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SIMULATION OF THE 1995 HYOGO-KEN-NANBU EARTHQUAKE USING STOCHASTIC GREEN'S FUNCTION IN CONSIDERATION OF SITE-SPECIFIC AMPLIFICATIONS AND PHASE CHARACTERISTICS

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ABSTRACT

Strong motions were recorded at the Kansai area during Hyogo-Ken-Nanbu Earthquake, 05:46 January 17, 1995. The target of this paper is to confirm capabilities for predicting strong ground motion by the stochastic Green's function method from simulating this earthquake. First in this paper, we tried to evaluate the three effects from array observation records in the frequency domain by inversion technique that be formulated by Iwata and Irikura(1988). Then we confirmed the validity of source effects S(f) as ω -square's scaling law, anelasticic path effects Q(f) as dependence on frequency, and site effects G(f) as amplification factor. Secondly, we checked site amplification effects G(f) with the observed spectral ratio against rock site. We must determine the site-specific phase characteristics in addition to the site amplification before we synthesized the stochastic Green's function as time history. Then we had the good idea of the phase defference d ϕ /df to characterize wave form in time domain. Finaly we then syhthesized strong ground motions by summing this stochastic Green's function. The agreement between the observed and predicted records was very good for maximum value, duration and spectral content. We found this method is very effective for predicting strong ground motion.

KEYWORDS

Hyogo-Ken-Nanbu Earthquake; stochastic Green's function method; scaling law; anelastic attenuation; site-specific amplifications; site-specific phase characteristics; phase difference; empirical group delay time tgr(f)

INTRODUCTION

Many statistical analysis of strong motion spectra have been carried by many workers through out the world. This analysis have been done for evaluating the input motion for the earthquake resistant design of a structure. Most of them were based on the multiple regression models in which the characteristics of the strong ground motions are assumed to vary linearly or logarithmic linearly acording to the explanatory variables such as magnitude, epicentral distance, etc.

On the other hand several workors (Andrews, 1982, Iwata and Irikura, 1988, Tai *et al.*, 1992) have tried to evaluate three major effects, source, path, and site effects using inversion method. Then they discussed these physical meaning. In predicting strong ground motion for the purpose of engineering design, so called, the empirical Green's function method is one of the most effective techniques. But the empirical Green function such as aftershock contained source, path, site effects, implicitly. There we wanted to consider and evaluate the three effects separately. And we constructed source-specific effects, path-specific effects and site-specific effects using observed earthquake records.
Then we synthesized artificial, stochastic Green function before we synthesized strong design earthquake by

summing this Green function. In this paper, we assumed source spectra as ω -square model and path effects as geometical and anelastic attenuation(Qs-value). And we confirmed the empirical Qs-value and the empirical site amplifications and phase characteristics using observed records. If we have gotten these empirical relations, we simulated the stochastic Green function artificially at the special site. Then strong ground motions were predicted by summing the Green function. This method has been done to simulate the strong motion during 1995 Hyogo-Ken-Nanbu Earthquake.

DATA SET

Earthquake datas that we studied were observed at the sites that have been established by The Committee of Earthquake Observation and Research in the Kansai Area(CEORKA). Figure 1 shows the location of 11 observation sites and the epicentral locations of earthquake. Observation has been set up in April 1994. And strong ground motions of Hyogo-Ken-Nanbu Earthquake were recorded at January 17, 1995. From the day, many aftershocks were observed. In this study we used the records of small event (M=4.0~5.2) and large event(M=7.2).

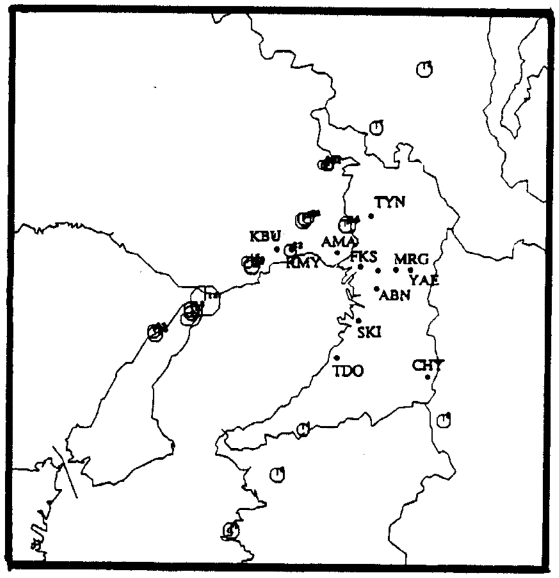


Fig. 1. The map of observation sites and epicentral locations of earthquake that be used in this study.

