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# A PROPAGATION MECHANISM OF SURFACE WAVES INDUCED BY A SEDIMENTARY BASIN -A CASE STUDY IN THE OSAKA BASIN, JAPAN, DURING THE 1995 HYOGO-KEN NANBU EARTHQUAKE-

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## SUMMARY

For the prediction of long period ground motions in Osaka basin, we investigated the propagation and generation process of them in Osaka basin using the 1995 Hyogo-ken nanbu earthquake. The seismogram observed at costal area (RKI) can be identified the long period later phase after 100sec of S-wave onset. From particle orbits and comparison of seismograms observed at other stations, there are some possibility that the propagation and generation process of the long period later phase is as following; (1): it was Love wave generated at the seismic source, and propagated to RKI via Mt. Izumi where is located at opposite side of RKI in Osaka basin. (2): it was Love wave generated at the bottom of mountain near RKI and propagated to opposite side, it was reflected at Mt. Izumi, and returned to RKI. (3): it was Love wave generated at the bottom of Mt. Izumi, and propagated to RKI.

## INTRODUCTION

Since ground motions in the period range from 2 to 10 sec expected to influence high rise buildings and long bridges were observed in Osaka basin, Japan [1], the study about this type of ground motions was started form the various point of view.

From the previous study, it was suggested that long period ground motions were influenced by deep underground structures and generated at the edge of sedimentary basin. So it is very important for the prediction of long period ground motions to understand the geological and geomorphologic environments in the target area.

For example, Osaka basin is surrounded with three mountains, Mt. Rokko, Mt. Ikoma, Mt. Izumi, and with Awaji Island. By the seismic refraction survey in Kobe area in 1995, it was found that Mt. Rokko functioned as a reflector and short period seismic waves through the sedimentary layers were reflected [2].

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This is one of effects of the geological and geomorphologic environments in this area, although it was short period ground motions.

For near future, it is expected that the Nankai and Tohnankai earthquakes of M8 class will occur, and long period ground motions will be observed in Osaka basin. On the other hand, there are some high rise buildings, long bridges and oil tanks. So it is significant to discuss the characteristics of long period ground motions using seismograms of past earthquakes.

In this study, we will investigate the propagation and generation process of long period ground motions in Osaka basin using seismograms of the 1995 Hyogo-ken nanbu earthquake observed in Osaka basin shown in Fig. 1.

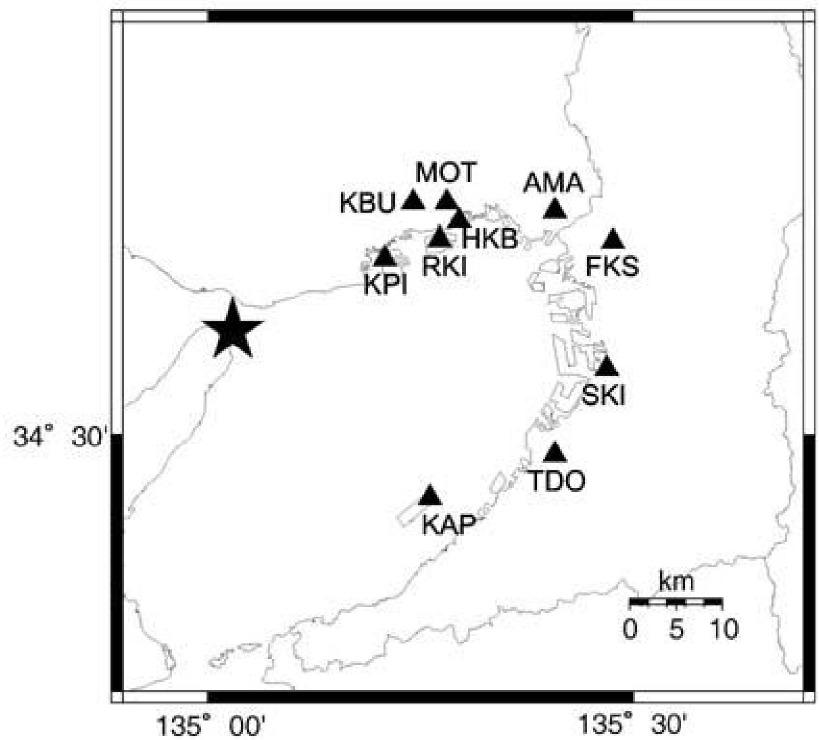


Fig.1. Map showing seismic observation stations and epicenter used in this study. The solid triangle indicates stations observed the 1995 Hyogo-ken nanbu earthquake. The solid star indicates epicenter of the 1995 Hyogo-ken nanbu earthquake determined by Japan Meteorological Agency.

## SEISMOGRAM CHARACTERISTICS OBSERVED IN KOBE DURING THE 1995 HYOGO-KEN NANBU EARTHQUAKE

Because one of reasons that were appeared the heavy damaged area in Kobe during the 1995 Hyogo-ken nanbu earthquake was related to the direct S wave [3], this part of analysis was done energetically. As the seismograms observed at Rokko Island where is located at a distance of some kilometers away from the heavy damaged area was shown in Fig. 2, the maximum amplitude of the direct S wave part is as large as 63.6 cm/s on NS component.

