STANDARD BASIN STRUCTURE MODEL CONSTRUCTION AND STRONG GROUND MOTION SIMULATION

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SUMMARY

Basin structure information together with the source models and waveform data were collected for the simultaneous simulation for the 1995 Hyogoken-Nanbu (Kobe) earthquake. This simultaneous simulation is conducted as a special session of the 2nd International Symposium on ESG98. We compiled geophysical survey results (mainly reflection surveys) which have already been opened to public and successfully constructed the basin structure model (P- and S-wave velocities and density) in Kobe. Based on the basin structure information, the three-dimensional basin structure model was constructed. We estimated strong ground motions in near-source area in Kobe-Hanshin region with using the basin structure and irregular source model. Wavefield calculations were done by the three-dimensional FDM. Our modeling is limited up to 1.0Hz and lowest S-wave velocity of the superficial layer is 600m/s because of the velocity structure information and/or computer limitations. Nevertheless, synthetic waveforms from this low-frequency modeling agree fairly well with the observations whose peak frequency are less than 1.0Hz. Obtained maximum horizontal velocity distribution is well related to the earthquake damage distributions. In Kobe case, finite source extension, amplification by the thick sediments, and basin-edge effects control near-source ground motions. These results show that the theoretical modeling is quite useful for the strong motion predictions.

INTRODUCTION

The Hyogoken-Nanbu (Kobe) earthquake of Jan. 17, 1995, struck Awaji-Kobe-Hanshin area and this medium-size earthquake (M_{JMA} 7.2 and Mw 6.9) generated huge earthquake disaster in near-source region. Observed maximum ground velocities and accelerations matched well the existing empirical attenuation relation [e.g. Irikura and Fukushima, 1995]. It means that the ground motion itself from this earthquake was not a special one, and some level of destructive ground motions could be expected in near-source area during future inland earthquakes similar of this size.

After the event, many researchers have modeled the source process and strong ground motions in near-source area and we learned that forward rupture directivity effect of the source and basin-edge effect (constructive interference between edge-diffracted waves and direct S-waves vertically propagating from the basin bottom) strongly influenced to generation of large earthquake disaster [e.g. Irikura et al.,1996; Kawase, 1996; Kawase et al.,1997; Pitarka et al.,1998].

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The Committee of Japanese National Working Group of ESG planed the session for simultaneous simulation experiment for Kobe during the 2nd International symposium on Effects of Surface Geology on Seismic Motion, which was held in Dec., 1998, Yokohama, Japan. Our aims were to make clear subjects related to prediction of strong ground motions, to recognize our status for theoretical strong ground motion modelings, and to find the effective way to the reliable prediction of strong ground motions. Rule of this simultaneous simulation for Kobe was that (1) strong motion data and geological information collected and prepared by the organizer will be open to participants. (2) The participants were requested to simulate waveforms at several target sites by their own methods and send it to the Committee. (3) The Committee reported the comparison between simulated results and observed ones in the session. This article summarized the distributed strong motion data and geological structure information.

DISTRIBUTED DATA FOR SIMULTANEOUS SIMULATION AND RULES

Strong Motion Data

Strong motion data were collected from 26 stations (JMO and OSA are overlapped) in Kobe-Osaka area as shown in Fig.1. It is noticed that all the stations except RKI and KBU are set on the free field or basement of the lower story buildings. The station KBU is located in the observational tunnel which in the reclaimed layer on the weathered rock. Depth of the station is about 10m from the surface. The station RKI is located on B1F of 40-stories sky-scraper building with a height of 130m. Not only mainshock data but also aftershock data were gathered when they can open the data. Hypocenter information of the mainshock and the aftershocks by Japan Meteorological Agency was distributed. In Fig. 2, original records of the mainshock at near-source stations, which were distributed, are shown as an example. All instruments have a flat amplitude response and negligible phase delay in the frequency range of interest.