INVERSION

Formulation of inversion method

We now have three type earthquake datas. First is strong ground motions of 1995 Hyogo-Ken-Nanbu Earthquake M=7.2, second is small event records before the large event, third is small event records after the large event. We tried to study the effects of source, path and site using small event data after the large event using the formulation of the inversion by Iwata and Irikura(1988).

$$O_{ij}(f) = S_i(f)\cdot\exp(-\pi f R_{ij}/Q_S(f)V_S)/R_{ij}\cdot G_j(f) \qquad (1)$$

where O(f): observed spectra, S(f): source spectra, R: hypocentral distance, Qs(f): anelastic attenuation factor, Vs: S-wave velocity, G(f): site amplification factor, f: frequency, i, j: i-the earthquake and j-th site. Eq.(1) is modified by taking the logarithm, then we could solve the linear simultaneous equations using linear least square problem with inequality constrain where $G(f) \geqq 1.0$(Lawson and Hanson,1974, Tai *et al.*,1992)

Result

In Figure 3 we shows the separated source spectra and Figure 2 shows the relation between 1/Qs-value and frequency. As result in Kansai area we determined the frequency dependence of Qs-value is proportional to $(f)^{-n}$,f:frequency, n=0.85, than $f \geqq 1.0$Hz. This result is good agreement with that of Aki(1979). Source spectra has flat level at low frequency , has corner frequency fc and tend to decrease with $(\text{frequency})^{-2}$. These result show that source spectra fit to ω^{-2} model. Site amplification factors (Figure 3)was discussed at next headline

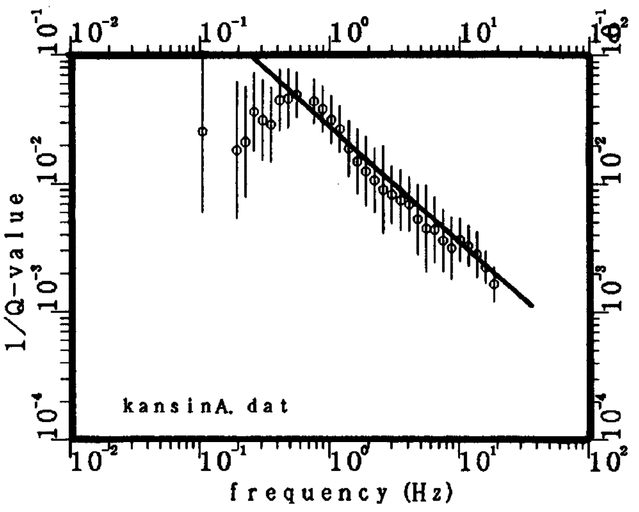
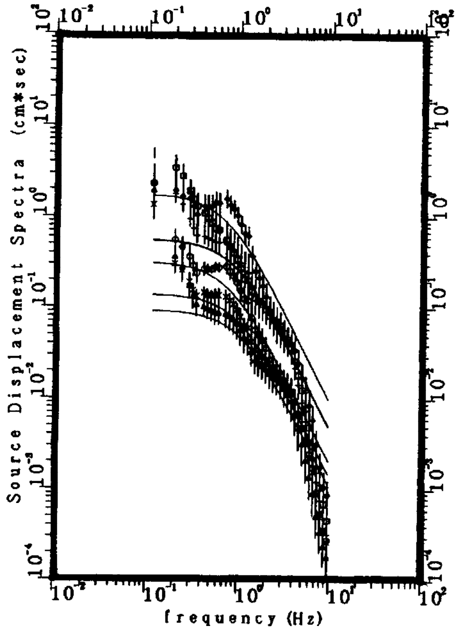


Fig.2. the relation between 1/Qs and frequency that be separated.