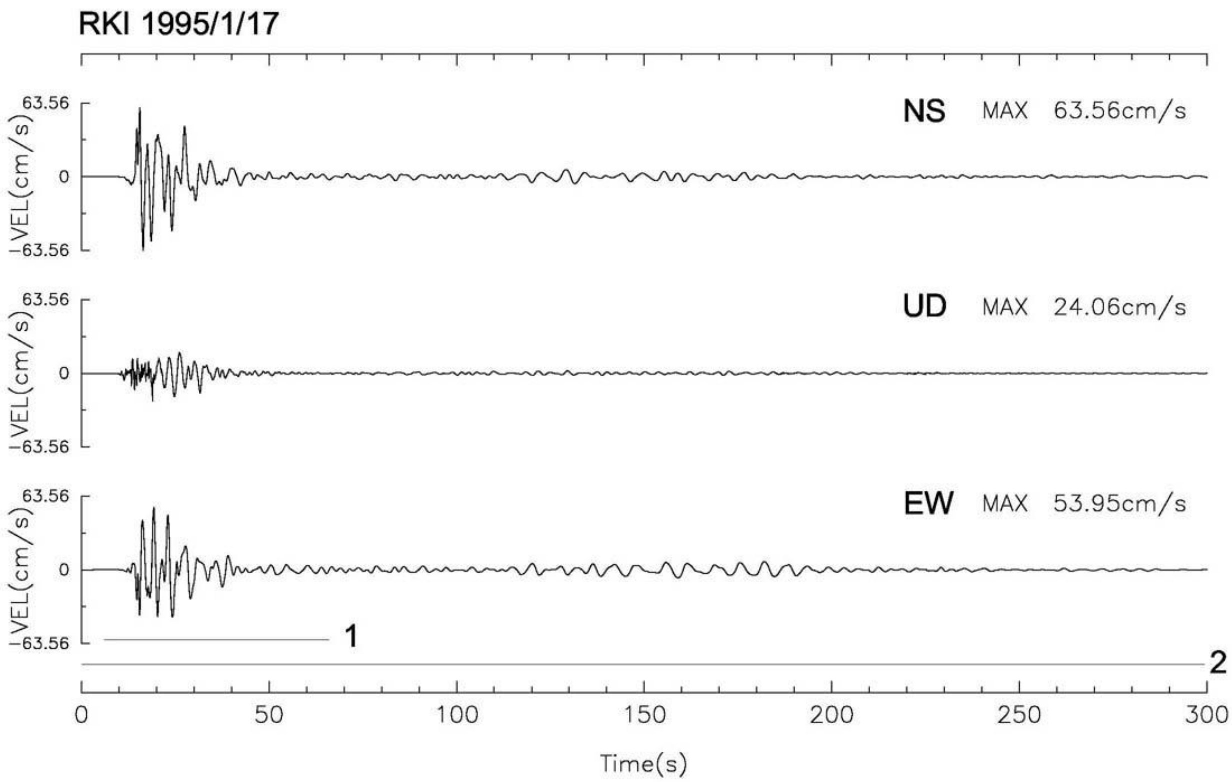


Fig. 2. Three orthogonal component seismograms of the 1995 Hyogo-ken nanbu earthquake observed at RKI. The epicenter of this earthquake was shown in Fig. 1. The bars showing under seismograms indicate the analysis window for Fourier spectra. 1: The direct S-wave. 2: Including the long period later phase.

On the other hand, long period ground motions can be identified after 100-200 sec from the direct S wave. Figure 3 shows a comparison of Fourier spectra using the time window between 60 sec and 300 sec including the long period later phase. It suggests that the long period later phase consists of the period range of approximately 7 sec. In order to find this later phase around RKI station, a comparison of the seismograms observed between at RKI and at MOT, where is located at a distance of 3 kilometers away from RKI and at the bottom of Mt. Rokko, was shown in Fig. 4. The seismogram at RKI can be identified the long period later phase in the period range from 7 to 8 sec and its maximum amplitude is approximately 8 cm/sec. On the other hand, the seismogram at MOT cannot find it. According to previous study about the deep underground structure in Kobe [4], the shape of basement from the bottom of Mt. Rokko to Osaka bay side changes drastically. The depth to basement was evaluated by seismic reflection survey, MOT and RKI are about 1000m and 1600m, respectively. Figure 5 shows 1-D SH wave transfer function based on an underground structure evaluated by microtoremor array measurements at MOT and RKI [5]. The peak of fundamental mode at MOT appears around 5sec, at RKI appears around 7sec although its amplitude is smaller than the second peak. It suggests that the long period later phase observed at RKI is related to the deep underground structure.

But considering the time difference between the direct S wave and the long period later phase at RKI where is located near the bottom of Mt. Rokko, it is difficult to explain the generation and propagation process of it.

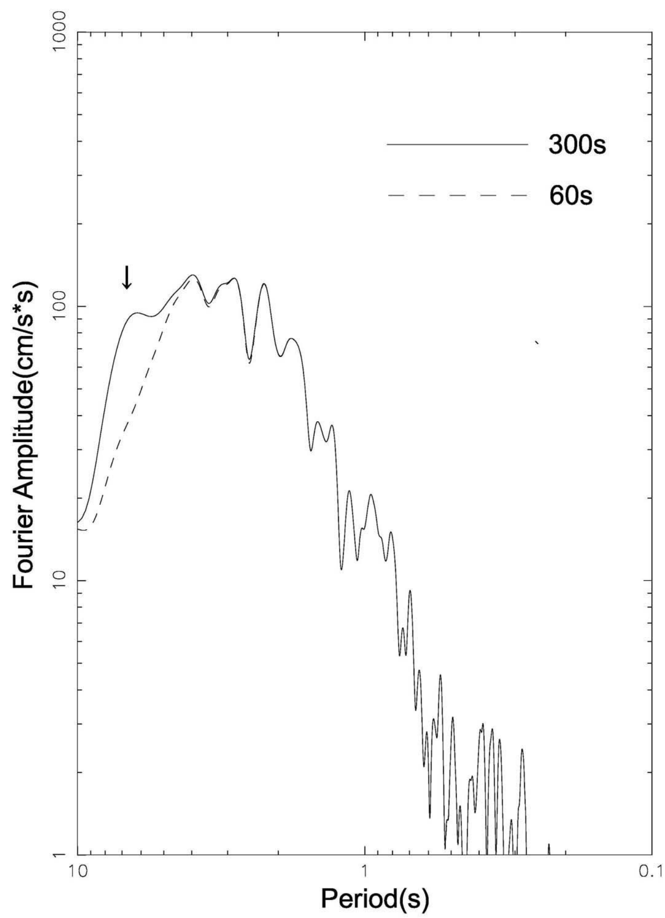


Fig. 3. Comparison of Fourier spectra on EW component at RKI using the time window between 60 sec (broken line) and 300 sec including the long period later phase (solid line). An allow shows a peak made by the long period later phase.

