THREE-DIMENSIONAL FINITE DIFFERENCE SIMULATION OF LONG-PERIOD GROUND MOTION IN THE KANTO PLAIN, JAPAN

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SUMMARY

This study tried to simulate the long-period earthquake motion around the Kanto plain, Japan by using a 3D finite difference technique. First, we investigated characteristics of long-period ground motion observed in the basin during a moderate event with a shallow focal depth. It was found that the long-period motion of a dominant period of 7sec is composed of surface waves. Next, we conducted finite-difference simulation using three existing basin models constructed from seismic refraction data, geology data and microtremor data. The simulations using models from geology data and microteremor data lead similar waveforms to observed data which have a long duration and large amplitude of the dominant a period of 7 sec.

INTRODUCTION

Kanto plain in Japan is a very large and deep sedimentary basin. The basin has a size of 200km×200km, and a depth of more than 4km. It shows a very complex structure, especially the topography of the basement with an S-wave velocity of 3km/s. Long-period earthquake motion at periods of 5 to 10sec were frequently dominant in observed records at sites in the basin. Such long-period ground motions were interpreted as surface waves, which are significant during shallow earthquakes. For example, Yamanaka *et al.* (1992) indicated that long-period motion due to a shallow event is composed of surface wave amplified by the deep sediment any layers. These observational studies suggested that 2D or 3D effects of irregular structure of a basin must be included in understanding characteristics of long-period motion in a basin. Accordingly, some studies conducted 3D simulations for earthquakes in the Kanto basin by considering a 3D underground structure [e.g., Sato *et al.*, 1999]. Recently, an increase of explorations of subsurface structure and records of strong ground motion in the basin make it possible to validate 3D simulation techniques including models for source and subsurface structure.

The aims of this study are to understand of the characteristics of long-period seismic wave propagation and to validate existing 3D models for the Kanto basin by a comparison of synthetics by 3D finite difference method with observed earthquake ground motions.

OBSERVED GROUND MOTION

An investigation area in this study indicates the southwestern part of the Kanto plain as shown in Fig. 1. Black squares in the figure are K-NET (Kyoshin NET) stations where a strong motion accelerograph was installed by NIED (National Research Institute for Earth Science and Disaster Prevention). In this study, we investigated the earthquake ground motion observed in K-NET during a shallow earthquake at the east of Izu Peninsula in May 1998 with a depth of 3.1km. The earthquake was the largest event (MJMA=5.7) in a chain of the earthquake swarm in 1998. 16 stations of 18 stations in Fig. 1 are triggered. Unfortunately, stations at Yokohama and Misaki

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were not triggered.   The observed waveforms in the north-south directions are shown in Fig. 2. All the traces in the figure indicate displacements by twice integration and band-pass filtering in a period range between 3 and 10 sec. The record at Ito site is dominated by one pulse with a large amplitude. The record at Atami has a small amplitude, because it is located on a hard rock. The records at sites in the center of the Kanto basin (ex. Futamatagawa and Kawasaki) have very large amplitudes with a dominant period of about 5 to 10sec and the long duration, especially in the later phases. Previous studies on long-period ground motion in the Kanto basin [e.g., Yamanaka et al. 1992] indicated that the phenomena are caused by the effect of the basin structure. We expect that the result of simulation includes the characteristics of the wave propagation as well as previous studies, and we can get information for a realistic 3D model by the simulation using the difference models.

SIMULATION MODEL

3D underground structure

We examine the performance of three different 3D underground structural models for the Tokyo Metropolitan area to simulate the earthquake. The two models are taken from refraction data by Koketsu (1995) and from geological data by Suzuki (1999). The last one is S-wave velocity structure contour which was made by compiling considering 1D S-wave profiles from array measurements of long-period microtremors in the basin [e.g., Yamanaka *et al*., 2000]. For all the models, we impose homogeneous layering to represent the velocity structure and the basement and crust with the same P- and S-wave velocities. A flat layering approximates the boundary between upper crust and basement at a depth of 7.5km. We don’t include surface topography, seawater and the sea bottom topography in the Sagami Bay, which is a very deep trench. We digitized basement depth maps by Koketsu (1995) and Suzuki (1999) for a use of numerical modeling.