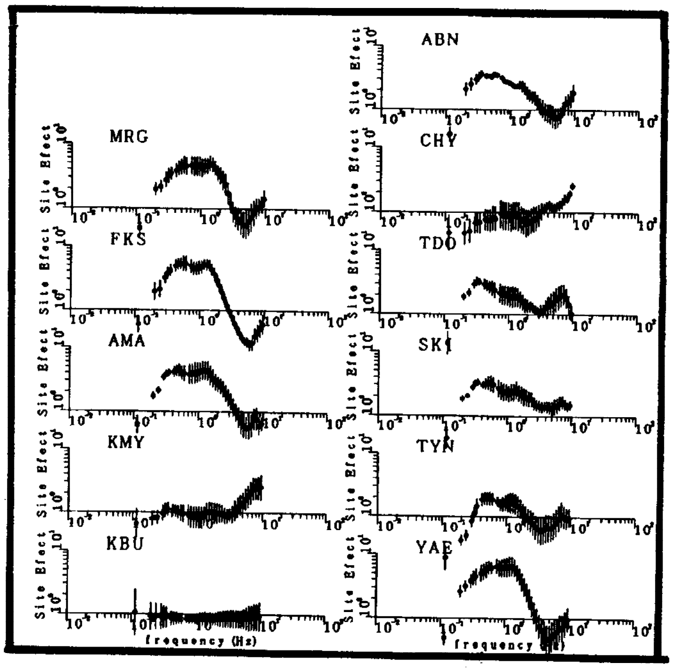


Fig.3. Source spectra be separated.

Fig.4. Site amplifications be separated

SITE-SPECIFIC AMPLIFICATIONS AND PHASE CHARACTERISTICS

Site-specific amplifications

We calculated all spectra of the small event's records. The vectlor summasion spectra of EW and NS component was used and was modified by distance and Qs-value. Then we evaluated the spectral ratios against rock site(KBU) as the site-specific amplifications, and compare the spectral ratios with the separated site effects by inversion method. Figure 5 show all spectral ratios, average value and inverted site effects at the each site. The agreement between average value and inverted value is very good and the deviation of observed data is not so large. Then we confirmed the empirical site-specific amplifications.

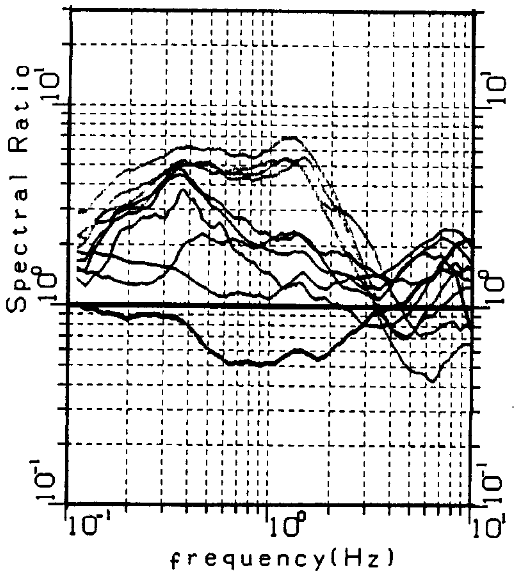


Fig.5. Site-specific amplifivations against rock site.

ite-specific phase characteristics

If we want to get the stochastic Green function as time domain, we must consider and evaluate the site-specific phase characteristics. Fourie spectrum at the observed site is expressed as follows,

$$O(f) = A(f)\cdot \exp(-i\phi(f)) \tag{2}$$

where ϕ (f) is phase angle. We tried to evaluate phase characteristics at the special site. But only phase angle is difficult to be modeled. There we had good idea about phase characteristics. The idea is that we evaluated phase characteristics with the term, phase difference by frequency as follows,

$$t_{gr}(f) = \frac{1}{2\pi}\frac{d\phi(f)}{df} \tag{3}$$

where we define tgr(f) as group delay time(Ohsaki,1979, Katukura *et al.*,1984, Kimura *et al.*,1989). Group delay time has physical meaning that is arrival time of maximum group wave. Group delay time is related with the dispersion property due to site condition at the low frequency domain(Tai *et al.*,1995). We evaluated the stochastic tgr-characteristics with calculating tgr of small event records and summing all normarized by arrival time of direct S wave. Figure 6 show the site-specific group delay time at the site. We show in Figure 5 average of the empirical group delay time.

