EFFECTS OF THE IRREGULAR UNDERGROUND STRUCTURES ON SEISMIC WAVE PROPAGATION NEAR THE WESTERN EDGE OF THE NOBI PLAIN

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ABSTRACT :

In this paper, we discuss the propagation process of ground motions generated by two earthquakes through the analysis of seismograms recorded on rock and sediment sites. Significant later phases following the S-wave arrivals in horizontal components often appear in the ground motions recorded in the sedimentary plain. We applied 2-D finite difference method to simulate the later phases during the earthquakes observed at the sediment sites using the subsurface structures derived from the seismic and micro tremors prospecting process. The results indicate that when considering then as basin excited waves, the characteristics of the simulated waveforms, including the later phases, display good agreement with the observed seismograms. Moreover, the earthquake motion characteristic was clarified by the propagation process of seismic waves in the western part of Nobi plain. We also clarified effects of the irregular underground structure on seismic wave propagation.

KEYWORDS: Seismic observation, 2-D finite difference method, Surface wave, Nobi plain

1. INTRODUCTION

The Hyogo-ken Nanbu earthquake of 1995 caused heavy damage, which was concentrated on a belt shaped zone 20km in length and 1km in width form Suma ward in Kobe City to Nishinomiya City (Architectural Institute of Japan, 1995). It was pointed out that this phenomenon caused by “the basin edge effect” due to irregular underground structure near the edge of the basin (Kawase, 1996; Pitarka *et al*., 1997). The deep subsurface structures in the Nobi plain is assuming the inclination structure which becomes deep toward west from east, and has vertical discontinuity at the western edge of the plain by the Yoro fault. Additionally, many active faults exist in surroundings of the Nobi plain, and it is essential to understand that the influence of the irregular subsurface structure on the seismic ground motion in the Nobi plain. It is recognized that the principal ingredient is surface waves with a period of 5-6 seconds are predominant in seismograms recorded at station on sediments in the Nobi plain during large earthquake (Miyake *et al*., 2005) It has been constructed the three dimension underground structural models based on information of the accumulated underground structure, and simulated the seismic ground motion wave form by a theoretical calculation in recent years actively (Kyuke *et al*., 2001; Nagumo *et al*., 2002). In the three-dimensional analysis, it is difficult to identify seismic wave that composes the seismic ground motion from the result, because the analysis model and the wave field are complex. It is easy to understand the wave propagation process at the edge of basin in the two-dimensional analysis, and many studies have been performed (Tanaka *et al*., 2000; Okochi *et al*., 2002; Narita *et al*., 2003). But these studies have not been mentioning the wave propagation process in detail. In this study, we discussed the characteristics of the seismic motions with the observed seismograms, and effects of the irregular underground structure on seismic wave propagation are clarified by the propagation process of seismic waves in the western part of Nobi plain.

2. SEISMIC OBSERVATION IN THE NOBI PLAIN

The Nobi plain, Japan is depicted in Figure 1 with the observation points and the surface geology conditions.

The seismic ground motion array observation has been continued while reinforcing the observation points after 1996. Acceleration type strong motion seismometers with three components each were installed are 8 sites in this area. The station AIT is located on the granite rock site, which has 3km/s of S-wave velocity. The station HRT is located at the western edge of the plain on the alluvium sediment site. It is gravity anomaly (Gravity Research Group in Southwest Japan, 2001) in this area is shown in Figure 1. In this area, the depth of bedrock estimated by gravity anomalies changes sharply from east to west as shown in Figure 1. In addition, a low gravity anomaly hollow is shown around the station HRT. It means that the depth of the bedrock must be the deepest in this area. In this study, the main purpose is clear up the effects irregular subsurface structure that located on the western edge of the Nobi plain on the seismic ground motion in the plain, and we discuss the surface waves generated from the edge of the plain. Thus earthquakes that the epicenter is located at the southwest and northeast direction for the Nobi plain of northeast are targeted and epicenters are shown in Figure 2.