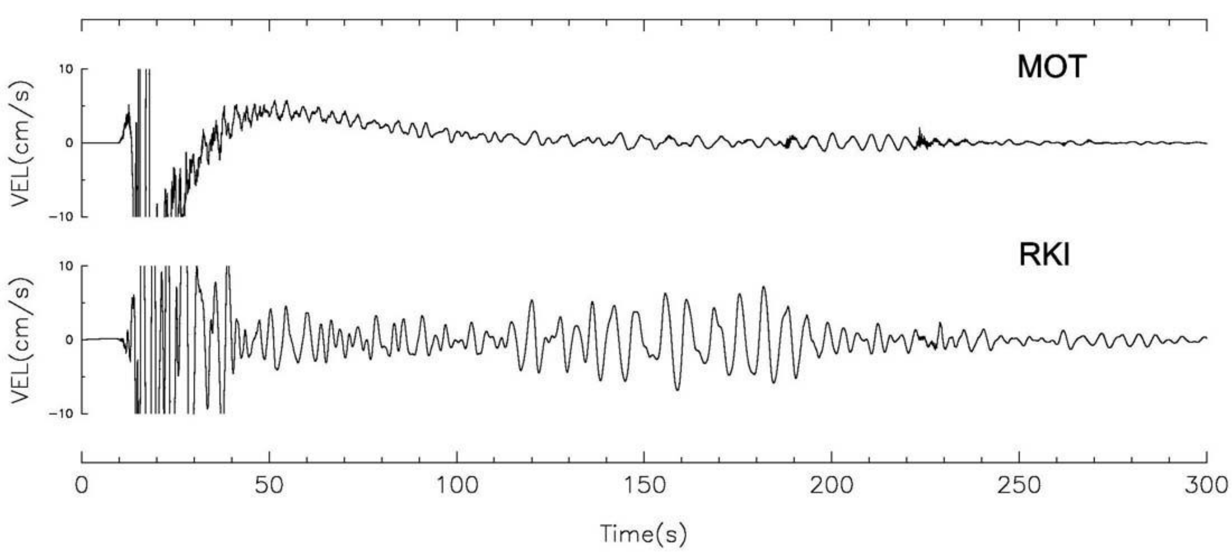


Fig. 4. Comparison of EW component seismograms observed at MOT and RKI.

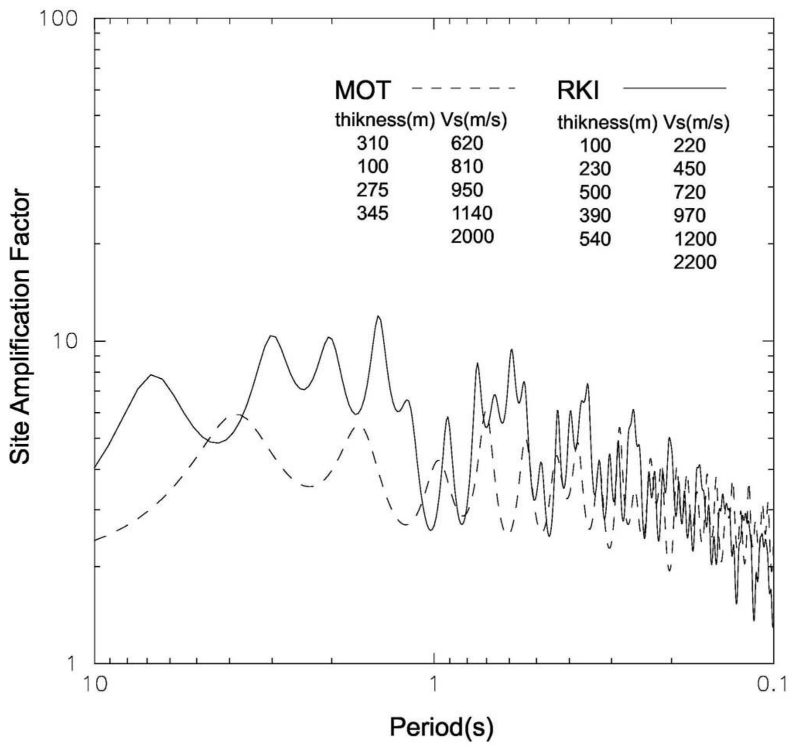


Fig. 5. 1-D transfer function of SH wave at RKI (solid line) and MOT (broken line). The underground structure mode at each station was shown in upper side.

## THE PROPAGATION AND GENERATION PROCESS OF THE LONG PERIOD LATER PHASE BASED ON OBSERVED SEISMOGRAMS IN KOBE

Figure 6 shows the EW component seismogram at RKI and its spectra amplitude by multiple filter analysis. It suggests that the long period later phase at the part of 100-200 sec shows normal dispersion. And figure 7 shows the seismograms through a band-pass filter in the center period of 7.0 sec, which is the largest spectrum amplitude in the long period later phase, and particle orbits. The amplitude on UD component when the long period later phase was identified on EW component is much smaller than horizontal one, sufficiently. And the principle axis of particle orbits at its part shows EW direction while at the direct S wave shows NS direction.