Source Models from Waveform Inversion

For the simultaneous simulation, we prepared four source models by waveform inversion method. Wald (1996), Yoshida et al.(1996), and Sekiguchi et al.(1996, 1998) provided source models of the Hyogoken-Nanbu earthquake. Sekiguchi et al.(1996, 1998) used only near-source strong motion data. Wald (1996) and Yoshida et al.(1996) used not only strong motion data but also tele-seismic and geodetic data for source inversion. All use the multi-time window method for source inversion, which was proposed by Hartzell and Heaton(1983). Digital forms of source parameters were distributed. Assumed fault geometry, treated frequency range, parameter number and smoothness conditions are different each other. Nevertheless, their results are similar in the macroscopic sense. Sekiguchi et al.(1998) improved their model (Sekiguchi et al., 1996) assuming five segment fault model. For source parameters such as focal mechanisms of the aftershocks, we distributed the ones obtained from polarity of P-wave onset (Katao et al.,1997) and from seismic moment tensor inversion using near-source waveforms (Nakagawa and Iwata, 1996).

Underground Structure Information

Basin edge structure in Kobe area was explored by dense reflection surveys. The aim of them is to explore the buried faults beneath the large disaster area. Cross sections of reflection surveys can be used for constructing underground velocity structure models. The LOC committee prepared those cross section information together with the model studies of Osaka basin.

General information on Osaka basin:
General overview on the formation of the Osaka basin is introduced by Ikebe et al.(1970) and Map of the ground of Osaka (1987). The Osaka basin is surrounded by Ikoma (East), Hokusetsu (North), Rokko (North-West), Awaji-shima (West), and Kii (South) hills whose heights are less than 1km. The shape of the Osaka basin is elliptical with the length of about 60km in NE-SW direction and the width of about 40km. This basin is bounded by active fault systems. Most of these active faults are reverse type ones and basin-edge are very deep (more than 0.5km at most part of the edges). Inside the Osaka basin, there are two significant faults named Uemachi fault system and Osaka-Bay fault.

Deep Sediment Structure of the Osaka Basin:
Kagawa et al.(1993) proposed a Osaka basin structure model for long-period waveform modeling. They compiled underground structure information from reflection and refraction surveys, gravity anomaly map, boring, microtremor array measurements, and surface geology and made the underground structure model of the basin. Miyakoshi et al.(1997) improved the model proposed by Kagawa et al.(1993) with adding the new information of many reflection surveys in Kobe area. The maximum thickness of the sediment is about 3km near the center of the Osaka basin. They used two-dimensional B-Sprine functions of the 3rd order to express layer boundary shapes, and so their model can not explain well the real structure near the basin-edge and buried faults in the middle of the basin (e.g. the Osaka-Bay fault and the Uemachi fault). The Organizer of Simultaneous Simulation for Kobe offered the underground structure model of the Osaka basin proposed by Miyakoshi et al.(1997) as a standard underground structure model.

For the Simultaneous simulation, we set up two simulation lines, one in Kobe and the other in Osaka. In Fig. 3, we show the simulation lines. We also distributed fine structure information to the participants near the simulation lines. For the simulation line in Osaka, papers related to the modeling of ground motion (Hatayama et al., 1995) and summary of underground structure by reflection surveys (Horike et al., 1995, 1996) were referred. For Kobe, after the Kobe earthquake, several organizations explored underground structure by reflection and refraction surveys and boring experiments. The Organizer of Simultaneous Simulation for Kobe distributed time and depth sections of major reflection survey lines (Great Hanshin-Awaji earthquake disaster and movement of Rokko hills, -Report on active underground structure in Kobe area-, 1997), together with the brief English captions because most of them are Japanese articles. As for the basin-edge structure modeling near the target site, the articles of Kawase (1996), Pitarka et al.(1996) and Pitarka et al. (1997) were distributed. Those who wanted to simulate strong ground motions in Kobe using the detailed structure near the edge could refer to the reflection cross sections.

