LONG-PERIOD GROUND MOTION SIMULATION OF 2004 OFF THE KII PENINSULA EARTHQUAKES AND PREDICTION OF FUTURE M8 CLASS EARTHQUAKES ALONG NANKAI TROUGH SUBDUCTION ZONE, SOUTH OF JAPAN ISLAND

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ABSTRACT :

We simulate long-period ground motions of observed Magnitude 7 class earthquake and predict those of future Magnitude 8 class large subduction earthquakes along Nankai Trough, south off Japanese archipelago. The numerical simulations are performed by a large-scale finite element method considering three-dimensional subsurface structure including both of propagation pass structure and large-scale sedimentary basin structure of Kanto plain on which Tokyo metropolitan is located. To verify the three-dimensional subsurface ground model, we simulate the 2004 off the Kii peninsula earthquake that occurred near Nankai Trough. The soft layer of the sedimentary wedge along Nankai trough has the effect to elongate the duration of ground motion and lessen the amplitude. We simulated the ground motion of the Tokai-Tonankai coupled earthquake. Long period ground motion reaches Kanto plain about 130 seconds after the rupture starts. The principal motion continues more than 4 minutes. The model shown in this study still has a limitation to underestimate the amplified ground motions in the Kanto plain. It is necessary to adjust velocity structure and Q value to obtain a better model.

KEYWORDS: Tonankai Earthquake, Tokai Earthquake, Finite Element Method, Sedimentary Wedge, Underground structure model, Kanto Plain

1. INTRODUCTION

Nankai Trough is the convergent boundary where Philippine Sea plate is subducting under the Southwestern part of Japanese archipelago. Historically, large thrust earthquakes of Magnitude 8 have occurred repeatedly with the recurrence interval of 100 to 150 years. They are named Tokai, Tonankai and Nankai earthquake (Fig. 1). The latest ones are 1944 Tonankai earthquake (M7.9) and 1946 Nankai earthquake (M8.0). The next M8 class large earthquake is supposed to occur in near future, and it is very important issue for disaster prevention in Japan.

The long period ground motions generated at the focal regions of these large earthquakes propagate long distance to large sedimentary basins such as Knato plain where Tokyo metropolitan is located. Those motions are amplified by sedimentary basin and shake the long period structures such as high-rise buildings and oil tanks. Therefore, it is important to evaluate the earthquake ground motions considering the appropriate modeling of the long propagation path structure and sedimentary basin structure. For this purpose, numerical simulations of earthquake ground motions by large-scale finite differences method(FDM) and finite elements method (FEM) have been studied .

Two M_{JMA} 7.1 and M_{JMA} 7.4 (Japan Meteorological Agency Magnitude) occurred on September 5, 2004 off the Kii peninsula. Those epicenters are located in the vicinity of the focal region of Tonankai earthquake. Long-period ground motions excited by these earthquakes were observed nationwide. Therefore, these Off the Kii peninsula earthquakes are good examples to verify the subsurface ground model including propagation path and Kanto basin.

Numerical simulations of the Off the Kii peninsula earthquakes are studied by Yamada and Iwata(2005), Hayakawa et al.(2005) and Ikegami et al.(2008). Along Nankai Trough, the low velocity layer called Sedimentary Wedge exists (Nakanishi et al.(2002)). Yamada and Iwata(2005) and Ikegami et al.(2008) point out that the Sedimentary Wedge causes the long duration of ground motions.

In this paper, we construct three-dimensional subsurface ground model considering the sedimentary wedge in the propagation path and the sedimentary basin structure of Kanto plain. Next, we perform numerical simulation of the Off the Kii peninsula earthquake(M_{JMA} 7.1) by a large-scale finite element method and compared the results to the observed records. Finally, we predict future M8 class earthquake.