So we compared the seismograms observed between at RKI and at HKB through a band-pass filter (Fig. 8) [6]. Here, the HKB is located at NE direction of 2.5 kilometers away from RKI. Although time data is important factor to compare a relation of the long period later phase between at RKI and at HKB, both station records have no time data. So we assumed that the direct P wave propagated the underground structure [7] shown in Table 1 from seismic source, the arrival time on P wave onset was calculated at each station. The amplitude of it observed at HKB is a little bit smaller than at RKI, it is possible to track phases relation between HKB and RKI. It indicates that the long period later phase arrived at RKI is faster than at HKB.

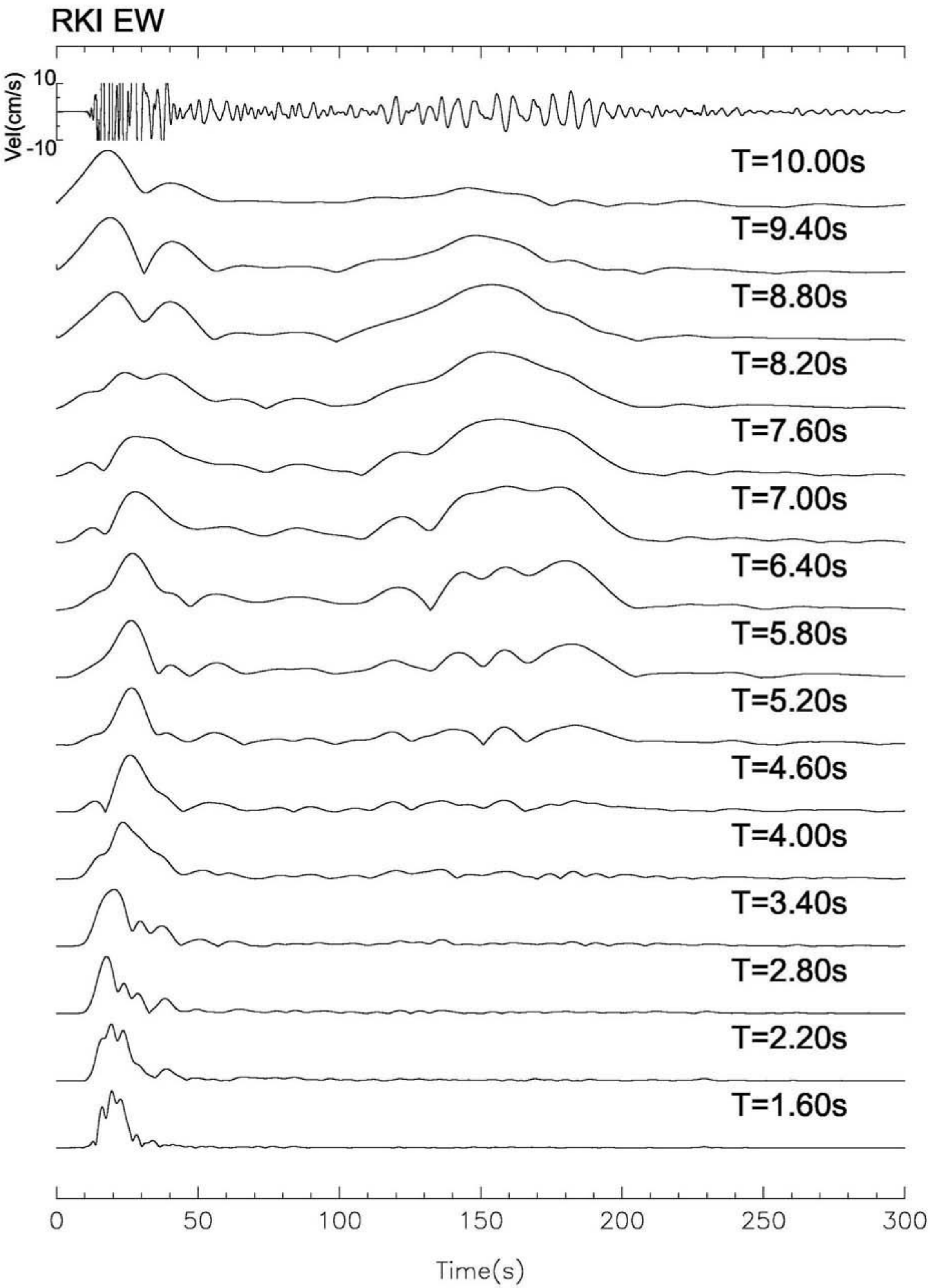


Fig. 6. The EW component seismogram observed at RKI and its spectra amplitude by multiple filter analysis. The center period of spectra amplitude was shown on the right side. The scale of spectra amplitude was normalized by maximum amplitude at each other.