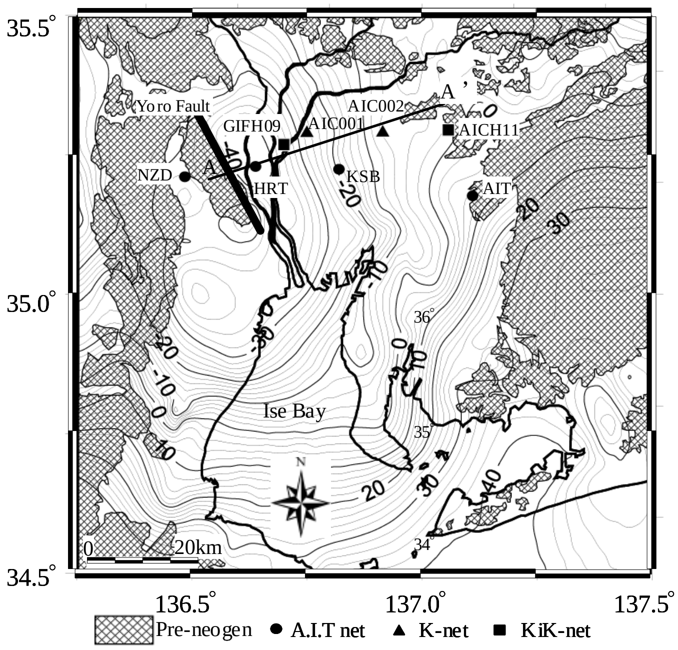

Figure 1 Map of the studied filed, the Nobi plain, Japan. The solid circles indicate seismic observation sites. Gravity anomaly is also shown

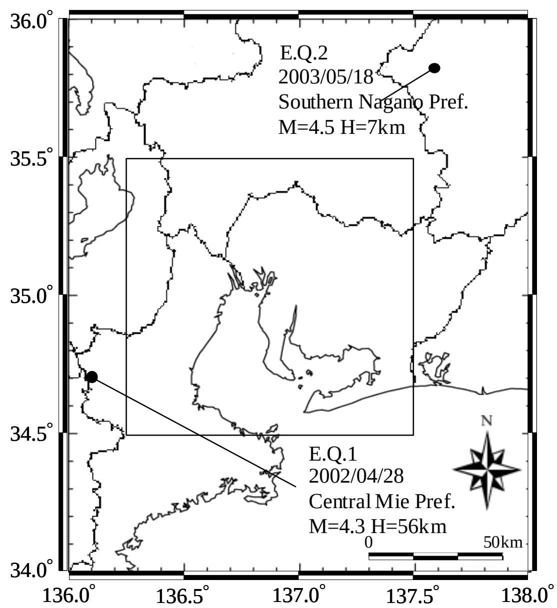

Figure 2 Location of the epicenter of the central Mie earthquake of 2002 and southern Nagano earthquake of 2003.

Figure 3 shows transverse components with velocity seismograms recorded at this region during the April 28, 2002 earthquake that occurred at the central part of Mie Prefecture (M=4.3, H=56km, EQ1) and during May 18, 2003 earthquake that occurred at the southern part of Nagano Prefecture (M=4.5, H=7km, EQ2) respectively. Each velocity seismogram is band-pass filtered in the period range from 1 to 6 seconds and in addition the seismograms recorded at K-NET and KiK-NET (NIED). During the EQ1 in figure 3, significant later phases (L1) appear following the first S-wave arrivals at HRT during both earthquakes. Moreover the particle motions of the first S-wave at all stations and later phase (L1) recorded at HRT have predominant at perpendicular component (N170E°) against the direction of the epicenter. Although the L1 phase after the first S-wave is remarkable at HRT, this phase disappears toward to the eastern part of the Nobi plain. Such phenomena can be seen to observation record only in case of the earthquake, which occurs in the area located in the southwest part of Nobi Plain, and it is easy to follow up the generation and a propagation process of the seismic waves from the edge of the plain, because each phases observed in seismograms can be separated and identified. During the EQ2 in figure 3, the particle motions of the first S-wave at all stations almost have predominant at perpendicular component (N150E°) against the direction of the epicenter. Significant later phases appear following the first S-wave at KSB, GIFH09, and HRT on the alluvium sites, the later phase (L1) arrived after 40 seconds of the first S-wave recorded at HRT have a similar predominant component to the first S-wave, and this phase have the biggest amplitude of the record especially. In addition, the later phases that appeared to the earthquake motions recorded at the HRT during EQ1 and EQ2 was tried to identification using the non-stationary spectrum analysis. The multiple filtering analyses were used in the process of obtaining the non-stationary spectrum. The transversely polarized ground velocities from the observed record and the results of the multiple filtering analyses at HRT during EQ1 and EQ2 are shown in Figure 4. The velocities are band-pass filtered in the period range from 1 to 6 seconds. As Figure 4 shows, the possibility that the later phases are the surface wave is low in EQ1, because wave trains are not dispersed. On the other hand, a well-dispersed wave train after 40 seconds can be clearly identified in the period range from 2 to 5 seconds in EQ2, suggesting the propagation of a Love wave.