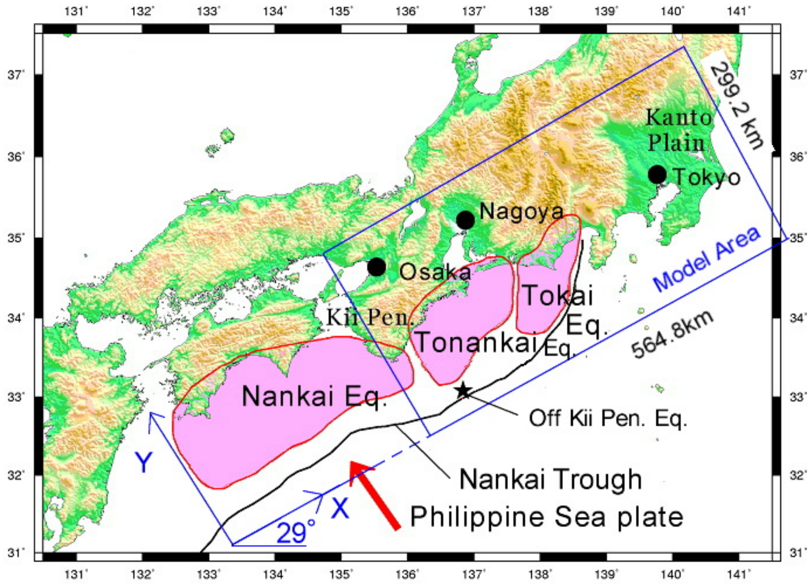


Fig.1 M8 earthquakes along Nanakai trough, the epicenter of the 2004 off the Kii peninsula earthquake and model area for FEM calculation

2. SUBSURFACE GROUND MODEL

We constructed the three-dimensional subsurface ground model for the area of 564.8km x 299.2 km as shown in Fig.1. Model depth is 49.6km. We modeled the upper surface of Philippine Sea plate, Moho discontinuity Conrad discontinuity, Sedimentary wedge along Nankai trough and sedimentary basin structure of Kanto plain. Figure 2 shows the depth of those boundaries. Using those boundaries, we modeled the domain into 13 layers. Table 1(a) shows the material properties of the layers.

We constructed the upper surface of Philippine Sea plate (top of layer 11, Fig.2(a)) combining the depth obtained by Nakamura(1997), Noguchi(1996), Ishida(1992), and Sato et al.(2005). Only for Nakamura(1997), we assumed 5km shallower depth because Nakamura's surface is the upper surface of seismic activities and the plate surface is shallower than it. We modeled the depth of Moho discontinuity (top of layer 10, Fig.2(b)) based on Ryoki(1999). The depth of Conrad discontinuity (top of layer 9) was set to be half of Moho discontinuity or 15 km near the Philippine Sea plate.

We modeled the Sedimentary wedge (layer 5,6) along Nankai trough based on Nakanishi et al. (1998) and Nakanishi at al. (2002). The left part of Fig 2(c) shows the thickness of the modeled sedimentary wedge. The P wave velocity (Vp) obtained by Nakanishi increases along the depth. We modeled it into 2 layers. Vp of the shallower part than 3km is 2.7km/s and that of deeper part is 4.0km/s. S wave velocity and density was given based on Ludwig et al. (1970).

We set the thickness of Philippine Sea plate (layer 11,12) to be 7km. Upper 2km has low velocity. At the surface, we modeled the Vs=1.1km/s layer (layer 4) with thickness of 1km at the sea and 0.5km at the land. The material properties are given based on Yamada and Iwata (2005) except the sedimentary wedge.

We modeled Knato plain into 3 layers (layer 1,2, 3) based on Yamanaka and Yamada(2002). The depth of layer boundaries are shown in the right part of Fig.2(c), Fig.2(d) and Fig.2(e). Q values are set to be equal to that of each study at the reference frequency 0.2 Hz. The sea floor and land topography are modeled to be flat. Figure 3 shows the vertical sections along Y direction at (a) X=375km section that cut across the sedimentary wedge and includes the hypocenter of the 2004 Off the Kii peninsula earthquake and (b) X=750 km section that cut across Kanto plain.

