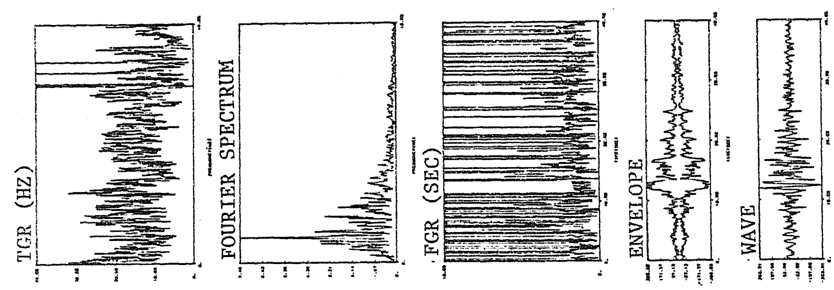


Fig.4

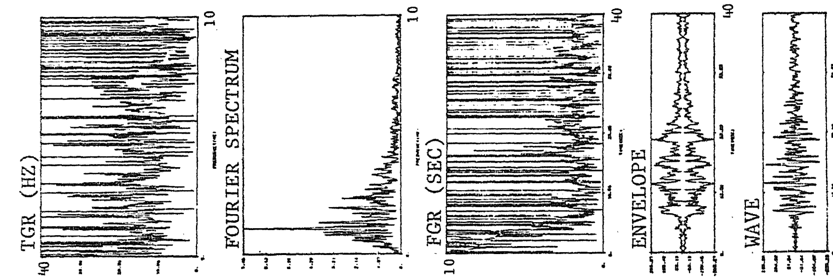


Fig.3

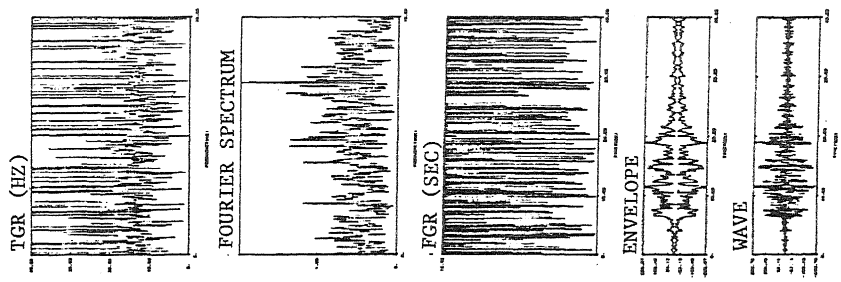
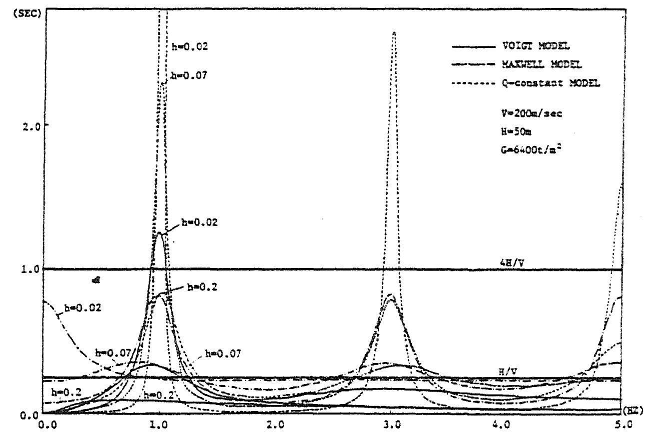
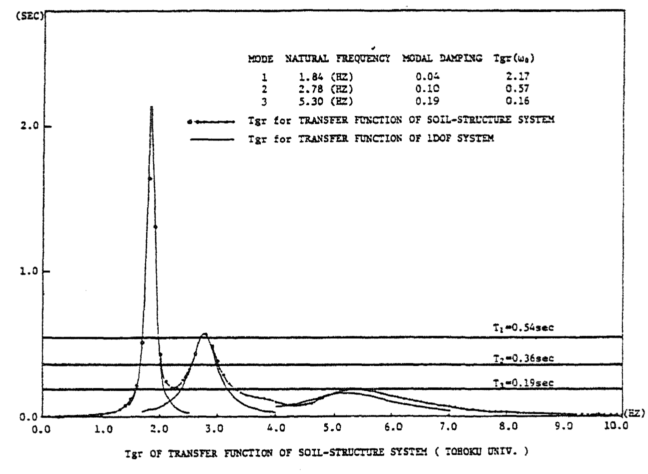


Fig.7



Tgr OF TRANSFER FUNCTION FOR ONE-LAYERED SYSTEM (V=200m/sec , H=50m)



Tgr OF TRANSFER FUNCTION OF SOIL-STRUCTURE SYSTEM (TOHOKU UNIV.)

