13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 791

A STUDY ON WAVEFORM INVERSION WITH SIMPLYFIED SOURCE MODEL USING GENETIC ARGORITHMS

Kentaro MOTOKI[1], Hiroaki YAMANAKA[2] and Kazuoh SEO[3]

SUMMARY

The heterogeniety of source process is very important for estimation of strong motions near the source regions or large earthquakes. In order to obtain the heterogeniety, a number of studies have been made on detailed source processes for the past few decades since Hartzell and Heaton(1983) and Olson and Apsel(1982) developed source inversion methods. There are some difficuilties to deal with many parameters and use least square method. In this study, we suggest to calculate characterized source model directly with the most simplified model using genetic algolithms.

INTRODUCTION

The heterogeniety of source process is very effective for estimation of strong motions near the source regions or large earthquakes.In order to obtain the heterogeniety, a number of studies have been made on detailed source processes for the past few decades since Hartzell and Heaton(1983) and Olson and Apsel(1982) developed source inversion methods. This resultant source model are regarded as one of the most appropriate models. For Kobe earthquake, Several model were published (e.g. Sekiguchi(2000)) and Takemura(1998) discussed the differences and the commons between them. We can say reasonable that the models approximate to each other by and large, and lots of differences can be found in detail due to differences of records of strong motions, models of underground structure and modelizations. The differences results from the produres; the source time functions for every subfault devided whole of the fault model equally are calculated. According to Yoshida (1995), such kind of inversion come to ill-condition model and reduce stability caused from a large number of unknown parameters against the number of observation data. To suppress instability, constaraints need to be added. On most of studies, smoothing operation were imposed as the constraint for time and spatial domain. Therefore, the consequent resolution come down than given a grid size against time and space, and the result cannot represent in detail as mentioned above. The source models calculated for past earthquakes are used as basic materials to estimate for future earthquakes. The characterization suggested by Somerville et. al. (1999) were performed to simplify the calculated source models, because of difficulty to compile them as it is. The criteria of it are not based on physically aspects and cannot be said that it is proper to make simple models. In this study, we suggested to calculate characterized source model directly with the most simplified model, that is point source, to make an basic material for future earhtquake. model using genetic algolithms. In this paper, we tried our developed method for Kobe earthquake, because the

[1]Research Assoc., Tokyo Institute of Technology, Japan, Email: kmoto@enveng.titech.ac.jp
[2]Assoc. Professor, Tokyo Institute of Technology, Japan, Email: yamanaka@depe.titech.ac.jp
[3]Professor, Tokyo Institute of Technology, Japan, Email: seo@enveng.titech.ac.jp

earthquake is the most devastating for recent 50 years, and it is to be desirable to analyze the causes as simple as possible.

METHOD

The source behavior in the inversion problem is parameterized to the moment rate tensor as a function of time and space. In general, the fault model are devided into subfault, and the source time function for each subfault along 2 slip direction are allocated as unknown parameter. In addition to space, the heterogeniety of time domain can be represented by history with time window. In the case of M7 earthquake, the number of subfault may reaches to 100, and if the number of time window is set to 5, the number of parameters to solve amounts to about 1000. A lot of parameter can be solved using least square method with some constraints which are smoothing or non-negative operator as mentioned above. However, we have some difficuilties in practical applications of linearized least square inversions. They are mainly on numerical instability in calculating inverse matrix and on preparation of an appropriate initial model. In order to solve these difficulties, we adopt genetic algolithms (GA) as a heurstic search method. The algolithms were developed to study artificial intelligence by Holland (1975). Yamanaka and Ishida (1996) successfully calculated the model underground velocity structure using GAs with phase velocity based on microtremor array exploration. The misfit ***E(m)*** for the model, ***m***, is calculated from

$$E(m) = \frac{1}{N}\sum_{j=1}^{N}\left|\frac{F_j^c - f_j^o}{\sigma_j}\right|^2$$