Table 1 Material Property

(a) Model A (with sedimentary wedge)

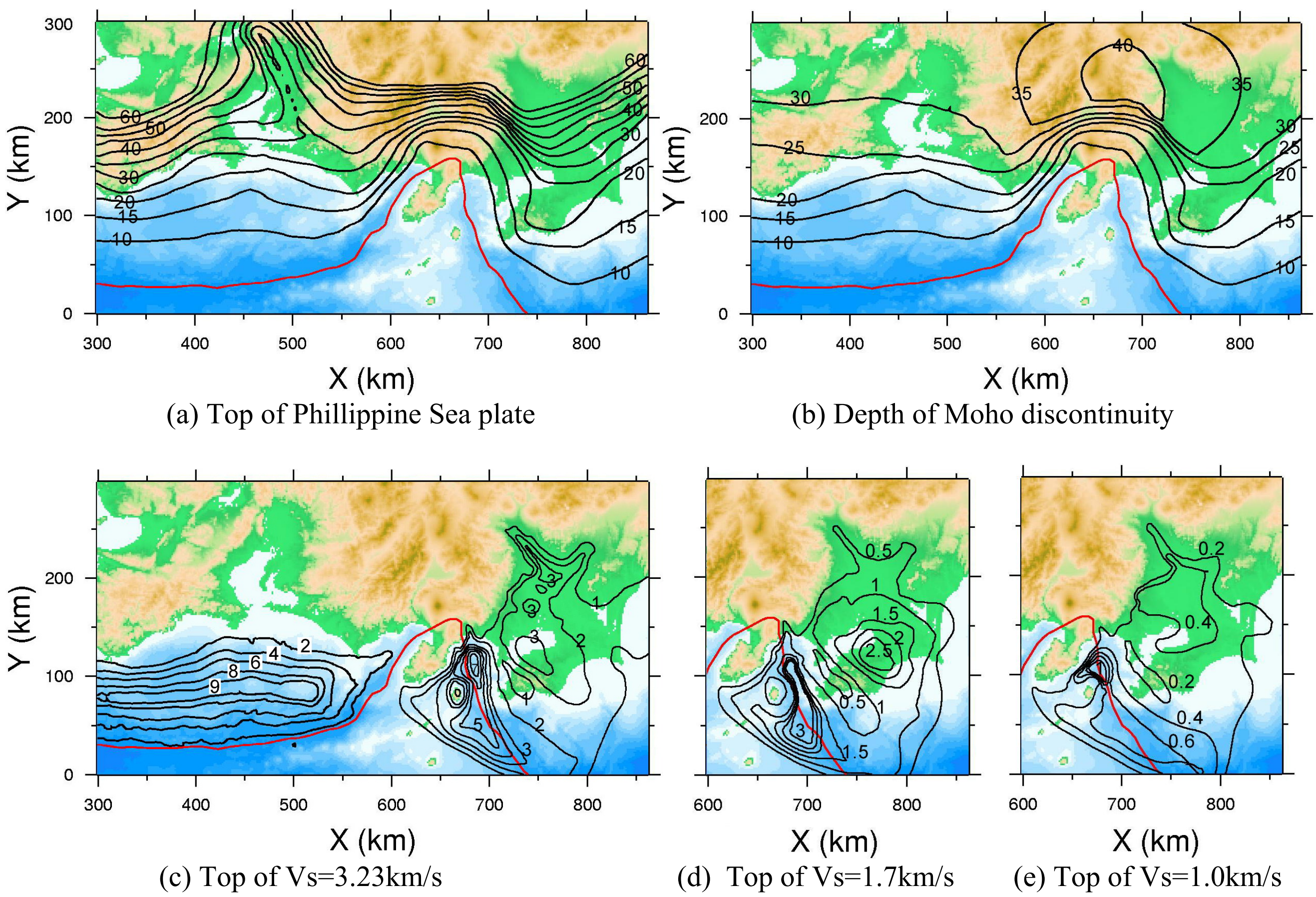
Layer	Vs (km/s)	Vp (km/s)	density (g/cm3)	Q	Q (at f=0.2Hz)
1	0.5	1.8	1.9	500f	100
2	1.0	2.4	2.1	500f	100
3	1.7	3.2	2.3	750f	150
4	1.1	2.0	2.0	1000f	200
5	1.4	2.7	2.4	1000f	200
6	2.2	4.0	2.5	1250f	250
7	3.23	5.5	2.5	1500f	300
8	3.53	6.0	2.7	2500f	500
9	3.94	6.7	2.8	3000f	600
10	4.6	7.8	3.2	3500f	700
11	2.9	5.0	2.4	1500f	300
12	4.0	6.8	2.9	3000f	600
13	4.7	8.0	3.2	5000f	1000

f:frequency(Hz)