The 3D underground structural model by Koketsu (1995) is shown in dotted area in Fig. 3 a). This model is based on a travel-time inversion of refraction data. We call this model R-model. This model consists of two layers of sediments and basement, and the contour in Fig. 3 a) is topography of this interface. The maximum depth to the basement is about 4000m near the Yokohama City. The contour map of the R-model is modified for simulation as shown in Fig. 4 a). The P- and S-wave velocities are determined from the average of the values by Shima *et al*. (1978), as tabulated in Table 1 a).

The 3D underground structure model by Suzuki (1999) has three layers that are shown in Figs. 3 b), c). This model is mainly made by geological data with the results of refraction, reflection, and gravity surveys. We call this model G-model. The G-model consists of the basement and the two sediments, and the contour map of depth to the top of basement is shown in Fig. 4 b). The velocities for such layers are listed in Table 1 b). The top two layers correspond to Kazusa and to Miura groups and the third layer belongs to Pre-Tertiary basement. The depth to the basement is 3500m near the Yokohama City, and the structure around Miura peninsula is very steep.

The third model was constructed by using S-wave velocity structures explored by array measurements of long-period microtrmors at 14 points around the Yokohama and Kawasaki Cities [e.g., Yamanaka *et al*., 2000]. The locations of microtremor measurements are shown by black triangles in Fig. 1. The S-wave velocity profile at each point is shown in Fig. 5. There are three layers in the sediments over the basement with an S-wave velocity of 3.0km/s. From the profiles, we decided a depth contour map of the each boundary in Figs. 3 d), e) and f). The S-wave velocity of each layer is determined by averages of the velocities of all the profiles. The contour map used in simulation is depicted in Fig. 4 c). The model has very low velocity layer and the maximum depth to the basement is 2.8km. We call this model M-model. The velocity structure is tabulated in Table 1 c). It is noted that the three 3D models do not cover entire of the investigated area, therefore, we extrapolate known information to model structure with no information.

Source modeling

The epicenter location of the target event is shown in Fig. 1. Seismic moment by JMA is 3.3×10^{17}Nm. To determine the source parameters, we tried to fit synthetic waveform with the observed one at Ito by try and error. The synthetic and observed waveforms are compared in Fig. 7. We assumed a simple vertical fault model with a rupture of six subfaults. Each subfault has the same rise time of 1 sec with a seismic moment of 5.5×10^{16}Nm, and the source time function used is a smoothed ramp function. The rupture velocity is constant of 2.0km/s. The orientation of the fault strike is N160°E. We apply a high-pass filter to synthetics to compare motions periods of more than 3 sec.

Numerical parameters

The simulation area is displayed in Fig. 1. The origin of this area is N34.9°, E139.0°, and the length is 68.6km and 88.8km in the NS and EW directions. The model has a thickness 19.2km. We used the staggered-grid 3D finite difference method, with fourth-order in space and second-order in time [e.g. Graves, 1996]. The grid spacing in horizontal components is 0.2km, and vertical spaces are 0.2km, 1.0km and 1.3km according to S-wave velocity in each layer. The total model dimensions is about 5.3 million grid points. A run for our model needs more than 20 hours on a single CPU of DEC Alpha 400MHz, with physical memory of 428Mbytes.

RESULT

Snapshots

In order to understand the characteristics of the propagation of long-period seismic waves, snapshots every 20sec at time from 20 to 80sec are depicted in Figs. 8. These snapshots indicate amplitudes of UD component of velocity on the surface calculated for the M-model and normalized by the maximum amplitude at 80sec.
At time of 20sec in Fig. 8a), the wave front of the S-wave (S1) appears in the area of the exposed basement which is the west side in this model. The propagation direction is north at first, because S1 propagates in the high S-wave velocity area. S-wave and the later arrival (S2) are dominant at the Sagami Bay. At time of 40sec, S-wave (S1) has reached around Yokohama area, and the later phases are generated at the west side of the Yokohama and Kawasaki areas. The wave front is bent with a wedge shape by the irregularity in the underground structure. The wave field is very complicated in the Sagami Bay in these snapshots. At time of 60sec, S2 phase reaches around Yokohama area, the wave field become more complicated than that at 40sec. The wave front for S2 is in a straight line. Those later phases with large amplitude and a long duration in the observation records at Kawasaki and Futamatagawa (Fig. 2) correspond with the S2 phase in the snapshots (Figs. 8). The propagation path interpreted from these snapshots is shown in the last snapshot at a time of 80sec with the contours of the basement. The S1 and S2 phases correspond to the paths A and B. These propagation paths are controlled by the irregularity of the 3D underground structure.