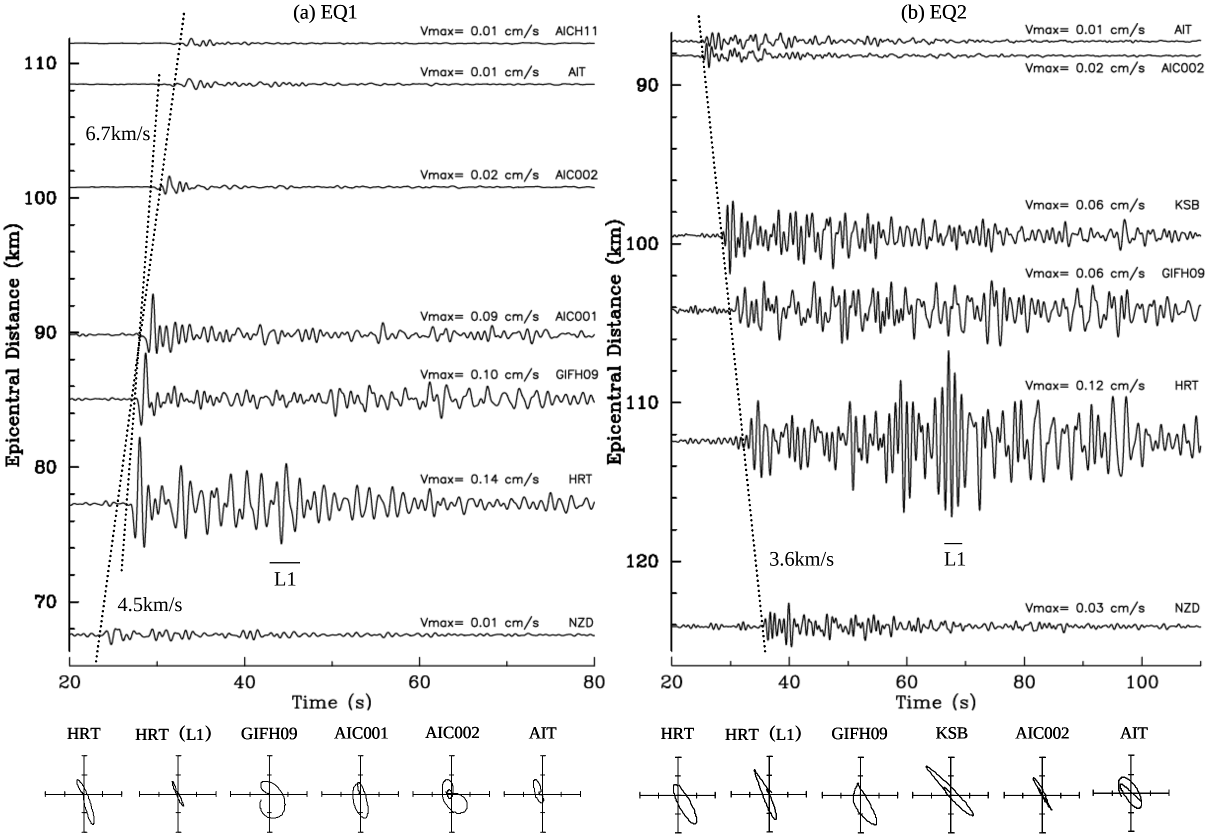

Figure 3 Transverse velocities observed in the Nobi plain during the earthquake on April 28 in 2002 (a) and on May 18 in 2003 (b). Each trace is filtered in a period range from 1 to 6 seconds.