where F^c and f^o are synthetic velocity and observed velocity at j-th station, and σ and N are standard deviation and the number of observed data, respectively. We set moment rate function superposition of overlapping isoscales triangles as shown in Fig. 1 (right) along conventional procedure and we can choose the amplitude for each time window and the location of the point sources in fault plane as shown in Fig. 1 (left). To begin with the inversion, the Greens functions from each subfault to each observation staion must be calculated. Namely, the point sources can move only on for each release point. The dx and dy in Fig. 1 are set to 1 km for the inversion. The synthetic waveforms can be calculated as follows

$$F_j^c = \sum_{k}^{N_{asp}}\sum_{l}^{2}\sum_{m}^{N_{tw}} X_{klm}\, g_{jkl}\left(t - \tau_{lm}\right)$$

$$\tau_{lm} = L_k / Vr + (m-1)\tau$$

where N_{asp} and N_{tw} are the number of asperities and time windows, and $g_{jkl}(t)$, Lk, Vr and τ are Green's function for j-th direction of observation, k-th asperity and along l-th slip vector, the distance from hypocenter to the point source, rupture velocity which yield the start timing to release and time increment of time window, in this paper 0.6 s, respectively. Vr are fixed at 2.8km/s, which is about 80% of S-wave velocity. We use the reflectivity method exteded by Kohketsu (1985) as Green's function, which represents g(t) in above formula. We did not perform smoothing mentioned above at all.

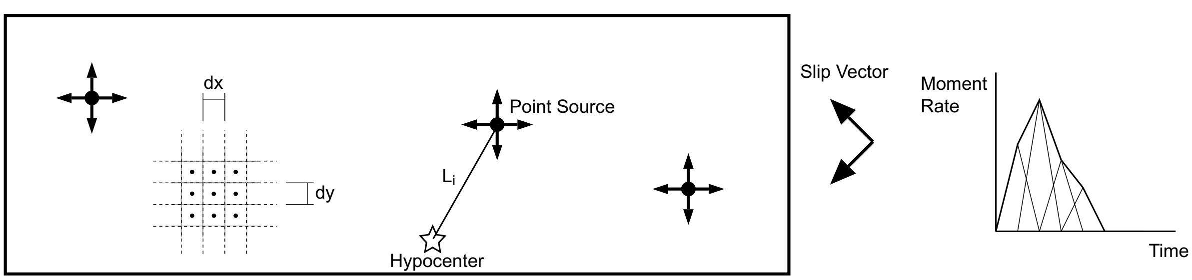

Fig. 1 Schematic Image of point souces model adopt in this study. The point sources can move only on release point on which Green's function were calculated in advance.

DATA

We used strong ground motion records observed by Committee of Earthquake Observation and Research in the Kansai Area (CEORKA) and Japan Meteorological Agency (JMA) for analysis and the locations of the stations are shown in Fig. 2. The distribution of stations covers evenly all direction from the source and the epicentral distances are less than 150km. However, the number of records near the source region is small. Although KOB sites are on the diluvial deposits and are affected by the amplification of the edge effect (Kawase(1996)), it is one of the most important station because it locates the closest from the source, and the record reflects source behavior the most directly. From this point of view, the records of closer stations are the key to clearing source process. Hence, several near source stations (AWA, KBU and KOB) are doubly weighted in the inverstion. The seismograms recorded by accelerographs shown in TABLE 1 were numerically integrated to obtain the velocity waveforms. The resultant velocities are band-pass filtered between 0.1 and 1.0 Hz and sampled with an interval of 0.2s for closer stations of which weight is twice, while between 0.1 and 0.4 Hz and 0.5s were applied to the other stations. In calculation of the Green's functions, frequency range are used same to the observed data. We adopt the stratified velocity structure model shown in TABLE 2, which was based on refraction experiments (Aoki and Muramatsu(1974))

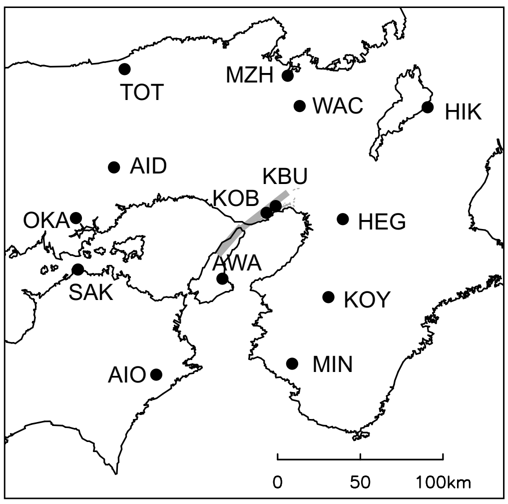

Fig. 2 Distribution of observation stations. The distribution can covers evenly every direction.