Comparison between observed and synthetic data

The observed and synthetic displacements for the three 3D velocity models for the Kanto basin are compared. Figs. 9 shows the waveforms at Hiratsuka, Fujisawa, Kamakura, Futamatagawa and Kawasaki. These stations are aligned with absolute time and distances from the epicenter. The subsurface structures between the epicenter and Hiratsuka in the Sagami Bay are not largely different for the three models. The Hiratsuka station has the sediments with a thickness of 2km to basement and the Sagami Bay has only one sediment any layer with an S-wave velocity of 1km/s.
The results for the three models are similar, although synthetic displacements have large amplitude than observed displacements. The G-model shows a little earlier arrival than those of the R- and M-models, so S-wave velocity in the G-model is a little faster in the Sagami Bay. Consequently, the input wave to Yokohama area for each model is the similar. Fujisawa has similar waveforms for R- and G-models with a large amplitude and dominant period of about 3s. However, the M-model is similar to the observation until about 80sec. Kamakura located in the thin sediment part near Miura Peninsula has the waveform with smaller amplitude than observed a waveform for all models. The Futamatagawa station has a large and a long-period observed motion. This is well simulated by the G-model except UD component. The amplitudes of all the synthetic waveforms are very small than the observation record at the Kawasaki station located at the northern end of the models. In all synthetic waveforms, estimated duration time is shorter than observed ones. However, the observation records show two phases in basin area. The synthetic waveforms by the G- and M-model simulated well these features. The two phases represent S1 and S2 phases in the snapshots (Figs. 8).

CONCLUSION

We qualitatively discussed the propagation characteristics of long-period ground motion by 3D numerical simulation. In particularly, it was found that the characteristics of the seismic wave propagation agrees with previous studies (e.g., Yamanaka *et al*., 1998). Reference of three 3D models are examined by comparing 3D FD simulation of long-period strong ground motion with the observed records. The results of the G- and M-model could represent observed better than R-model in respect of the amplitude and period for later phases. M-model shows a more realistic model for the long-period seismic simulations, because the model has low velocity and some layers in the basin. The model by array microtremor measurement is considered the wave theory. Although, we can not conclude the best model in those models, because there are many assumptions about underground velocity 3D structures, especially the structure of Sagami Bay. The structure of the Sagami Bay needs improvement in detail. Furthermore, we guess that the reason for the small synthetics in the basin area is the large attenuation in the sediments the models. Therefore, if we'll be improved these simulation model, the synthetic waveform will correspond well to the observed waveform more and more.

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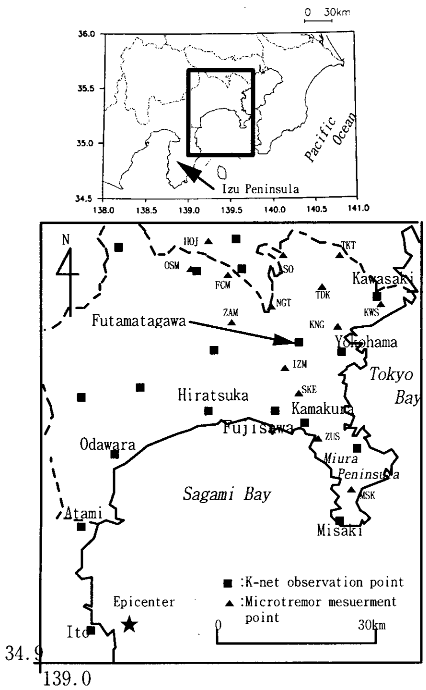
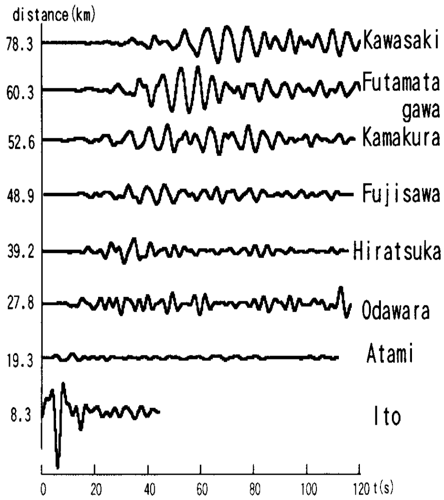




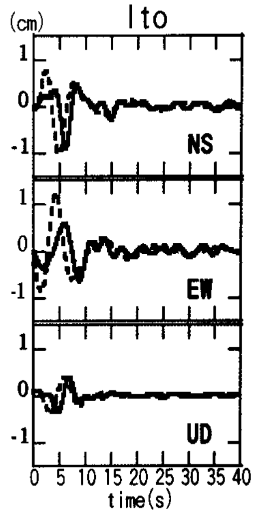


Fig. 1 Map of the southwestern Kanto plain, with Strong motion stations (square) and microtremors observation points (triangle).