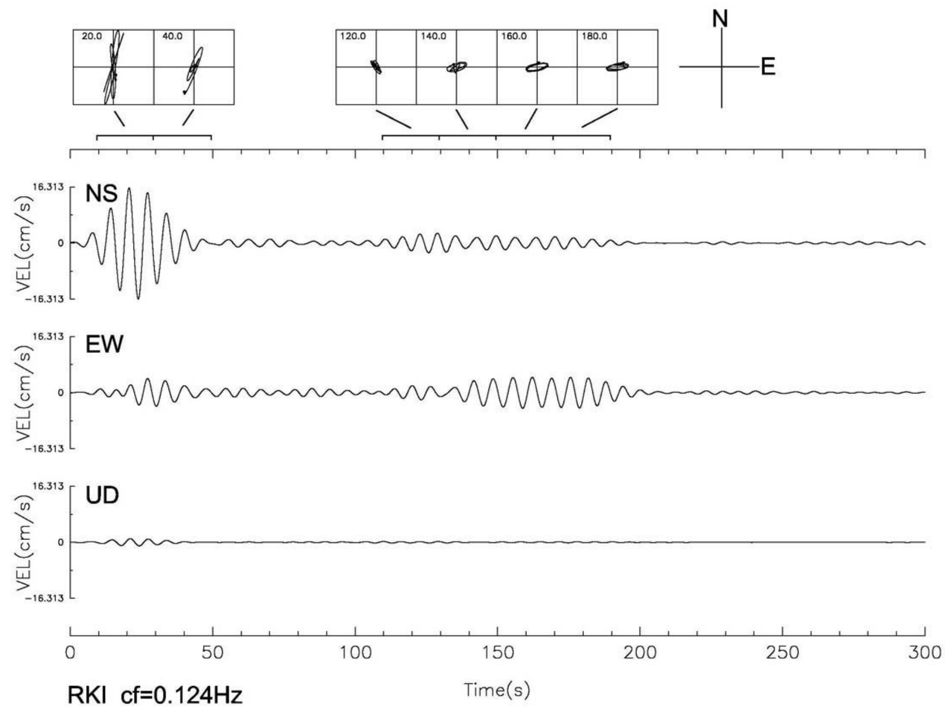


Fig. 7. The seismograms observed at RKI through a band-pass filter in the center period of 7.0 sec and their particle orbits.

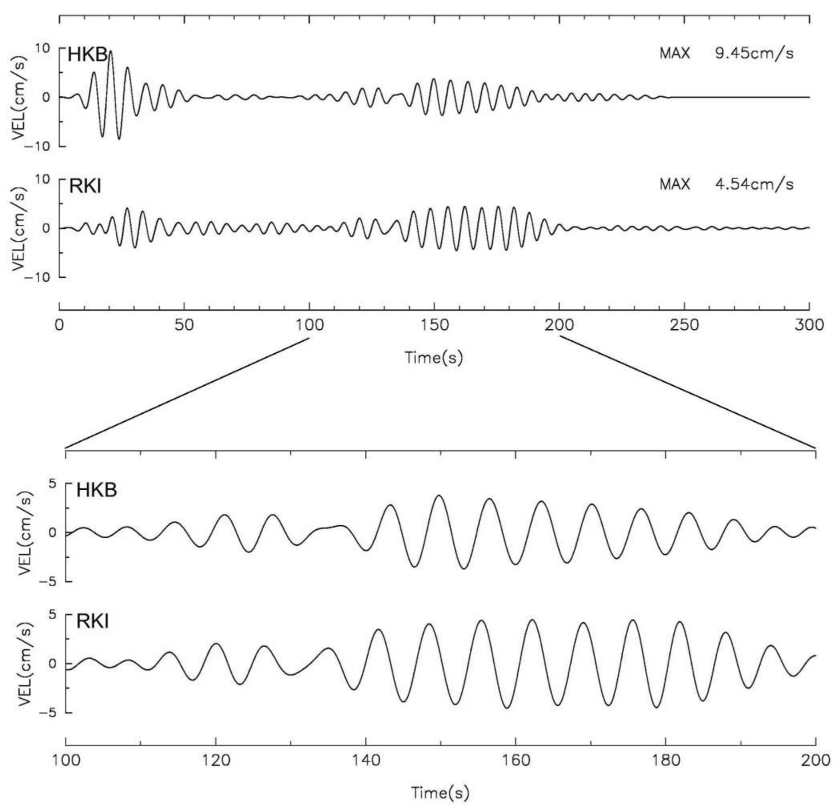


Fig.8. Up: Comparison of the seismograms observed at RKI and at HKB through a band-pass filter in the period range of 7 sec. Down: Magnification of upper figure from 100 to 200 sec.

Table 1. The underground structure assumed for travel time calculation

| Thickness(km) | $V_p$(km/s) |
|---|---|
| 4 | 5.5 |
| 17.8 | 6.0 |
| | 6.7 |

From these reasons, there are some possibilities that the propagation and generation process of the long period later phase is as follows;

(1): The long period later phase was Love wave generated at the seismic source, and propagated to RKI via Mt. Izumi side where is located at opposite side of RKI in Osaka basin.

(2): The long period later phase was Love wave generated at the bottom of Mt. Rokko and propagated to south area. And it was reflected at Mt. Izumi, returned to RKI.

(3): The long period later phase was Love wave generated at the bottom of Mt. Izumi, and propagated to RKI.

## AN EXPLANATION OF THE PROPAGATION AND GENERATION PROCESS OF THE LONG PERIOD LATER PHASE BY SYNTHETIC ANALYSIS USING 2-D UNDERGROUND STRUCTURE MODEL

In order to understand the propagation and generation process of the long period later phase, we will compare the waveform between seismogram observed at RKI and synthetic one calculated by 2-D Finite Difference Method (FDM). Here, because one of characteristics of the long period later phase shows Love wave, the SH field was used in this analysis.

After the 1995 Hyogo-ken nanbu earthquake, many geophysical surveys were done in Kobe area. So some underground structure model in Osaka basin based on these results were proposed. In this study, we used two 2-D underground structure models (Model A and Model B) based on 3-D model (Fig. 9) [8]. Model A was assumed that the sedimentary layers seem to be one layer and its seismic velocity is the average value of total sedimentary layers. On the other hand, Model B was assumed that the sedimentary layers seem to be three layers proposed by Miyakoshi et al. [8].

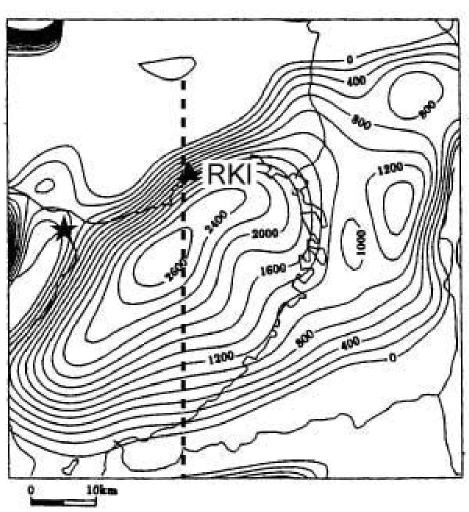


Fig. 9. Map showing the depth to basement by contour lines [8]. The broken line indicates the location of 2-D underground structure. The solid triangle indicates the location of RKI. The solid star indicates epicenter of the 1995 Hyogo-ken nanbu earthquake determined by Japan Meteorological Agency.