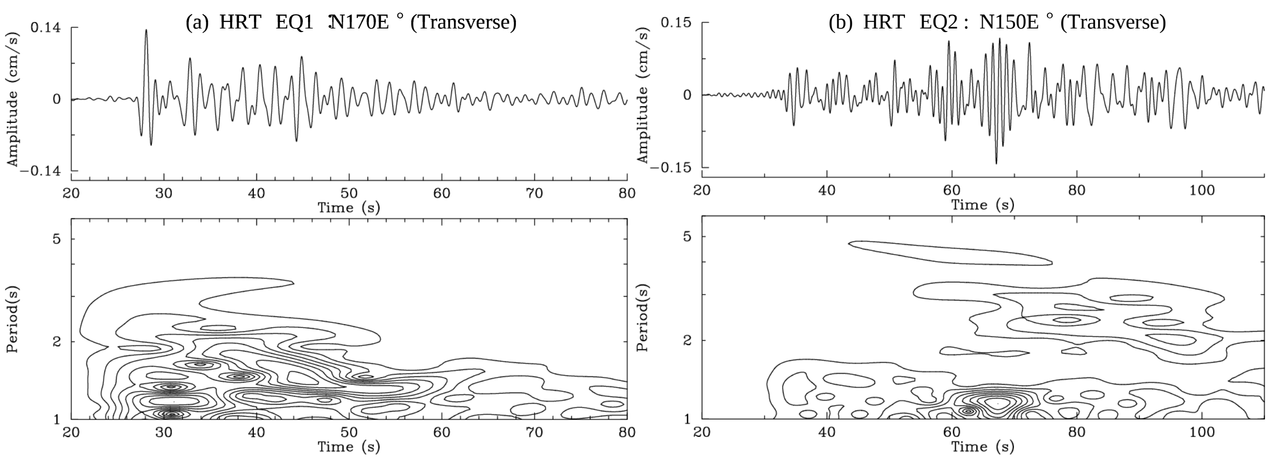

Figure 4 Multiple filtering analyses of the transverse components at HRT during the earthquake on April 28 in 2002 (a) and on May 18 in 2003 (b). Each trace is filtered in a period range from 1 to 6 seconds.

3. DEEP SUBSURFACE STRUCTURES IN THE NOBI PLAIN

Various kinds of surveys have been conducted in the Nobi plain in recent years by Aichi Prefecture (Aichi Prefecture, 2000-2002), the ground structure to the bedrock have been clarified in the Nobi plain. We try to the microtremor array surveys in the Nobi plain. Array measurements of microtremors were conducted at earthquake observation stations to know S-wave velocity profiles for estimating strong ground motion. We observed microtremors at 4 sites by installing temporarily three arrays at each site (Saguchi *et al*., 2000). Each array consists of seven vertical seismometers with station spacing of 0.2 to 2km. Phase velocities of microtremors were estimated from a frequency-wavenumber (F-K) analysis. They show dispersive features in a frequency rang from 0.2 to 3.5Hz, suggesting propagation of Rayleigh wave in the station HRT, as shown in Figure 5. The phase velocity data were inverted to S-wave velocity profiles of thick sediments by an inversion based on the least squares method. Figure 6 shows S-wave velocity profiles in the station HRT.

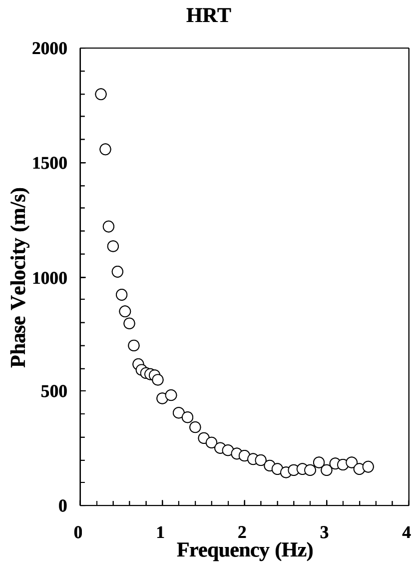

Figure 5 Phase velocity of microtremors observed at HRT

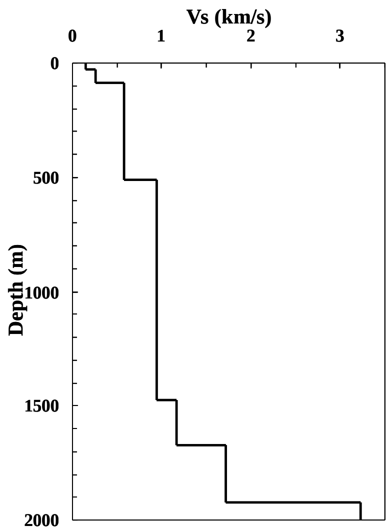

Figure 6 Subsurface structure of deep sediments inverted form the phase velocity shown in Figure 5