Fig. 2 Observation displacement in the NS direction by K-NET and used band-pass filter 3 to 10sec.

Fig. 7 Comparison of observed data (solid line) and waveform is B.P.F. 3 to 10sec.

Table 1 a). Velocity model (R-model)

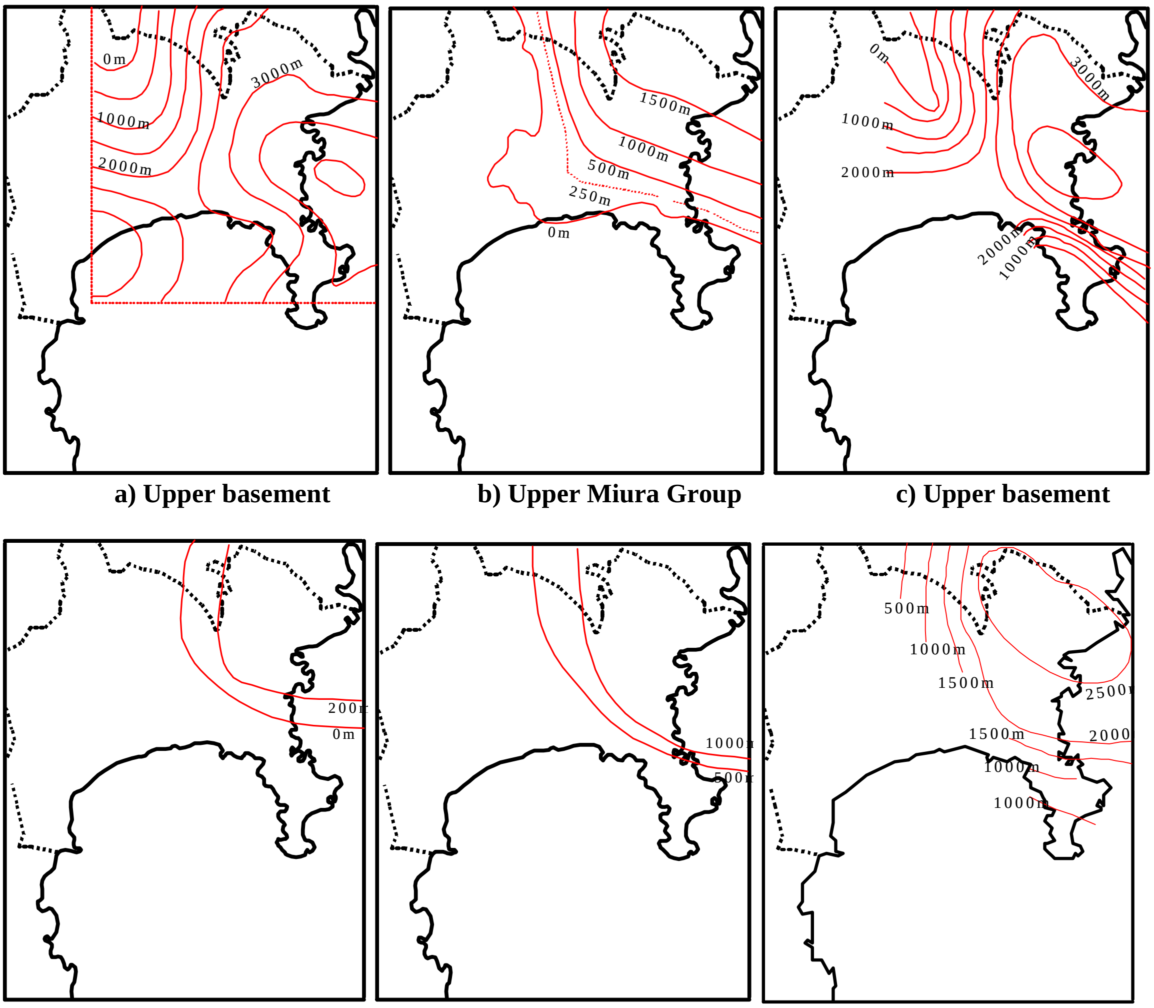
LAYER	Vp (km/s)	Vs (km/s)	ρ(g/cm^3)	Q
1	2.3	1.05	2.3	75
2	5.6	3.0	2.5	300
3	6.0	3.4	2.6	400