Rules for Simultaneous Simulation for Kobe

The target sites at which participants were requested to calculate their own synthetics. Only some of them have strong motion records of mainshock and aftershocks. Among the target sites, six were in Kobe and six in Osaka. To submit mainshock synthetics at these target sites was compulsory, while to submit mainshock synthetics at other sites or aftershock synthetics were optional. We did not restrict the method to be used. We also asked the participants to submit a paper which describes the methodology, assumptions, and the calculated results. We recommended to use one of the well-constrained inversion results if you needed to consider the source effects. Data on the CDROM and printed materials were distributed on early May, 98 and the S. S. participants submitted the synthetics as a digital form together with their paper [Irikura et al., 1999]. Summaries were also reported in the proc. of ESG98 [Irikura et al., 1999] and by the accompanied paper [Kawase and Iwata, 1999].

UNDERGROUND STRUCTURE MODELING AND GROUND MOTION SIMULATION

Modeling of Source and Underground Structure

In this chapter, we show the results of our study submitted to the simultaneous simulations for Kobe [Iwata et al.,1999], as an example. The source model we used here was obtained by Sekiguchi et al. (1998), one of the distributed source data. The rupture started beneath Akashi strait and propagated bi-laterally. Large moment release areas are seen near the hypocenter, at the shallow part of the Nojima fault and at deep beneath Kobe downtown. Additionally, there are some seismic moment releases on the segments D (it could be related to the quaternary Gosukebashi fault) and E (Okamoto Fault). This source model was obtained by the strong motion data of velocity within the epicentral distance of less than 200km and effective frequency range is limited from 0.1 to 1Hz.

For underground structure modeling, we mainly referred to the distributed information. Additionally using several published reports and papers [reports in Huzita, 1996; Yokota, 1997; Kobe city and Institute of Construction Engineering, 1998, Sato et al., 1998], we made the bedrock topography model. In Fig. 4, we show our model area used here and contour map of bedrock topography together with target sites for the S.S. Kobe. We did not consider the surface topographic effects though the Rokko hillside (North-Western direction of the basin-edge) has some altitude and irregular topography. Velocity and density parameters are basically assumed based on the results of Miyakoshi et al. (1997). Because of the limitation on model size for numerical calculation and the limitation on the low-frequency source model (<1.0Hz), we used two-layer sediment model whose S-wave velocities are 0.6km/s and 1.1km/s, respectively. We assumed the thickness of the 1st and 2nd layers to be the same value. For deeper structure, we adopted the velocity structure of upper crust that is used to determine hypocenters in Kinki area by RCEP-DPRI, Kyoto University.

Simulation Result of Strong Ground Motions at S.S. Kobe Sites

Using the heterogeneous source and underground structure models, we simulated strong ground motions by three-dimensional Finite Difference Method [Pitarka et al., 1998]. Grid spacing is 120m and size of simulation area is 58km in length, 13.6km in width and 23km in depth, as shown in Fig.4. Simulation frequency range is between 0.1 and 1.0Hz. Half number of point sources on the segment A are out of the our model region, as shown in Fig.4, which were omitted in our simulation. Pitarka et al.(1998), Iwata et al.(1998a), Sekiguchi et al.(1998) have already shown that effects of the segment on waveforms in Kobe downtown area are negligible. In Fig. 5, we show the simulated velocity waveforms at six target sites of SS Kobe. For sites of KBU and RKI, we put together the (filtered) observed velocity waveforms by dotted lines. N352E and N082E component records at RKI are treated as N000E and N090E components for plotting, respectively. In Fig. 5, duration of waveforms become larger as sites move from KBU to RKI sites because of the basin-effects. In our simulation, NS component of KB2 site has the maximum value of about 90cm/s. At RKI, maximum horizontal velocities of simulated waveforms of two components are smaller than those of observed, this also occurred at KBU. Concerning waveform, simulation and observation are similar and this means that 3D underground structure modeling is fairly acceptable on the point of the generation of basin-induced and/or basin-transmitted waves seen in the frequency range of our simulation. However, our basin model still seems to be insufficient for quantitative evaluation.