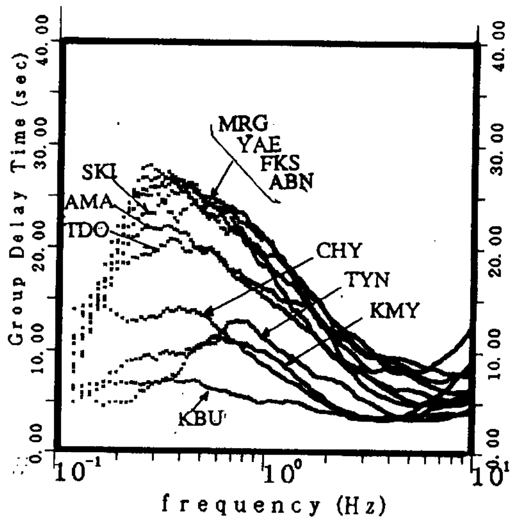


Fig.6. Site-specific group delay time tgr(f)

SYNTHSIZED STRONG GROUND MOTION

Stochastic Green's function method

We synthesized stochastic Green function in consideration of the formulations that was constructed by Boore(1983) as follows

$$A(f) = CM_0S(f,f_C)P(f,f_{max})\exp(-\pi fR/QsVs)/R \cdot G(f) \tag{4}$$

$$C = \frac{R_{\theta\phi} \cdot FS \cdot PRTITN}{4\pi\rho V_S^3} \tag{5}$$

$$S(f,f_C) = \frac{(2\pi f)^2}{1+(f/f_C)^2} \tag{6}$$

$$P(f,f_{max}) = \frac{1}{1+(f/f_{max})^n} \tag{7}$$

where A(f) is the spectra at the site. C is the coefficient that be determined by $R_{\theta\phi}$: radiation pattern, FS: amplification due to free surface, PRITITN: reduction factor into two horizontal component, ρ : density, Vs: S-wave velocity. fc is corner frequency, fmax is maximum frequency be considered. When we have gotten the value of eq.(4),(5),(6),(7), we can evaluate the synthesized Green function as time function using inverse fourier transform of X(f) as follows,

$$O(f) = A(f)\exp(-i\phi(f)) \tag{8}$$

$$\phi(f) = 2\pi\int_0^f t_{gr}(f)df \tag{9}$$

Fault model

Fault model at Hyogo-Ken-Nanbu Earthquake(that is shown in Figure 6) was determined with empirical Green function method(Kamae,1995). We synthsized this large event record by summing stochastic Green function using 3 asperity model of Figure 7.

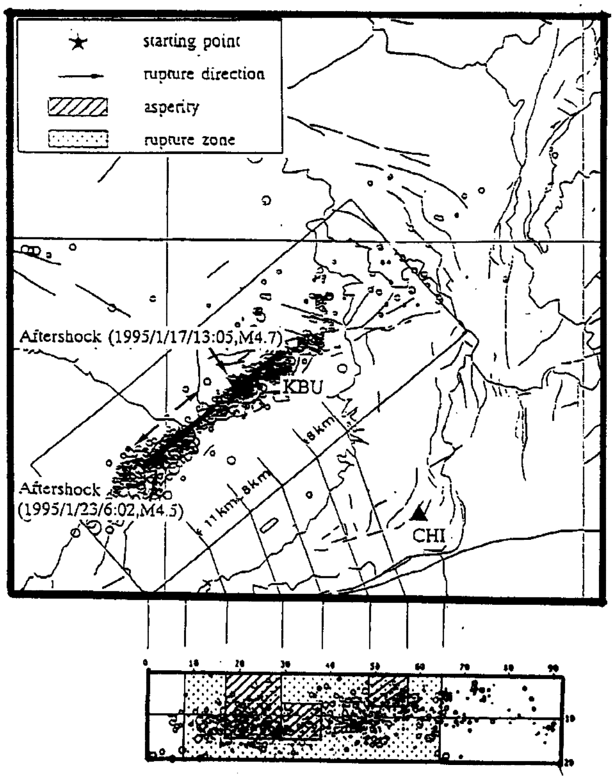


Fig.7. Fault model of 1995 Hyogo-Ken-Nanbu earthquake by Kamae(1995)