Table 1 b). Velocity model (G-model)

LAYER	Vp (km/s)	Vs (km/s)	ρ(g/cm^3)	Q
1	1.8	0.7	2.0	50
2	2.7	1.2	2.3	100
3	5.6	3.0	2.5	300
4	6.0	3.4	2.6	400

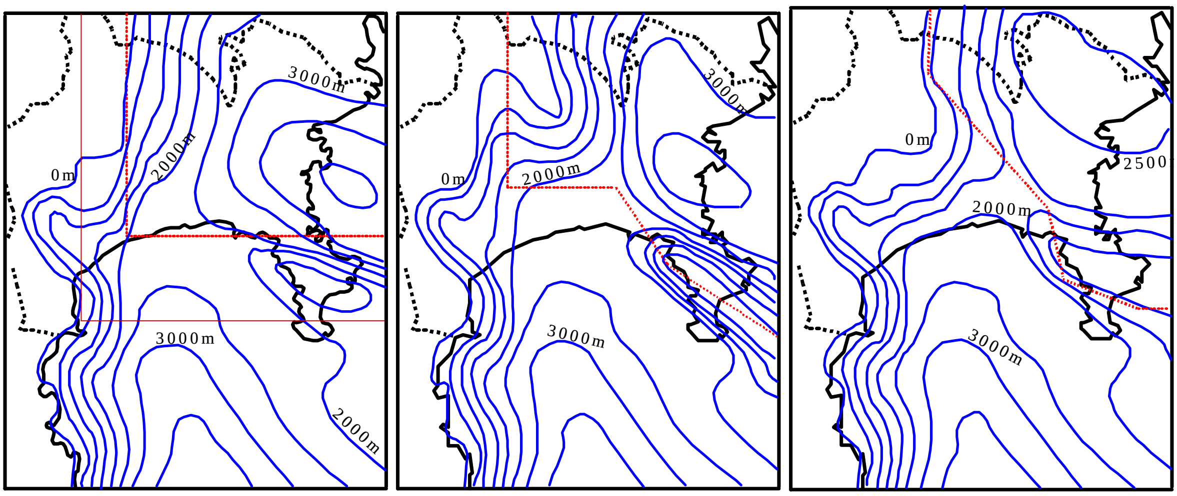
Table 1 c). Velocity model (M-model)

LAYER	Vp (km/s)	Vs (km/s)	ρ(g/cm^3)	Q
1	1.8	0.5	1.9	30
2	2.4	1.0	2.1	75
3	3.2	1.7	2.3	100
4	5.6	3.0	2.5	300
5	6.0	3.4	2.6	400



d) e) f)

Fig. 3 Contour maps of the depth of the boundary between layers by a) (Koketsu (1995)), b), c), (Suzuki (1999)), d), e), f) microtremor measurement.



a) R-model **b) G-model** **c) M-model**

Fig. 4 Contour maps of the depth of the upper basement for simulation. a) R-model, b) G-model, c) M-model

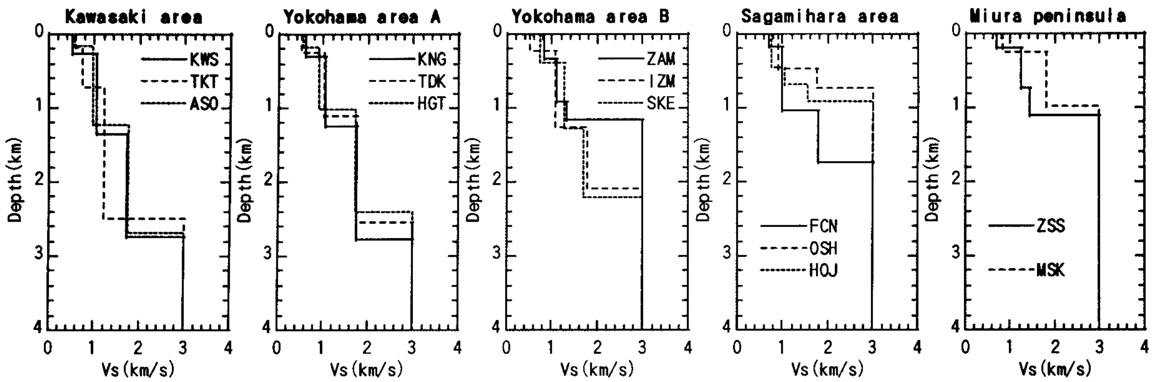


Fig. 5 Profiles of S-wave velocity structure by array measurement microtremors at the sites of around the Yokohama and Kawasaki Cities in Fig. 1 (triangle).