CONCLUSIONS

We show the simulation rules and distributed data of the Simultaneous Simulation for Kobe during 2nd ESG International Symposium. We also show the study of our group on the underground structure construction and simulation results of strong ground motions at SS Kobe sites using the heterogeneous source model and underground structure model by three-dimensional FDM. Discussion about the source and underground structure effects on ground motions in near-source area are done. Although theoretical modeling is still limited in the lower frequency range of up to about 1Hz, characteristics of destructive ground motions in near-source area are well understood through this Kobe experiment. Knowledge from this experiment will strongly help the progression of precise strong ground motion modeling. Moreover, we learned that key factors for reliable prediction of strong ground motions for scenario earthquakes are construction of fine underground (especially, basin) structure model and source characterizations that include irregular source ruptures. Those basin structure models should also be validated through the waveform simulations.

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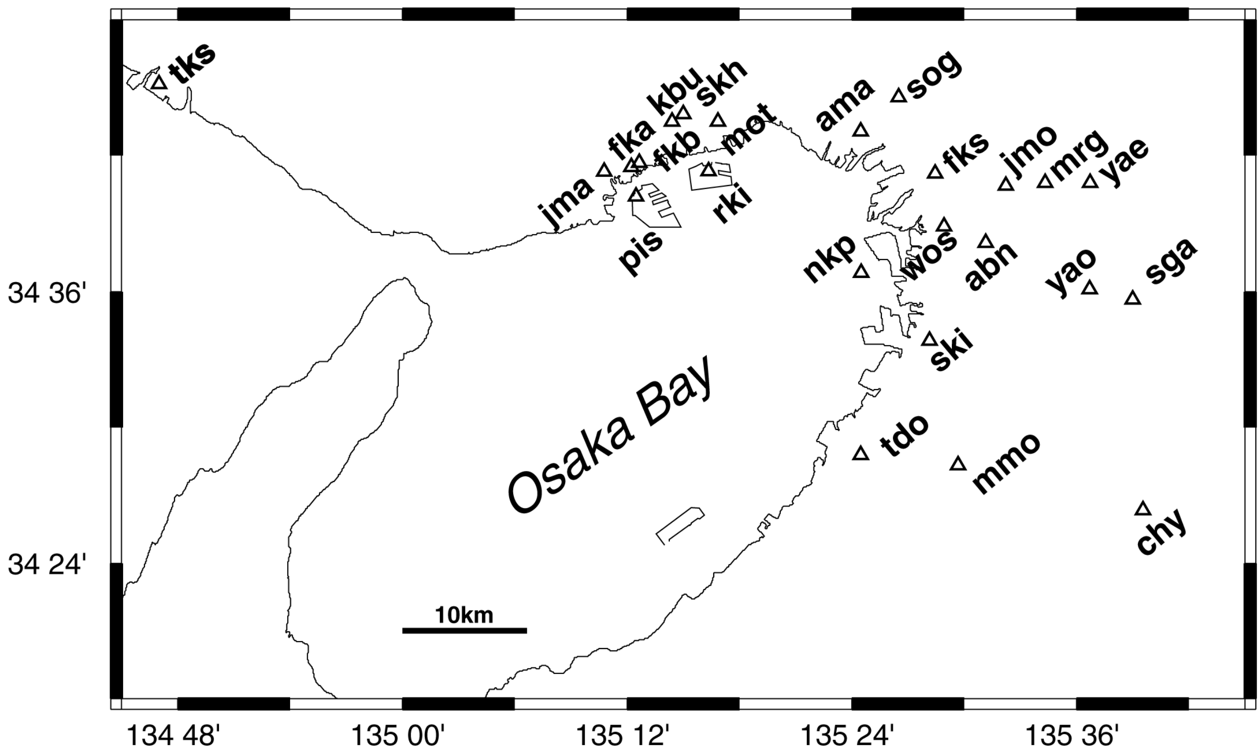

Fig.1 Map of observation stations of strong motion. Data at these stations (mainshock and aftershocks) were distributed to the simultaneous simulation participants.