TABLE 1 Strong motion records list used in this study

Name	Latitude	Longitude	Seismograph	Using Component
AID	34.940	134.168	Acc	EW UD
AIO	33.792	134.452	Acc	EW UD
AWA	34.336	134.908	Acc	EW UD
HEG	34.653	135.685	Acc	EW UD
HIK	35.273	136.247	Acc	EW NS UD
KBU	34.725	135.240	Vel	EW NS
KOB	34.688	135.180	Acc	EW NS UD
KOY	34.218	135.593	Acc	EW UD
MIN	33.850	135.353	Acc	EW UD
MZH	35.449	135.321	Acc	EW NS UD
OKA	34.659	133.919	Acc	EW NS UD
SAK	34.373	133.932	Acc	EW UD
TOT	35.486	134.240	Acc	EW NS UD
WAC	35.283	135.402	Acc	EW UD

TABLE 2 Velocity Structure

H(km)	Vp(km/s)	Vs(km/s)	ρ(g/cm3)	Qp	Qs
2.0	5.5	3.2	2.6	300	150
20.0	6.0	3.46	2.7	500	250
10.0	6.6	3.81	3.0	800	400
∞	7.8	4.5	3.2	1000	500

RESULTS AND DISCUSSION

The search areas given are in fault plane for the location and between 0 and 6×10^{18}dyncm for seismic moment for each subfault and each time window. And the area are devided with 8-bit code for seismic moment and with 4-bit and 6-bit for dip and strike directional space on fault. We used 500 models for the population and 0.9 for the probability for crossover. Initial the probability are set to 0.3 and decrease exponentially along generation. We tried the inversion for 2 asperities and 6 time windows, first. The total length of the bit string is 212 bits for a model. The calculations finished at 5000th generation. The comparison of observed waveform and synthetic one with the inversed model are shown in Fig. 3. On some station e.g. OKA, we obtained good fitting, but the synthetic and