Comparison between synthsized and observed strong ground motion

We used the parameters that be shown on Table 1 to synthesize the large event in consideration of Kamae *et al.* (1995)'s results. The stochastic Green' function s nearly equal to the earthquake M=4.7.

Table 1 Parameters of stochastic Green function method

	Stochastic Green function		
source	seismic moment M_0	$7.1x10^{22}$	dyne · cm
	corner frequency fc	1.5	Hz
	max. frequency fmax	7.0	Hz
	stress drop	126	bar
path	Qs-value	Figure	2
site	site-specific amplifications	Figure	5
	site-specific group delay time tgr(f)	Figure	6

Fault model			
stike	233		
dip	85		
total seismic moment	$1.3x10^{26}$ dynecm		
	No. of division n x n	seismic moment dyne · cm	stress drop bar
1st. fault		$0.99x10^{26}$	252
2nd fault		$0.23x10^{26}$	163
3rd fault		$0.89x10^{25}$	63

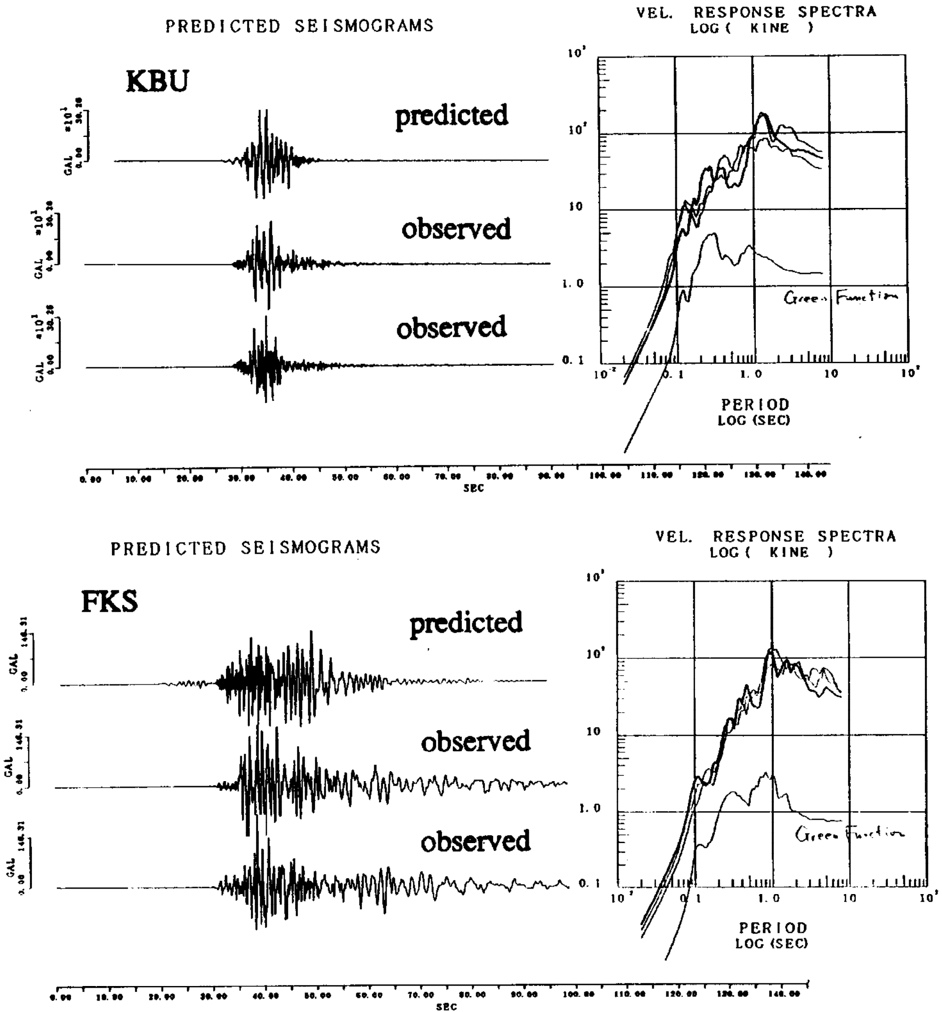


Fig.8. Synthsized and Observed wave and spectra.