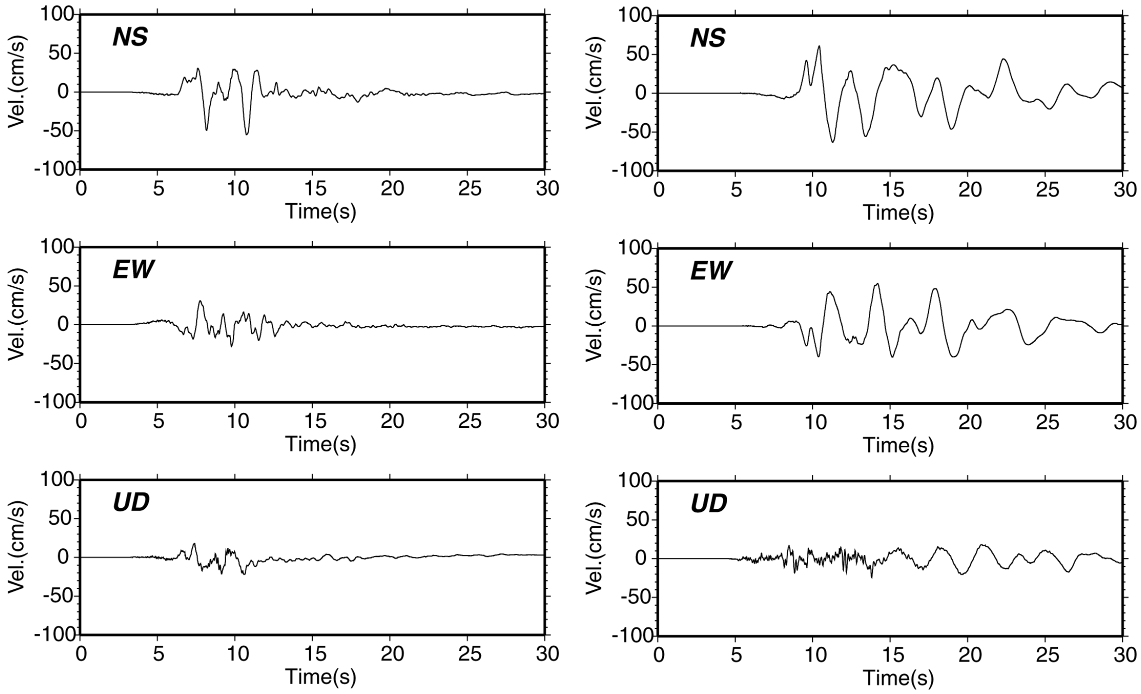

Fig. 2 Examples of velocity waveforms observed at KBU (left) and RKI (right) during the mainshock.