The alluvium layer, which has 0.15km/s of S wave velocity, exists on surface of the station HRT located at the western edge of the plain. Then, a one-dimensional analysis based on multiple reflection theory was performed to clarify whether the later phases recorded at HRT was excited by this layer during EQ1 and EQ2. An amplification factor and the comparison between the observed and the synthetic seismograms at HRT are shown in Figure 7. As Figure 7 shows, the amplitude of the first S-wave in the synthetic seismogram is smaller than that of the observation seismogram, and later phases that appear after 30 second is not reproduce at all in EQ1. Similarly, later phases that appear after 55 second is not reproduce at all in EQ2. Therefore, it is clarified that the later phases recorded at HRT was not excited by an alluvium layer during EQ1 and EQ2. These significant later phases recoded at HRT generated from the edge of plain and propagated within sedimentary layers, and it is necessary to consider underground structures not only particular observation sites but also process of propagation of seismic motion in order to clarify the propagation characteristics of the seismic ground motions. Moreover, it is need to construct an underground structural model corresponding to the A-A ' line in Figure 1. We try to construct the 2D underground structural model based on results from array surveys and various kinds of surveys by Aichi Prefecture in the Nobi plain. At first, we constructed the structure of the sedimentary layer to the seismic basement based on result of a reflection survey by Aichi Prefecture. Then, the structure in the sedimentary layer was divided three layers by the geologic province, and four layer structure model that consists of Holocene, Pleistocene, Miocene and basement rock was constructed as shown in Figure 8. On the other hand, the P-wave velocities and densities of each layer were decided from the result of the refraction survey and PS logging by Aichi Prefecture. The S-wave velocities of each layer were determined from the result of the microtremor array surveys in a seismic observation sites. Q values of each layer were adjusted from the result of the one-dimensional analysis using earthquake record of the deep earthquake that occurred under the Nobi plain. We assumed that the Q value was fixed in spite of a frequency. The origin of the subsurface structure model is indicated in table 1.

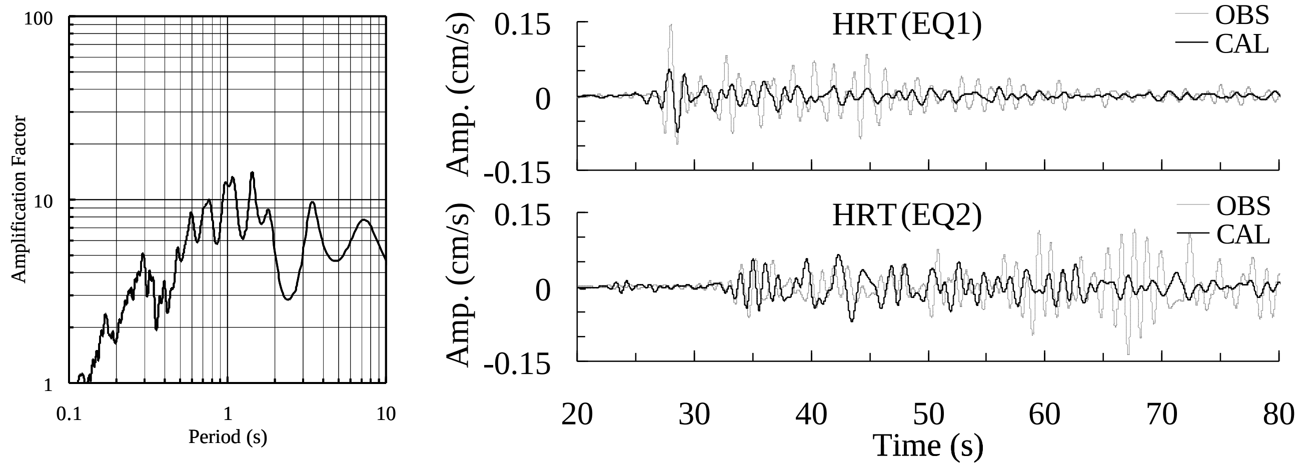

Figure 7 Amplification factor and the comparison between the observed and the synthetic seismograms at HRT. Band pass filter with period from 1 to 6 seconds for the observed and the synthetic seismograms.

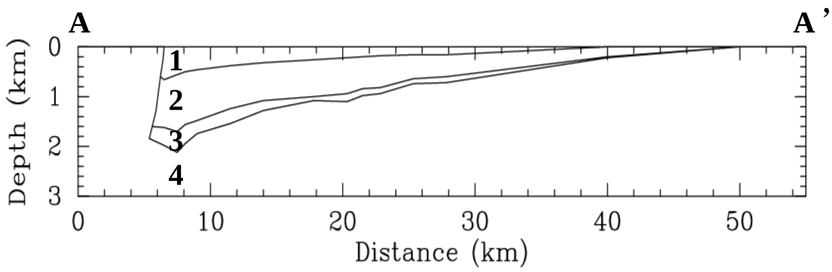

Figure 8 2D underground structural model corresponding to the A-A ' line in Figure 1

Table 1 The origin of the subsurface structure model

Vp(km/s)	Vs(km/s)	ρ (t/m^3)	Q
1.78	0.47	1.81	100
2.39	0.92	2.12	200
2.80	1.60	2.35	300
5.50	2.80	2.50	∞