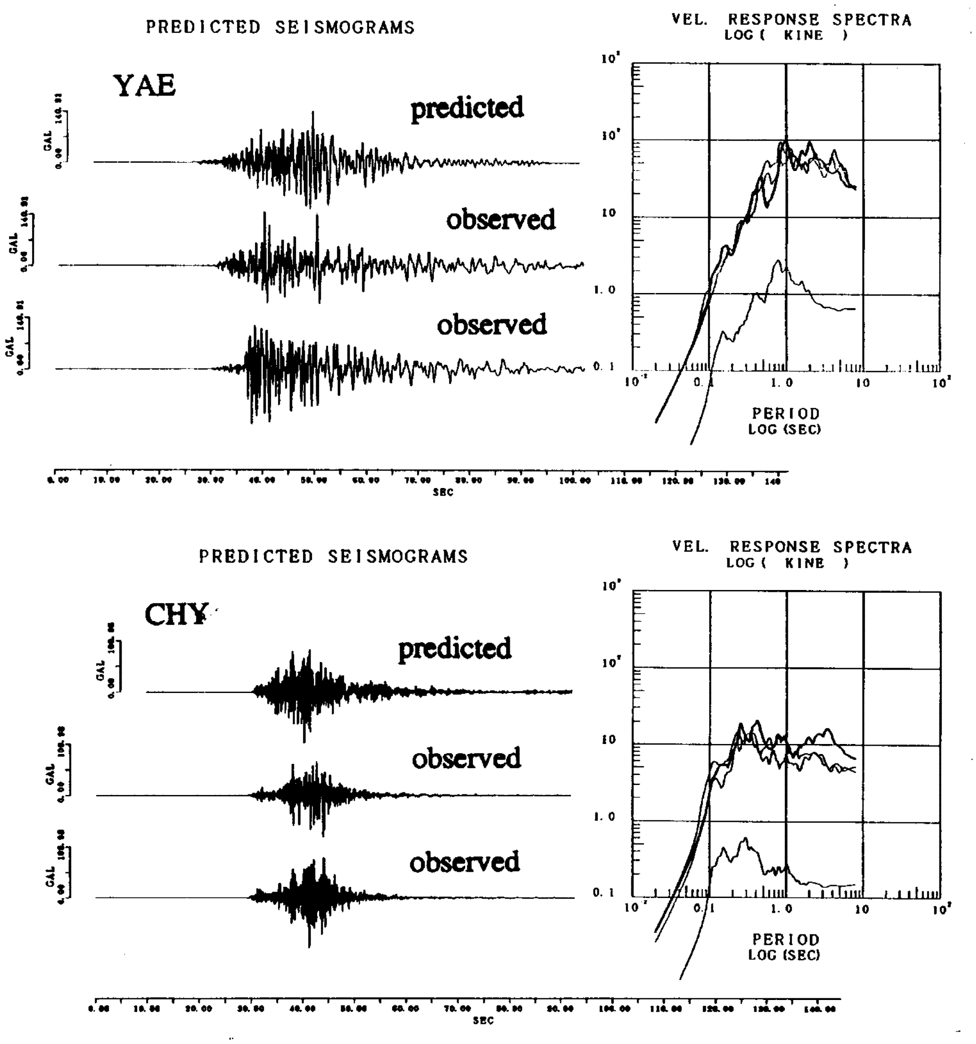


Fig.8. Synthsized and Obserbed wave and spectra.