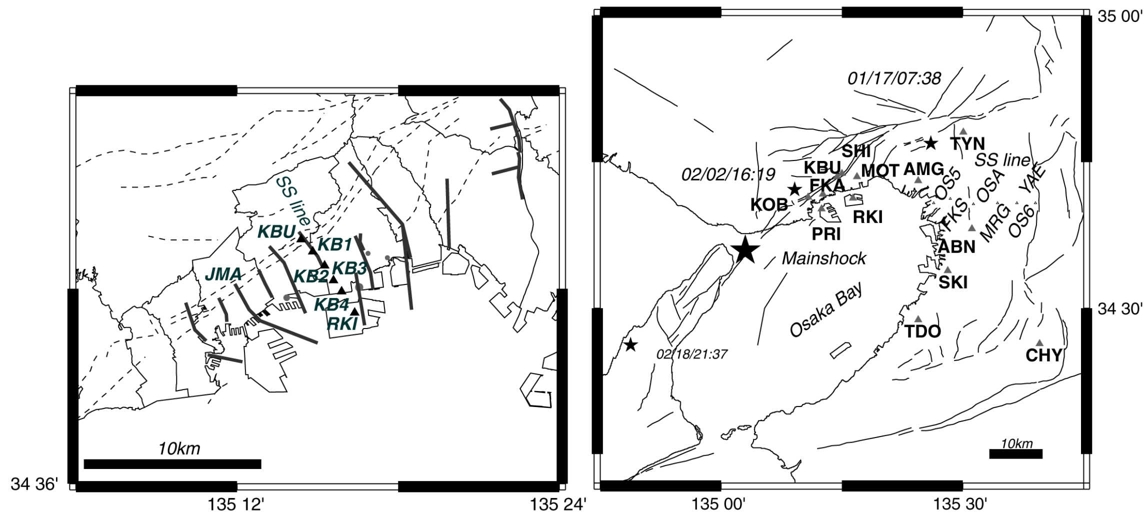

Fig. 3 Map of target sites for the simultaneous simulation for Kobe (left) and Osaka (right). The sites named KBU, KB1, KB2, KB3, KB4, and RKI were the target sites for Kobe and those OS5, FKS, OSA, MRG, YAE, and OS6, for Osaka.