Figure 10 and 11 show the underground structure models and synthetic waveforms using Model A and B, respectively. It suggests that the later phase was generated at the bottom of Mt. Rokko and Mt. Izumi in both models. After the later phase was arrived at the other side in Osaka basin, it was reflected at there and returned in Model A.

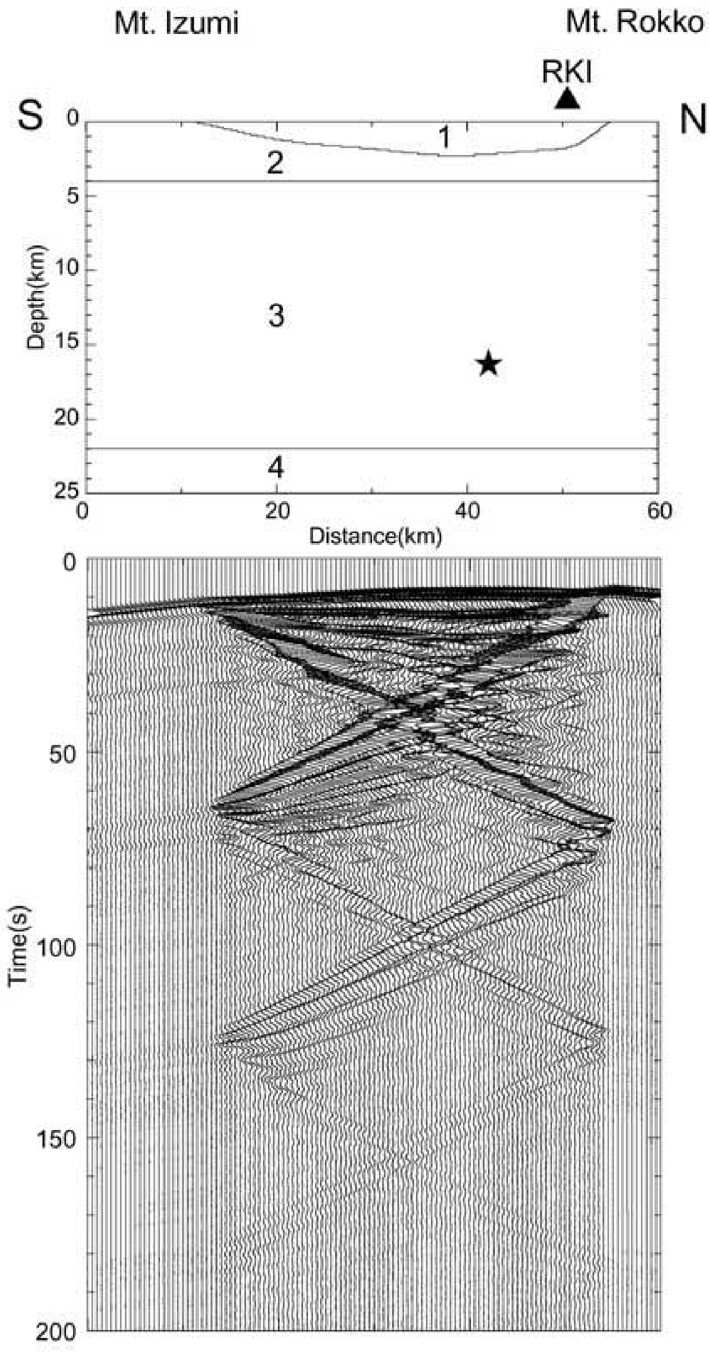


Table 2 Model A

| | $\rho$(g/cm$^3$) | Vs(km/s) | Q |
|---|---|---|---|
| 1 | 2.0 | 0.77 | 50 |
| 2 | 2.7 | 3.2 | 300 |
| 3 | 2.7 | 3.5 | 400 |
| 4 | 2.8 | 3.9 | 500 |

Fig. 10. Up: 2-D underground structure model (Model A). Down: Response of velocity waveforms at the surface calculated by FDM. The solid triangle indicates the location of RKI. The solid star indicates a location of source. The input wave from a location of source was used the sine wave in the period range of 7 sec, duration 3.5 sec.