(b) Model B (without sedimentary wedge)

Layer	Vs (km/s)	Vp (km/s)	density (g/cm3)	Q	Q (at f=0.2Hz)
1	0.5	1.8	1.9	500f	100
2	1.0	2.4	2.1	500f	100
3	1.7	3.2	2.3	750f	150
4	1.1	2.0	2.0	1000f	200
5	3.23	5.5	2.5	1500f	300
6	3.23	5.5	2.5	1500f	300
7	3.23	5.5	2.5	1500f	300
8	3.53	6.0	2.7	2500f	500
9	3.94	6.7	2.8	3000f	600
10	4.6	7.8	3.2	3500f	700
11	2.9	5.0	2.4	1500f	300
12	4.0	6.8	2.9	3000f	600
13	4.7	8.0	3.2	5000f	1000

f:frequency(Hz)



(a) Top of Phillippine Sea plate

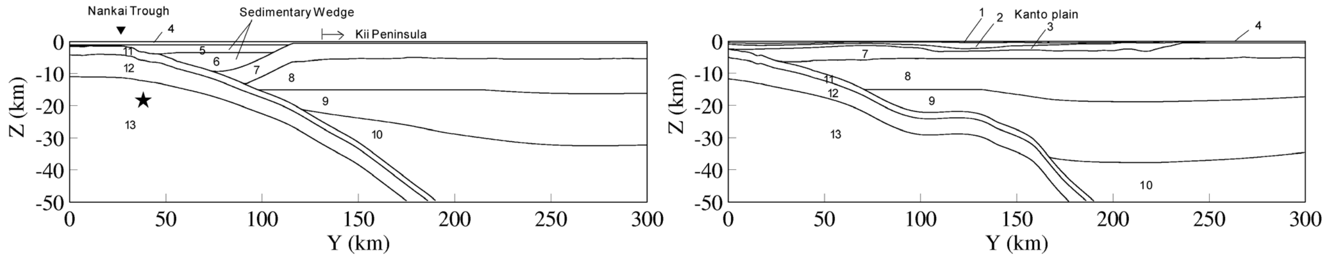
(b) Depth of Moho discontinuity

(c) Top of Vs=3.23km/s

(d) Top of Vs=1.7km/s

(e) Top of Vs=1.0km/s

Fig.2 Depth of layer boundaries.



(a) X=357km (b)X=750km

Fig.3 Vertical sections along Y direction(N 29W).

We considered two models as shown in Table1. Model A has the sedimentary wedge and Model B is without sedimentary wedge. The layer 5 and 6 is replaced with the same material of layer 7. The FEM model is constructed using tetrahedron. The number of nodes is 15,425,786 and that of elements is 85,536,015. The largest elemnet size is 1600m and the smallest is 200m. This model is effective at the period domain more than 4 seconds. The width of elements is chosen so that more than 10 elements exist for the wavelength of Swave in each layer.

3. SIMULATION OF THE 2004 OFF THE KII PENINSULA EARTHQUAKE

The seismic source of the Off the Kii peninsula earthquake (September 5, 2004, MJMA 7.1) is modeled by a point source based on Yamada and Iwata(2005). Table 2 shows the source parameter and Fig.4 shows the source time function.

Figure 5 shows snapshots of Y (N29W) component of velocity for Model A (with sedimentary wedge) and Model B (without sedimentary wedge). The result of Model A shows the seismic waves are once captured in the sedimentary wedge and are released gradually. This causes long duration of ground motion at a site. On the other hand, the result of Model B shows the seismic waves propagate only concentrically.