Fig.8 PHASE-TRANSFER FUNCTION

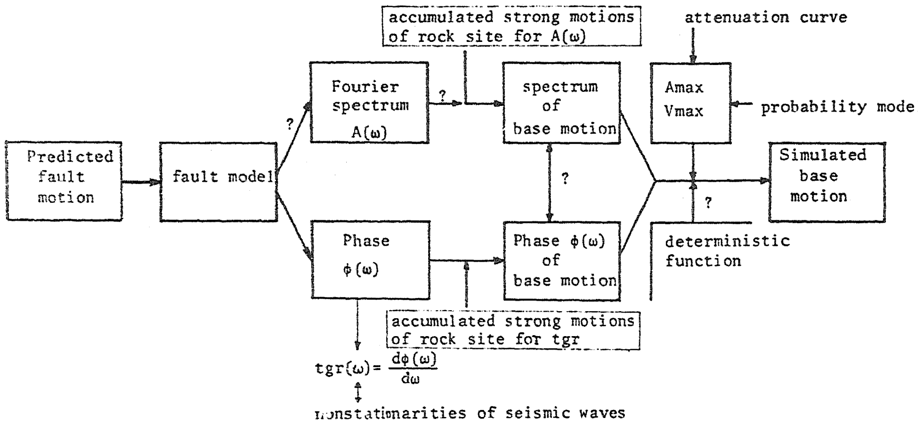


Fig.9 FLOW CHART TO SIMULATE BASE MOTION

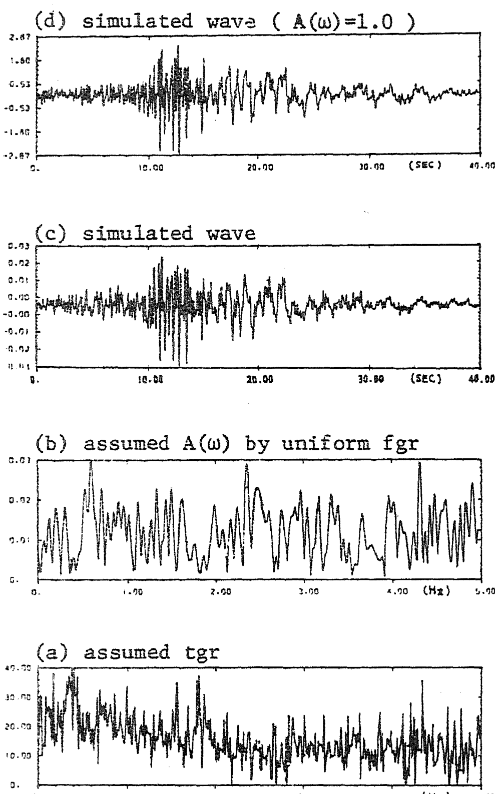


Fig.10 SIMULATED WAVE

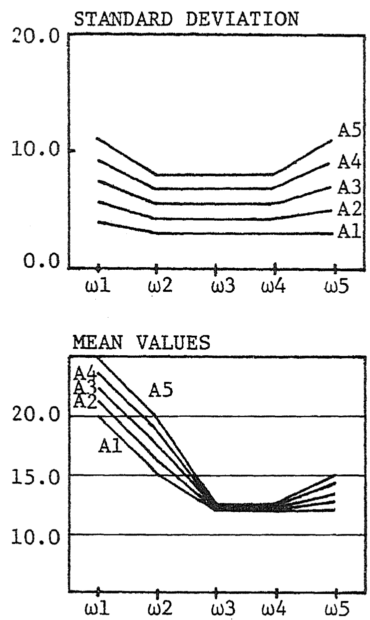


Fig.11 TGR PROPERTIES