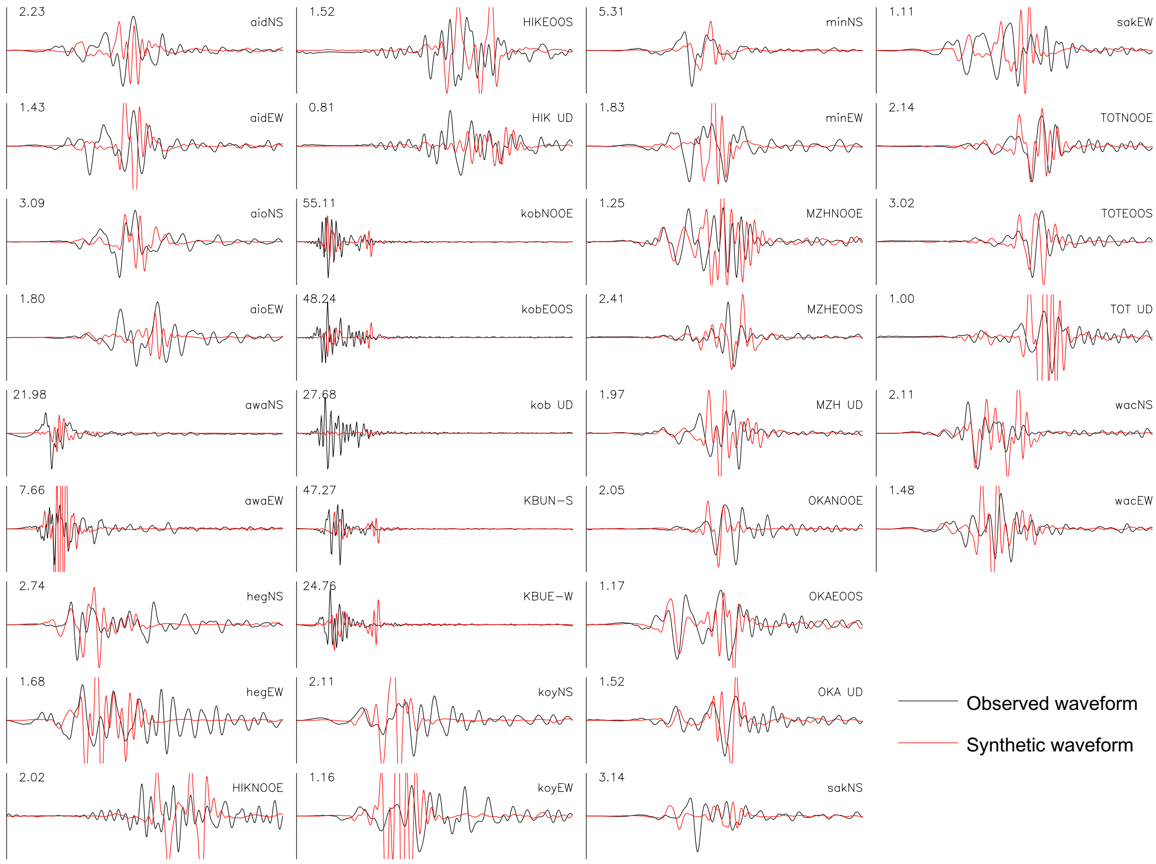

Fig. 3 Comparison of synthetic and observed waveforms.
The synthetic are based on 2 asperities inversed directly.