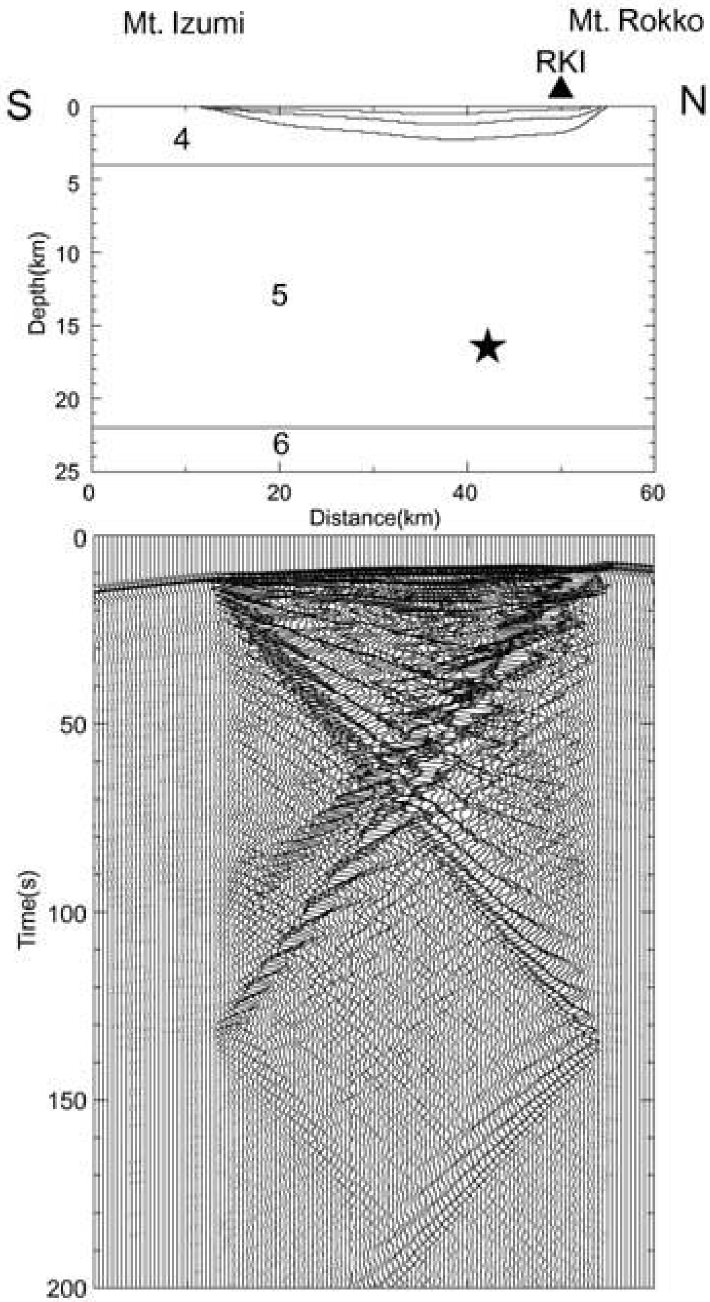


Table 3 Model B

| | $\rho$(g/cm$^3$) | Vs(km/s) | Q |
|---|---|---|---|
| 1 | 1.7 | 0.35 | 40 |
| 2 | 1.8 | 0.55 | 80 |
| 3 | 2.1 | 1.0 | 170 |
| 4 | 2.7 | 3.2 | 300 |
| 5 | 2.7 | 3.5 | 400 |
| 6 | 2.8 | 3.9 | 500 |

Fig. 11. Up: 2-D underground structure model (Model B). Down: Response of velocity waveforms at the surface calculated by FDM. The solid triangle indicates the location of RKI. The solid star indicates a location of source. The input wave from a location of source was used the sine wave in the period range of 7 sec, duration 3.5 sec.

Figure 13 shows the comparison between observed seismogram through a band-pass filter in the center period of 7 sec and the synthetic waveforms corresponding to the location at RKI. In Model A, the synthetic waveform corresponding to the long period later phase observed at RKI was generated at the bottom of Mt. Rokko, reflected at Mt. Izumi and returned to RKI. In Model B, it was generated at the bottom of Mt. Izumi and propagated to RKI. But the long period later phase calculated by FDM using both models identifies faster than observed one, and the amplitude is smaller. So it is difficult to conclude the generation and propagation process of it.

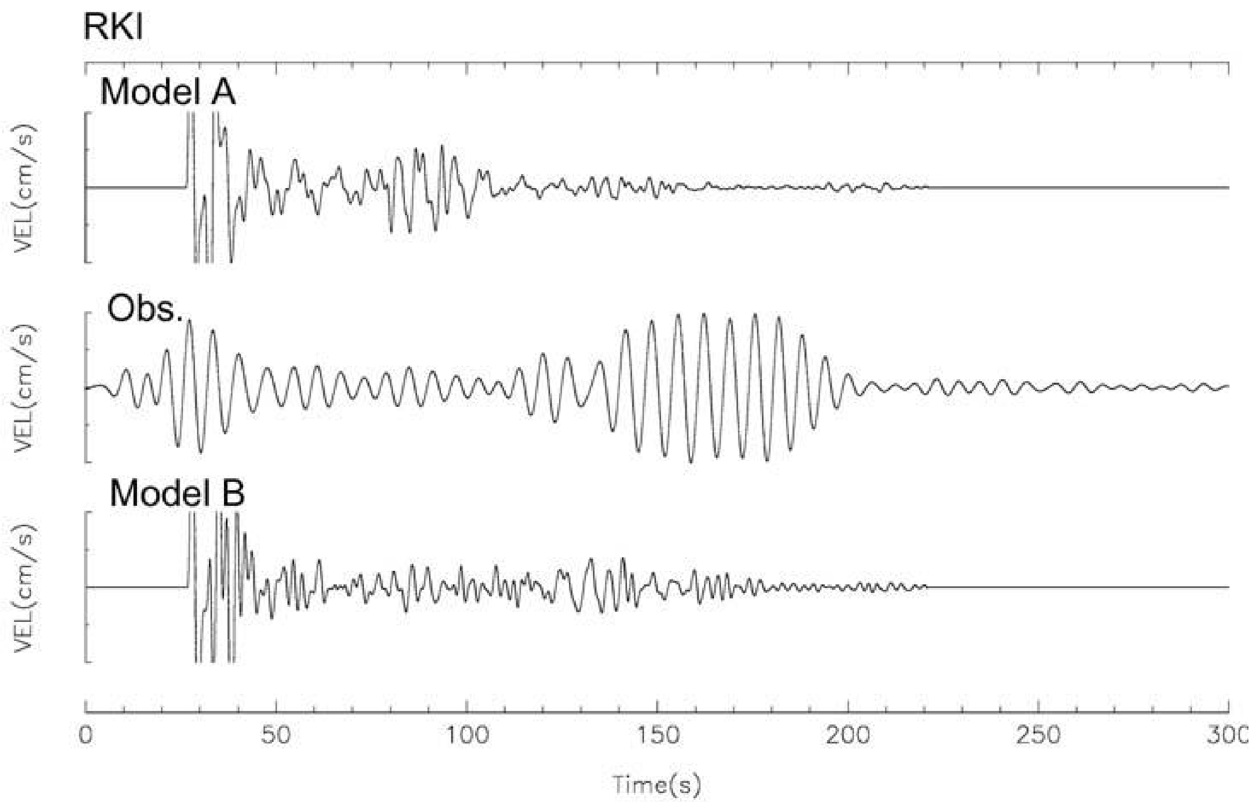


Fig. 12. Comparison between calculated response of velocity waveforms at the surface corresponding to RKI and the seismogram observed at RKI through a band-pass filter.