CONCLUTION

Firstly, we studied the three effects of source, path and site effects at Kansai area using the observated records by the CEORKA. Secondly, we constructed the models of pathe-specific relation between Qs-value and frequency, site-specific amplifications G(f) and site-specific group delay time tgr(f). Then we could synthsize the artificial and stochastic Green function on time domain assuming ω -square law as the source effects. There we found that strong motion records during 1995 Hyogo-Ken-Nanbu Earthquake could be synthesized using the stochastic Green's function method. The agreement between synthesized and observed waves was very good for maximum value, duration and spectral content. We could conclude in sumary as follows,

(1) The source spectra of small earthquake(M=4.0~5.2) that happened at Kinki area are considered to be ω -square's scaling law.

(2) We constructed the relation between Qs-value and frequency, as like $Qs(f) \sim (frequency)^{-n}, n=0.85$.

(3) We found that there are the site-specific amplifications and the site-specific group delay time at the small events. And the model of both site-specific properties could be made in the empirical manner.

(4) We can say, as the site-specific amplifications, there are good agreement between empirical spectral ratio against rock site and separated site amplifications by inversion method.

(5) As the site-specific group delay time, we found that this idea is very good for expressing envelope and duration of the waveform at the special site.

(6) Lastly, we found that the stochastic Green's function method because of using site-specific waveform is very effective to predict strong ground motion.

We have gotten many effective and avilable results in this paper, but there are some problems left with us. Firstly we could not understand the relation between empirical and theoretical amplifications due to soil structure. But on the confined conditions, we will be able to explain the relation, for example by one-dimensional multi reflection method. Now new computer technique will be developed—three dimensional finite difference method. Secondly we have only knowlege of empirical amplifications and phase characteristics. It is important that we have compare the site-specific effect with the result of theoretical method, of cource with more advanced method.

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REFERENCES

Aki, K. (1967): Scaling relation of seismic spectrum. *J. Geophys. Res.*, 72.

Aki, K. (1980): Attenuation of sheare waves in the lithosphere for frequencies from 0.05 to 20 Hz. *Phys. Earth Planet.* 21.

Andrews, D.J. (1982): Separation of source and propagation spectra of seven Mammoth Lakes aftershocks. *Proceeding of workshop, Dynamic characteristic of faulting. U.S. Geological Survey Open File Report.*, 437.

Boore, D.M. (1983): Stochastic simulation of high frequency ground motions based on seismological models of the radiated spectra. *Bulletin of The Seismological Society of America*, 73, 1865-1894

Irikura, K. (1983): Semi-empirical estimation of stron ground motions during large earthquakes. *Bull. Disaster Prevention Res. Inst., Kyoto Univ.*

Irikura, K. (1986): Prediction of strong acceleration motion using empirical Green's function, *Proceedings of the Seventh Japan Earthquake Engineering Symposium*,151-156

Iwata, T. and K. Irikura (1988): Source parameters of the 1983 Japan Sea Earthquake Sequence. *J. Phys. Earth*, 36.

Kamae, K. and K. Irikura (1995): A fault rupture model of the 1995 Hyogoken-nanbu earthquake(Mjma=7.2) estimated by empirical Green's function method, *Journal of Natural Disaster Science*,vol. 16.

Katukura, H. *et al.* (1984): A study on the Fourier analysis of non-stationary seismic waves. *Proceeding of 8th World Conference on Earthquake Engineering*, vol. 2, 525-532.

Kimura, M. and M. Izumi (1989): A method of artificial generation of earthquake ground motion. *Earthquake Engineering and Structural Dynamics*, vol.18, 867-874.

Lawson, C. L. and R. J. Hanson (1974): Solving least squares problem. Prentice-Hill.

Ohsaki, Y. (1979): On the signification of phase content in earthquake ground motions. *Earthquake Engineering and Structural Dynamics*. vol.7, 427-439.

Tai, M., Y. Iwasaki and M. Oue (1992): Separation of source, propagation and local site effects from accelerographs and its application to predict strong motion by summing small events. *Proceedings of the Tenth World Conference on Earthquake Engineering*. Vol. 2. 747-750.

Tai, M. and M. Ozaki (1995): A study of site effects by empirical group delay time.