Table 2 Source parameter

Latitude (deg)	33.09
Longitude (deg)	136.63
depth (km)	18
strike (deg)	280
dip (deg)	42
rake (deg)	105
Seismic Moment (Nm)	6.0×10^{19}

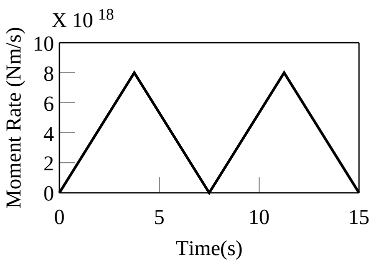
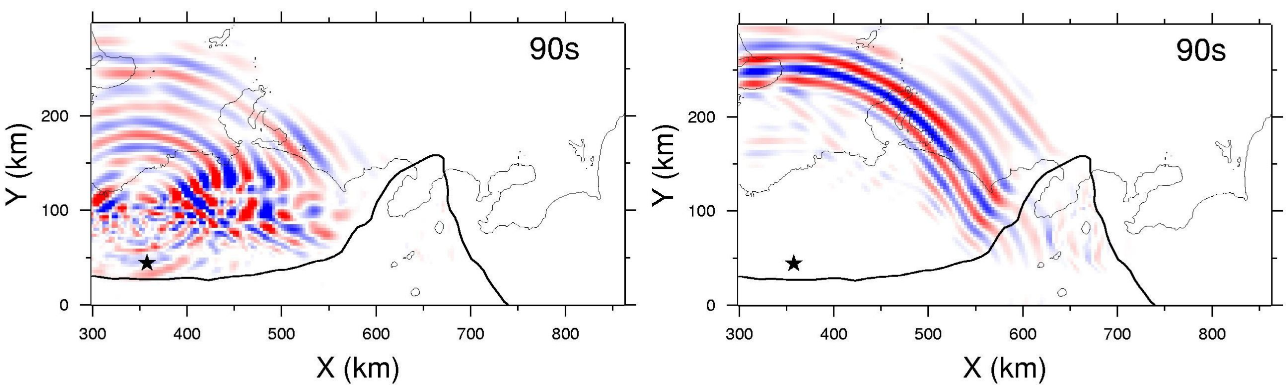


Fig.4 Source time function



(a) Model A (with Sedientary Wedge) (b) Model B (without Sedimentary Wedge)

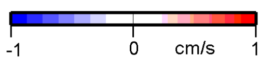


Fig.5 Snapshot of velocity Y (N29W) component

Figure 7 shows the observed and calculated velocity waveform (North-South component) at the observation sites shown in Fig .6. All the waves are low-pass filtered components longer than 4 seconds. OSKH04, AICH12, KNGH19 and SZOH41 are KiK-net observation stations operated by NIED. The record of SHS was observed at the 1st floor of the Shizuoka branch office of Taisei Corporation. The record of SJK was observed in a borehole (G.L. -65m) in the firm gravel layer at Shinjuku, Tokyo.