4. NUMERICAL SIMULATION BY FINITE-DIFFERENCE METHOD

4.1. Analytical outline and analytical result

In this study, the 2-D finite difference method is used to perform a numerical simulation. We are interested in significant later phases generation and propagation within sedimentary layers, and an observed seismogram on the rock site can be regarded as an input wave to sedimentary layers. Therefore, the velocity records of transverse component, which observed at AIT station on a hard rock, during EQ1and EQ2, are used as input wave. The main portion of the seismogram consists of SH wave and Love waves, and set each input waves as plane wave with 39-degree and 45-degree incidence respectively. In the computation, a band pass filter with periods from 1 to 6 second was applied considering the stable condition. The comparison between the observed and the synthetic seismograms at each station on the sedimentary in EQ1 and EQ2 are shown in Figure 9 respectively. The results indicate that the characteristics of the simulated waveforms, including the later phases, display good agreement with the observed seismograms, compared with one-dimensional analyses shown in Figure 7.

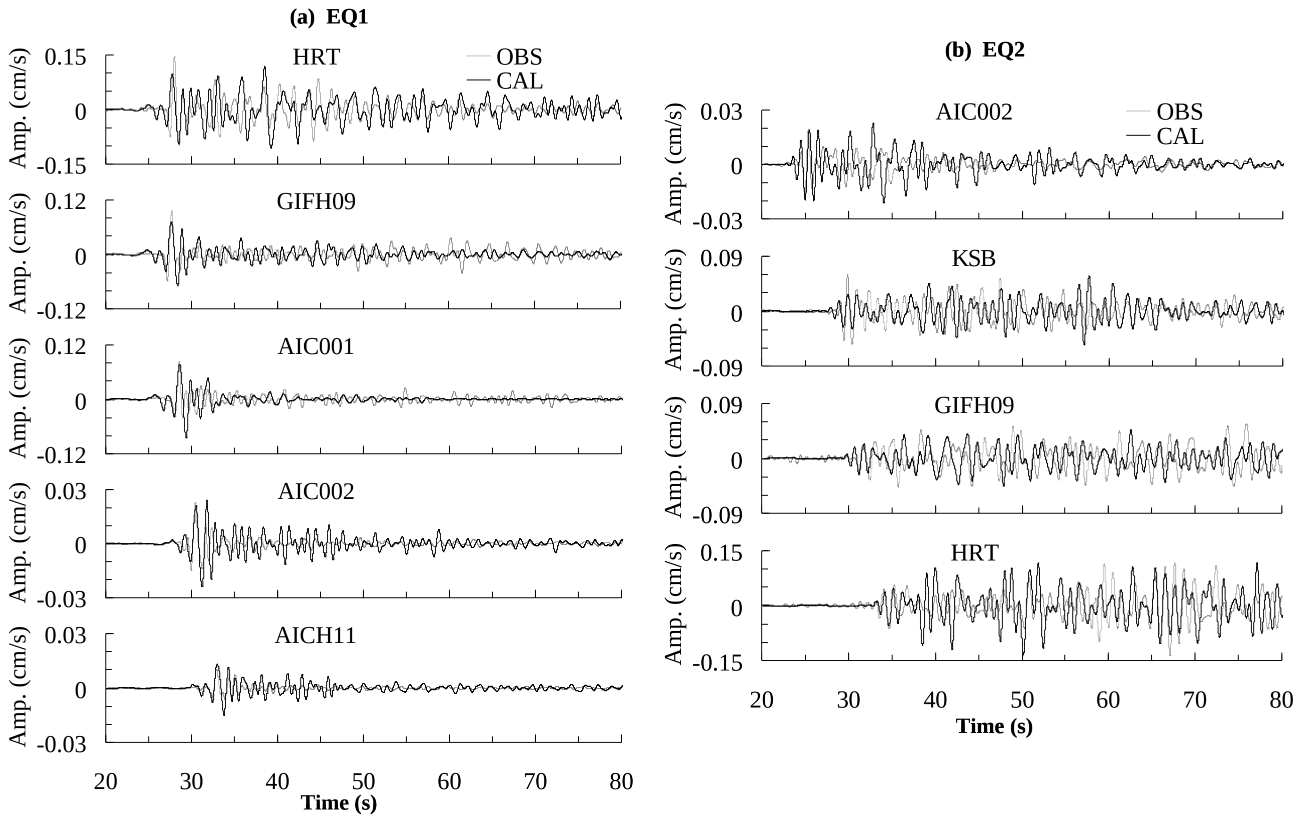

Figure 9 Comparison between the observed and the synthetic seismograms at each station on the sedimentary in (a) EQ1 and (b) EQ2. Band pass filter with period from 1 to 6 seconds for the observed and the synthetic seismograms.