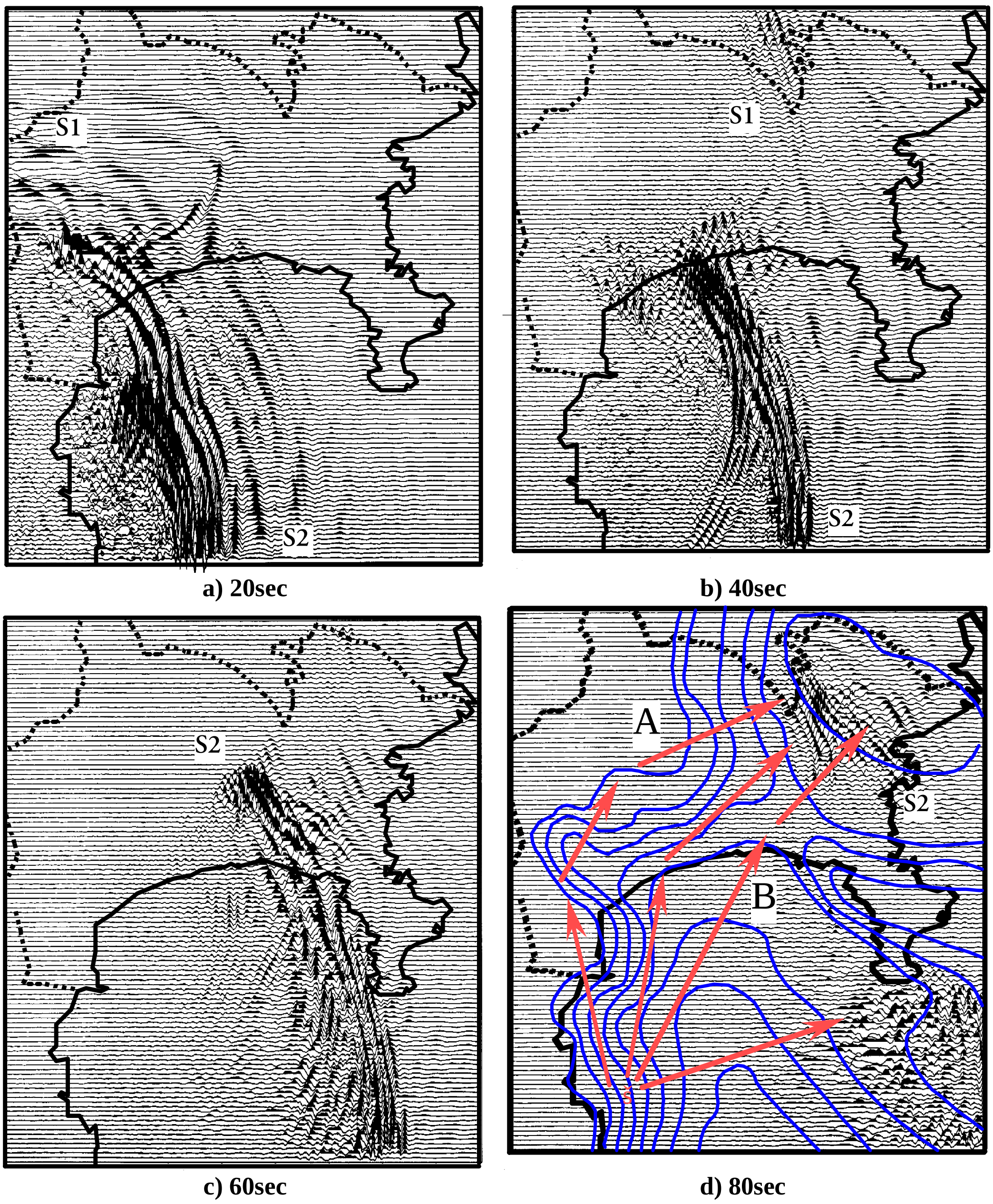


Fig. 8 Snapshots. a) 20s, b) 40s, c) 60s and d) 80s. At the 80sec shows the path of the mainly phases path.