## DISCUSSION AND CONCLUSIONS

According to the study by Yamaguchi et al. [9], the seismogram observed at KAP where is located at the Mt. Izumi side in Osaka basin can be identified the long period later phase in the period range of 5 sec after 75-115 sec on P wave onset, clearly. From the particle orbits and semblance analysis, it was Love wave propagated from Mt. Izumi.

Figure 13 shows EW component seismograms through a band pass filter in the center period of 7 sec during the 1995 Hyogo-ken nanbu earthquake. Distance in this figure was measured from the cross point between the bottom of Mt. Izumi and the perpendicular direction of principal axis that is a particle orbit on the long period later phase observed at RKI. It seems that the long period later phase observed at RKI was propagated from the bottom of Mt. Izumi with an apparent velocity of 400 m/s, although its amplitude at each station is different. And theoretical group velocity of Love wave in the period range of 7 sec is also 350 m/s at RKI (Fig. 14). On the other side, the long period later phase of synthetic waveforms is approximately 380 m/s in Model B. These are comparable, it seems that the long period later phase is Love wave generated at the bottom of Mt. Izumi and propagated to RKI.

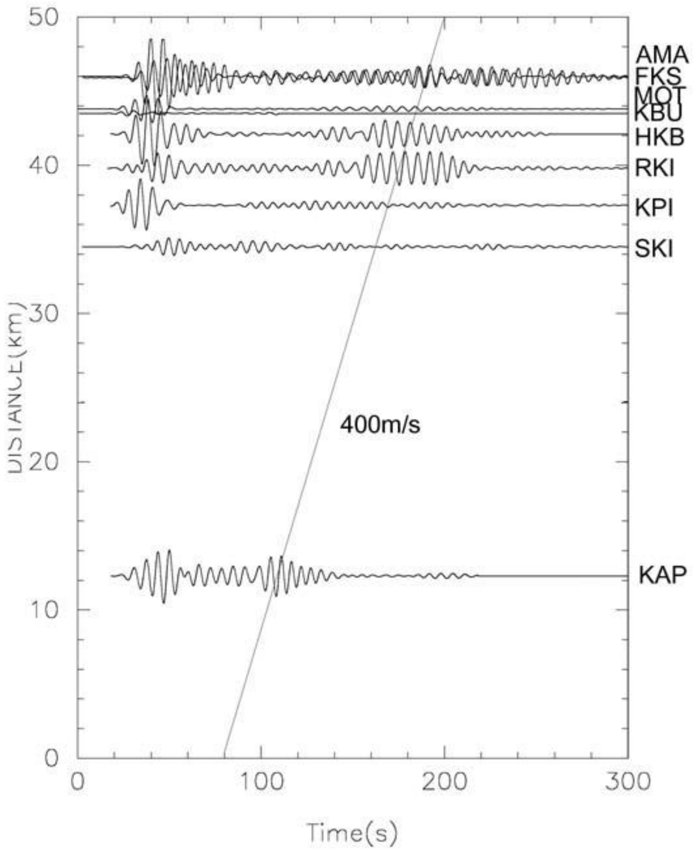


Fig. 13. EW component seismograms at each site shown in Fig.1. Distance in this figure was measured from the cross point between the bottom of Mt. Izumi and the perpendicular direction of principal axis that is a particle orbit on the long period later phase observed at RKI.

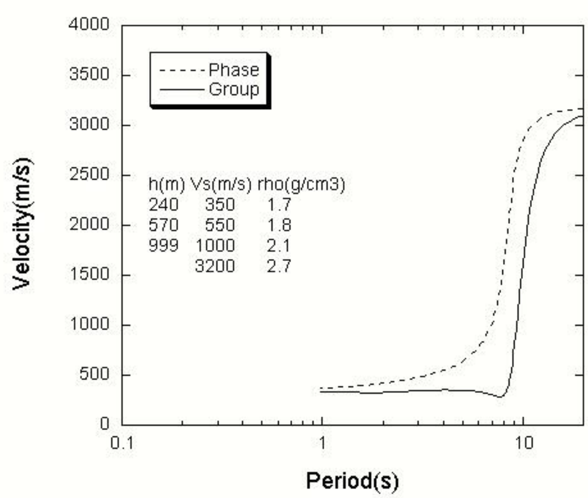


Fig. 14. Theoretical phase and group velocity curves of fundamental Love wave. An underground structure model in the middle left was used for their velocity.

But the principal axis of particle orbits at KAP shows not EW but NW direction [9], it is difficult to explain the characteristics of the long period later phase at RKI. So it needs to investigate the propagation and generation process using 3-D model in Osaka basin.

There are some possibilities that the propagation and generation process of the long period later phase is as follows;
(1): The long period later phase was Love wave generated at the seismic source, and propagated to RKI via Mt. Izumi side where is located at opposite side of RKI in Osaka basin.
(2): The long period later phase was Love wave generated at the bottom of Mt. Rokko and propagated to south area. And it was reflected at Mt. Izumi, returned to RKI.
(3): The long period later phase was Love wave generated at the bottom of Mt. Izumi, and propagated to RKI.

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