4.2. Generation mechanism of the following phase at edge of plains

The generation and propagation process of the later phases into the sedimentary plain is clarified from the snap shot of two-dimension section during EQ1 and EQ2. Figure 10 shows snapshots of the response at different times as the incident seismic wave travels through the sedimentary in EQ1. The wave that generated from the edge starts to propagate in the horizontal direction, and this wave continues propagating to east as shown in the snapshots at t=25.67 seconds. When the direct S-wave hits the surface at t=27.73 seconds, we can see clearly a constructive interference between the direct S-wave inside the sedimentary and the wave that generated from the edge in the snapshot at t=27.73 seconds. Therefore, it became clear that the same phenomenon in Kobe Area during the Hyogo-ken Nanbu earthquake of 1995 is also occurring near the western edge of the Nobi plain. A multi-reflection wave of direct S-wave isn't seen in the snapshots after t= 34.22 seconds, since subsurface structure is rise inclination to the direction of propagation of the seismic waves. Figure 11 shows snapshots of the response at different times as the incident seismic wave travels through the sedimentary in EQ2. We can see multiple reflection waves (A') that reflects between ground surface and the seismic bedrock while going away from the edge of plain appears remarkably in the snapshots at t=34.76-40.17 seconds, after the direct S- wave (A) incident from the seismic bedrock into the sedimentary layer. Moreover this multiple reflection wave become the wave (B) which propagate into the sedimentary layer from east to west in the horizontal direction in the snapshots at t=45.58-50.99 seconds. The wave (C) is performed multiple reflection in the surface layer, and propagate into the sedimentary layer from east to west in the horizontal direction in the snapshots at t=56.45s-72.64 seconds. Therefore, the earthquake wave (B) and wave (C) are trapped in the sedimentary layer; it is suggest that they are Love waves clearly. It is a factor that the amplitude of the later phase (L1) arrived after 40 seconds of the first S-wave recorded at HRT became large especially.

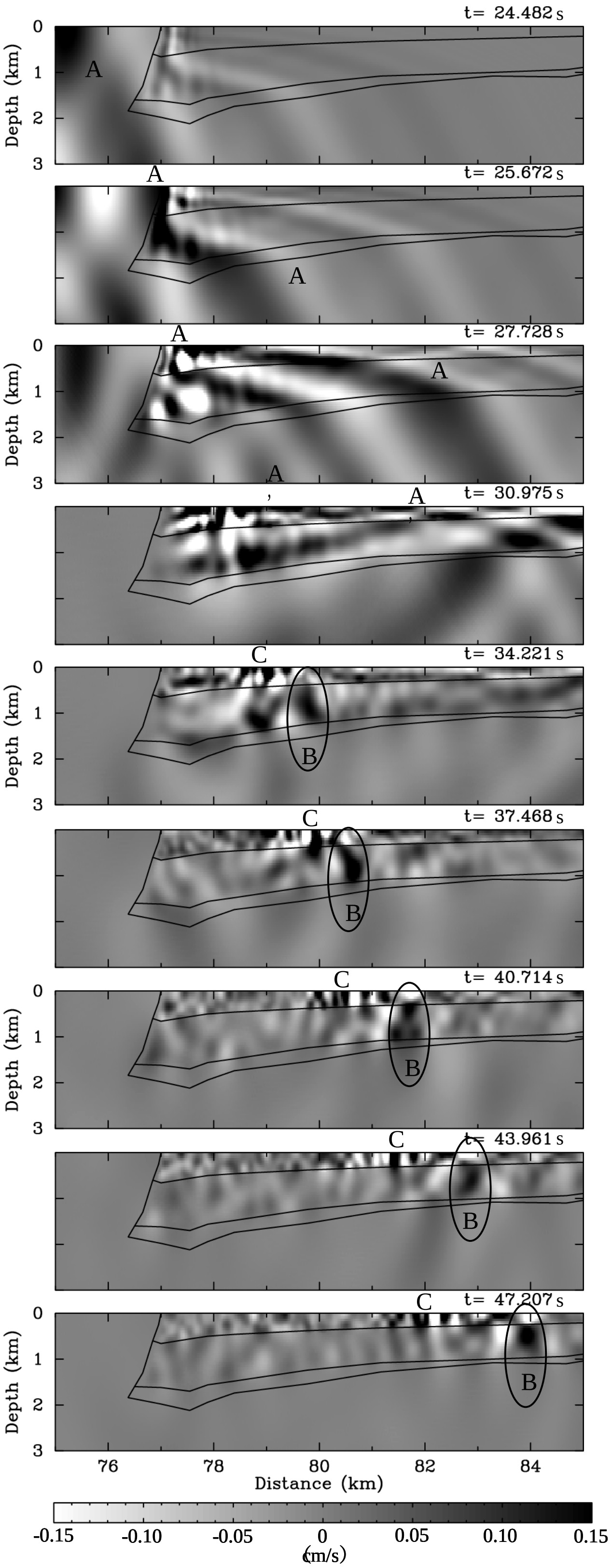

Figure 10 snapshots of 2D wave propagation in the Nobi plain during the central Mie earthquake of 2002 (EQ1).