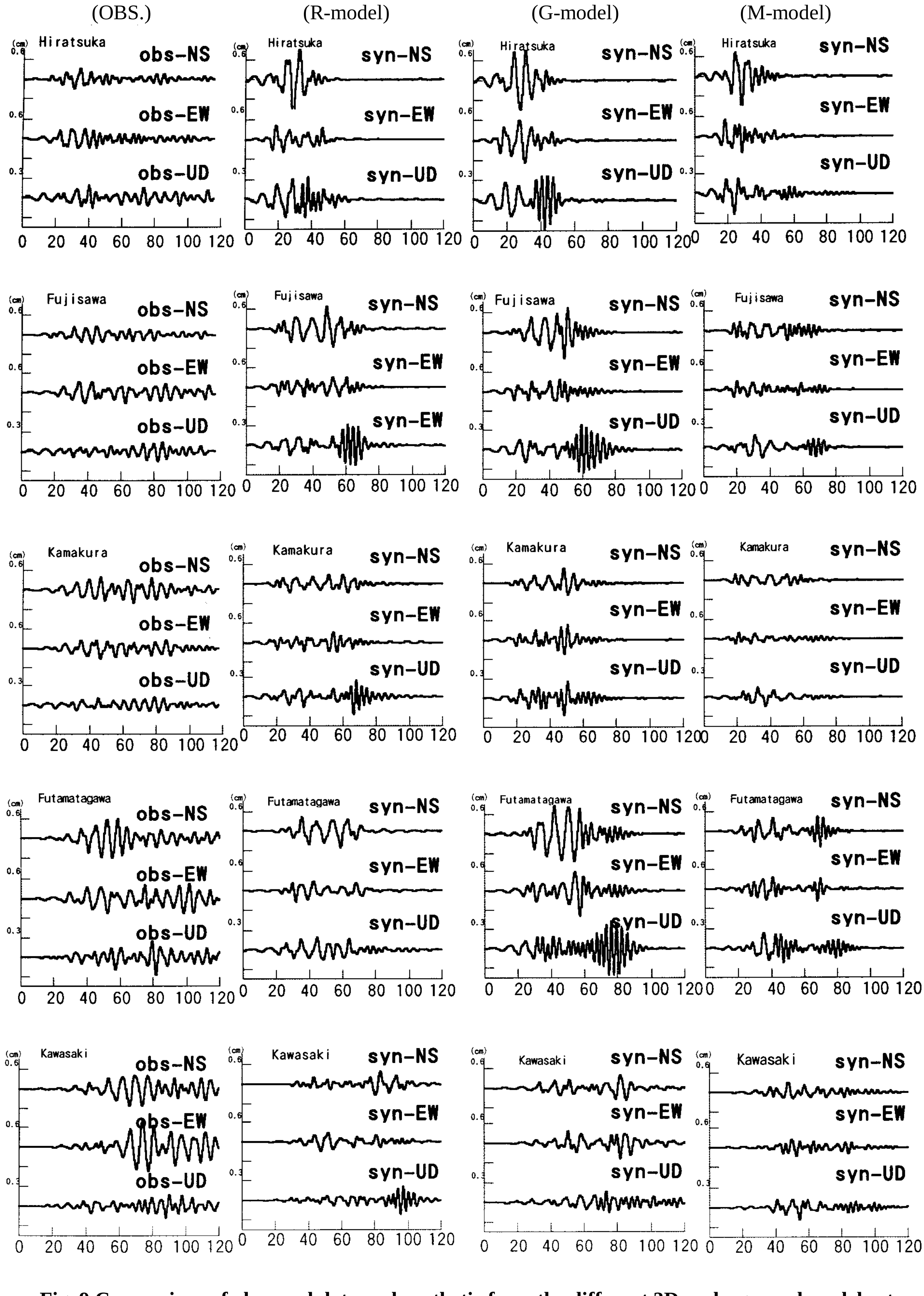


Fig. 9 Comparison of observed data and synthetic from the different 3D underground models at Hiratsuka,
Fujisawa, Kamakura, Futamatagawa, and Kawasaki. These waveforms are displacement used band-pass filter 3 to 10sec.