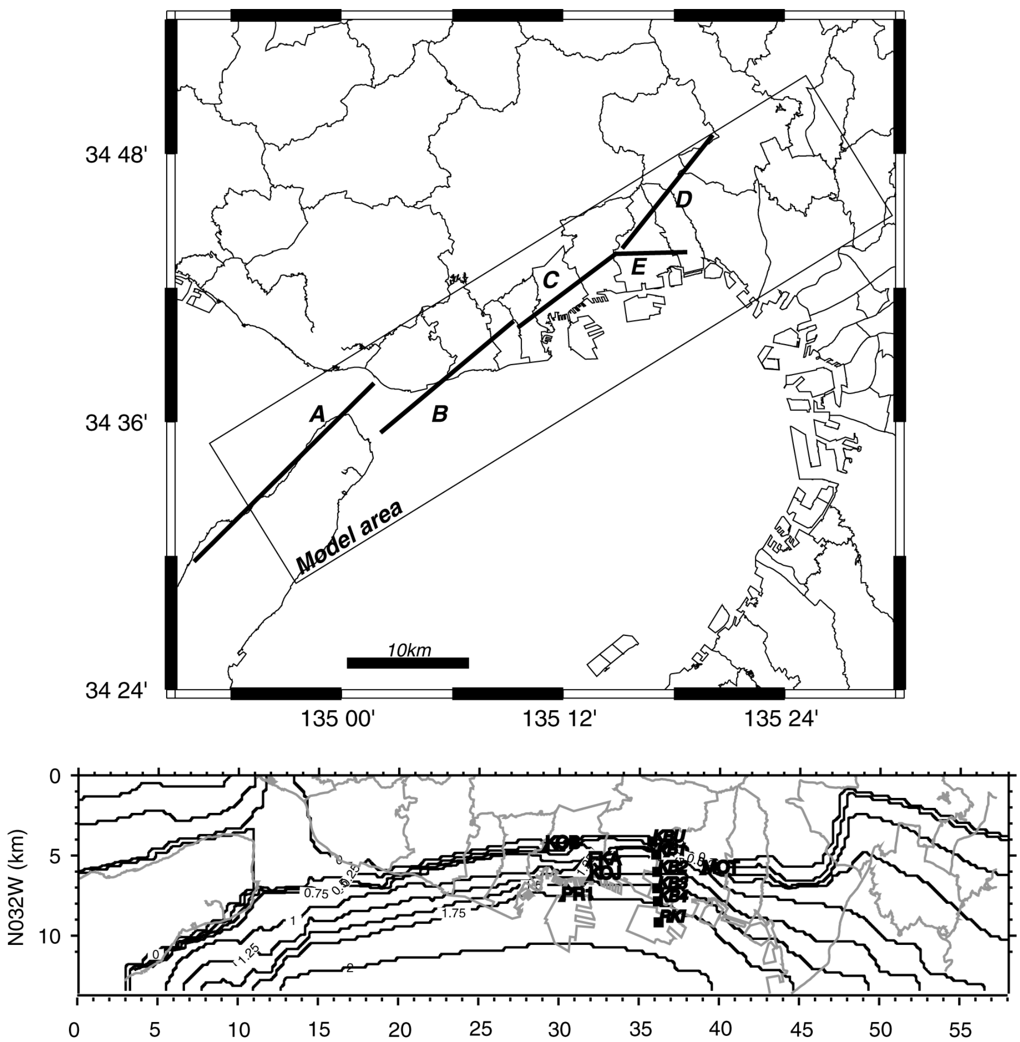

Fig. 4 Upper: Model area for 3D simulation. Lower: Contour map of the bedrock topography of basin structure model in this study. Squares show the target sites for the simultaneous simulation for Kobe.

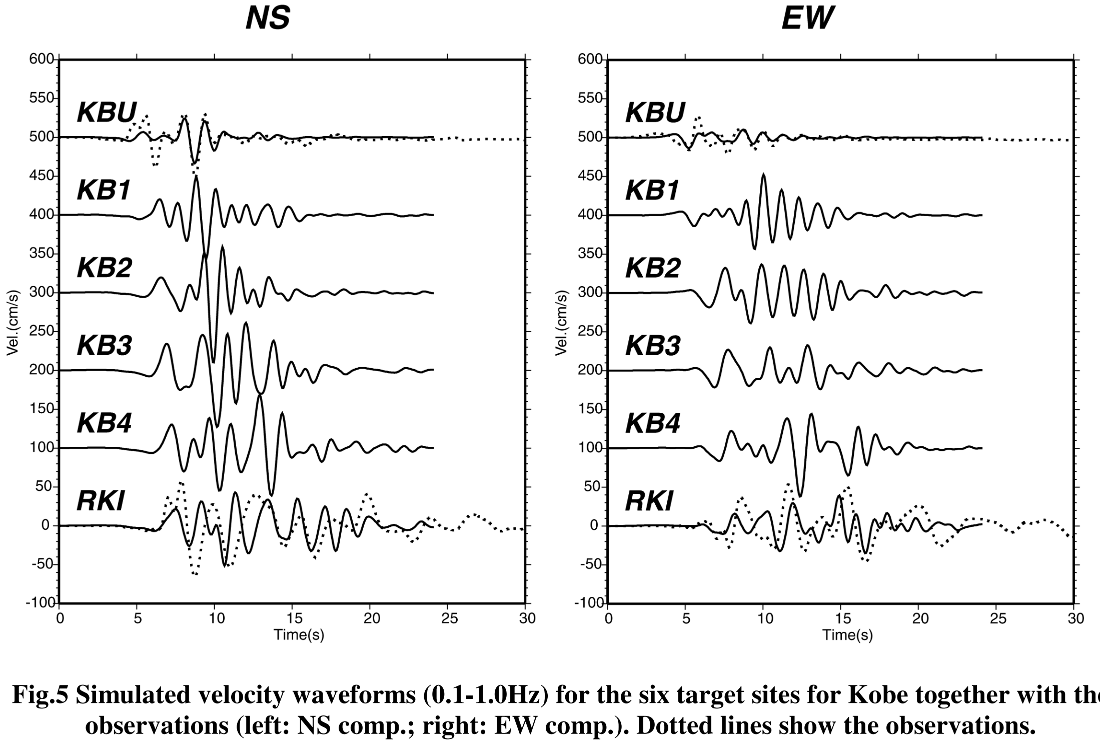

Fig.5 Simulated velocity waveforms (0.1-1.0Hz) for the six target sites for Kobe together with the observations (left: NS comp.; right: EW comp.). Dotted lines show the observations.