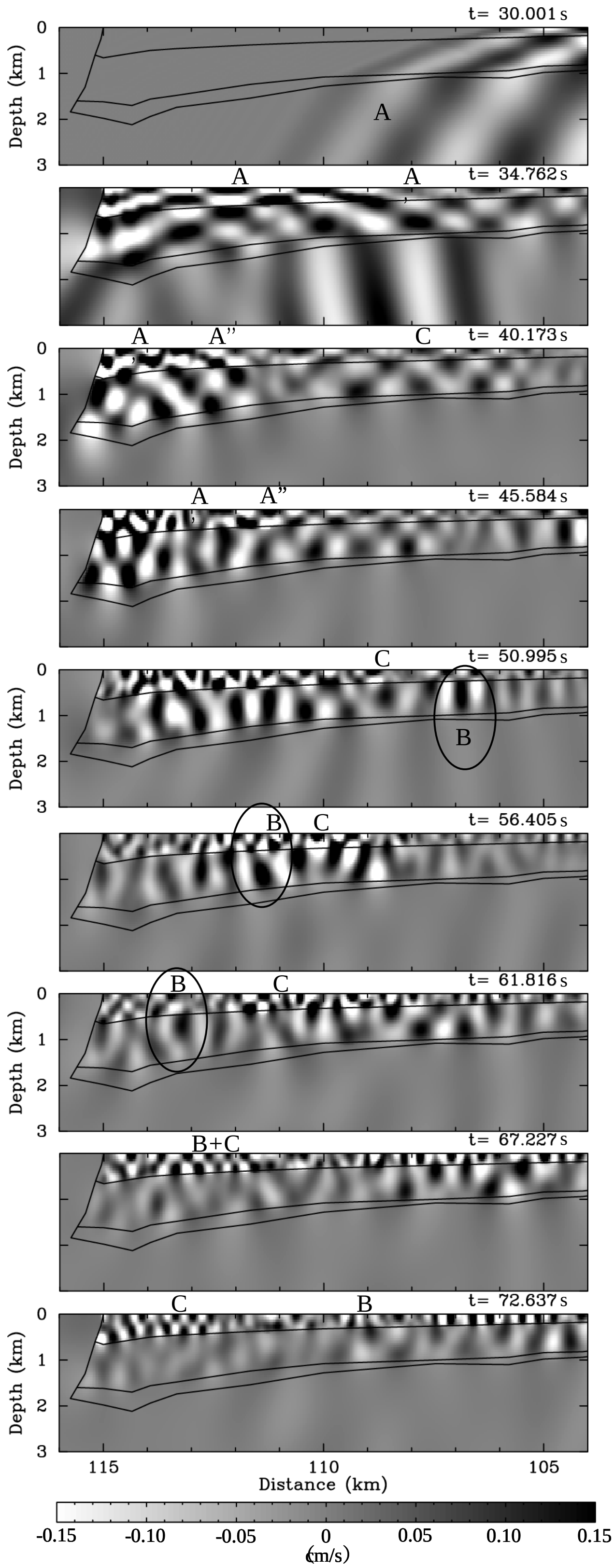

Figure 11 snapshots of 2D wave propagation in the Nobi plain during the southern Nagano earthquake of 2003 (EQ2).

5. CONCLUSIONS

In this study, we applied 2D finite difference method to simulate the later phases during earthquakes observed at the sediment sites using the subsurface structures derived from the seismic and microtremors prospecting process. The results indicate that when considering then as basin excited waves, the characteristics of the simulated waveforms, including the later phases, display good agreement with the observed seismograms. Moreover, the earthquake motion characteristic was clarified by the propagation process of seismic waves in the western part of Nobi plain. We also clarified effects of the irregular underground structure on seismic wave propagation. When the seismic wave came from the direction of the west to the Nobi plain, it was clarified that the amplitude of the later phase became large about 3 to 4 time compared with one dimensional analyses near the western edge of plain. The other hand, when the Love wave which has generated from the eastern edge and propagated in the sedimentary layers reflected at the western edge of the Nobi plain and amplitude of the seismic motions become larger in amplitude near the western edge of plain and longer in duration.

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