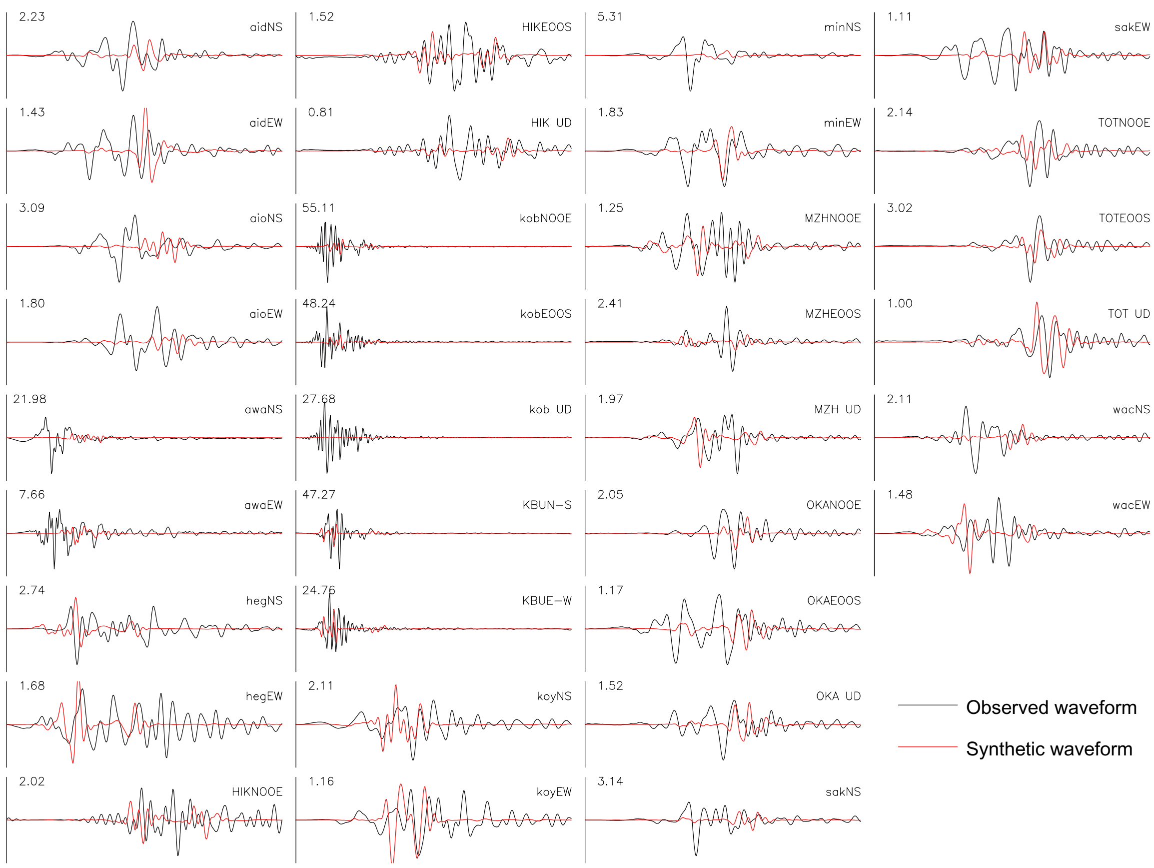

Fig. 3 Comparison of synthetic and observed waveforms.
The synthetic are based on connecting asperities.

observed waveform do not resemble each other by and large. We cannot say it is successfully inversed. The reason why inconsistency can be considered that ill-modelizations which are due to Green's function and simplification, or lack of population, mutation and generation even same parameter to successfully done in numerical test. In order to clarify which the reason lies on, I made inversion on other model which is for 1 asperity and 6 time windows. And we connect the models when the location is different. The resultant synthetic waveforms are rather small, but better than the previous model. If we put long generation and numerous population at the expence of time, we must be able to calculate the better or equal than connecting model with 2 asperities, because the connecting model is essentially same to 2 asperities model. Such kind of parametric study is necessary for inversion.

CONCLUSION

We performed the waveform inversion using genetic algolithms. This inversion result cannot get good fitting. Parametrical study concerned with inverse problem is necessary to obtain appropriate source process. Besides, developments from point source model to asperity model make it realistic model which can apply to estimation for future earthquakes.

ACKNOWLEDGEMENTS

We thank the Committee of Earthquake Observation and Research in the Kansai Area and the Japan Meteorological Agency for providing the strong motion data. The Research was partially supported by the Minisry of Education, Science, Sports and Culture-in-Aid for Young Scientists (B), 15760423, 2003.

REFERENCES

1. Hartzell, S. H. and T. H. Heaton, Inversion of strong ground motion and teleseismic waveform data for the fault rupture history of the 1979 Imperial Valley, California, earthquake, Bull. Seism. Soc. Am., 73 1553-1585, 1983.
2. Olson, A. H. and R. J. Apsel, Finite faults and inverse theory with applications to the 1979 Imperial Valley earthquake, Bull. Seism. Soc. Am., 72, 1969-2001, 1982
3. Sekiguchi, H., K. Irikura and T. Iwata, Fault geometry at the rupture termination of the 1995 Hyogo-ken nanbu earthquake, Bull. Seism. Soc. Am., 90, 117-133, 2000
4. Takemura M., Review of source process studies for the 1995 Hyogo-ken-nanbu earthquake part. 1 results from waveform inversion, Programme and Abstracts The Seismological Society of Japan, A49, 1996 No.2, (in Japanese)
5. Yoshida S., Waveform inversion methods for the earthquake source, J. Phys. Earth, 43, 183-209, 1995
6. Somerville, P., K. Irikura, R. Graves, S. Sawada, D. Wald, N. Abrahamson, Y. Iwasaki, T. Kagawa, N. Smith and A. Kowada, Characterizing crustal earthquake slip models for the prediction of strong ground motion, Seism. Res. Lett., 70, No.1, 59-80, 1999
7. Holland, J. H., Adaptation in natural and artificial systems, University of Michigan press, Ann. Arbor, MI. 1975
8. Yamanaka H. and H. Ishida, Application of genetic algolithms to an inversion of surface-wave dispersion data, Bull. Seism. Soc. Am., 86, 436-444, 1996
9. Koketsu K., The extended reflectivity method for synthetic near-field seismograms, J. Phys. Earth, 33,121-131, 1985
10. Kawase H., The cause of the damage belt in Kobe: the basin-edge effect constructive interference of the direct S-wave with the basin-induced diffracted/Rayleigh waves, Seism. Res. Lett., 67, No.5, 25-34, 1996
11. Aoki H. and I. Muramatsu, Crustal structure in the profile across Kinki and Shikoku, Japan, as derived from the Miboro and the Toyama explotions, Zishin, 27, 104-109, 1974 (in Japanese)