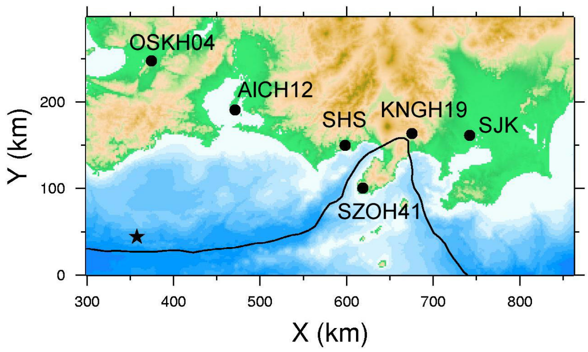


Fig.6 Strong motion observation site

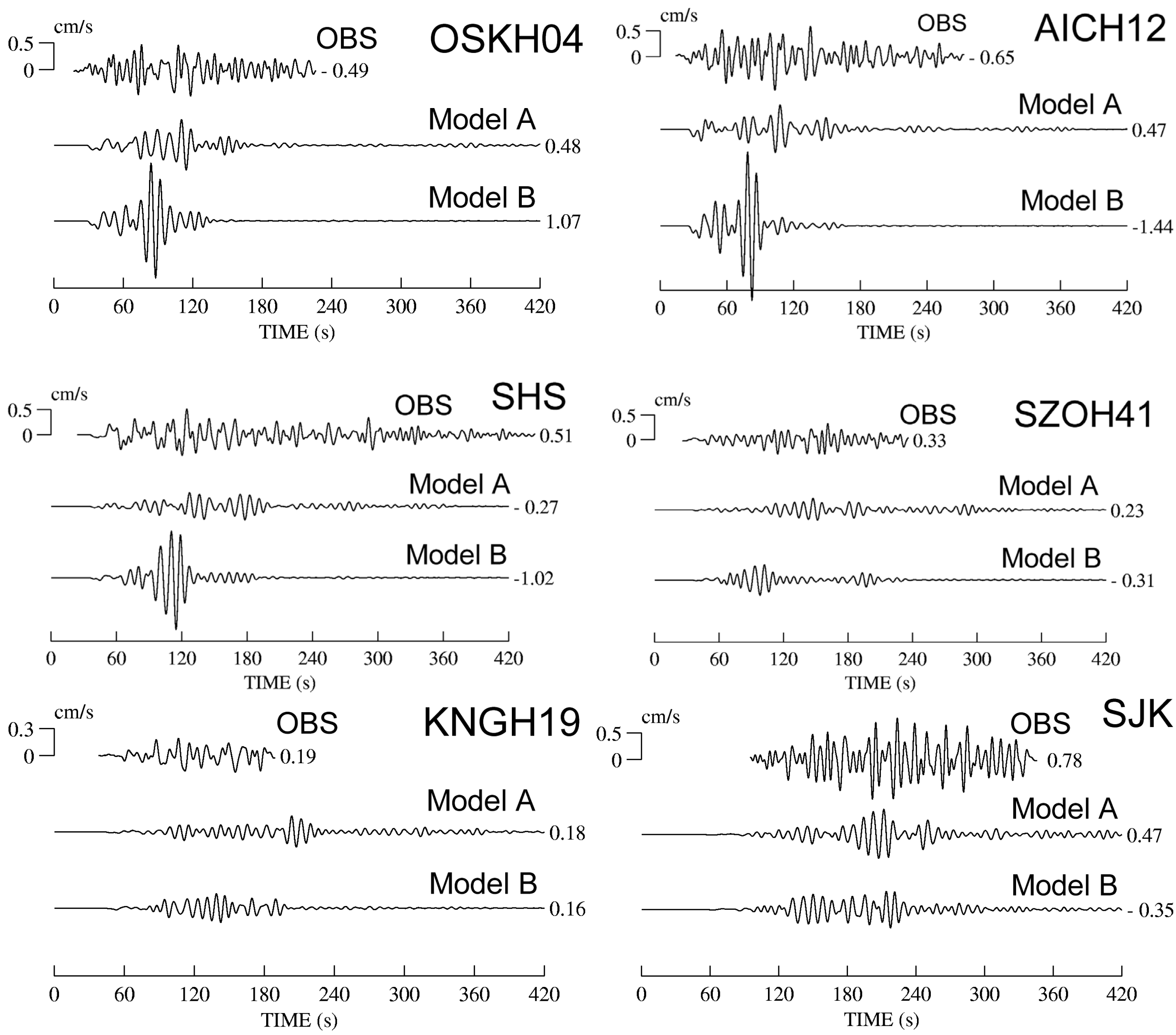


Fig.7 Comparison of Velocity NS component

For OSKH04, AICH12 and SHS, Model A (with sedimentary wedge) reproduces the long duration of observed records. On the other hand, the waveform calculated by Model B (without sedimentary wedge) have shorter duration and larger amplitude than observed records. The soft layer of sedimentary wedge has the effect to elongate the duration of ground motion and lessen the amplitude.

In this study, the sedimentary basin structure of Osaka plain around OSKH04 and Nobi plain around AICH12 are not considered. Observed records of OSKH04 and AICH12 have short period components more than calculated waves. These seem to be the ground motions amplified by basin structure.

Although the Kanto plain structure is considered in the model, the calculated wave at SJK underestimate the observed record. It is necessary to adjust velocity structure and Q value to obtain a better model.

4. PREDICTION OF MAGNITUDE 8 EARTHQUAKE

We simulated the ground motion of the Tokai-Tonankai coupled earthquake. We considered the source model as shown in Fig.8, which is proposed by Central Disaster Prevention Council, Cabinet office, Government of Japan. The source parameters are shown in Table 3. Smoothed ramp function was used for source time function. The model consists of 497 point sources. Tonankai earthquake has 3 asperities (red circles, 5, 6, 7) and Tokai earthquake has 6 asperities (9-1, 9-2, 10-1, 10-2, 11-1, 11-2). The rupture starts from hypocenter 1 and propagates to the eastern end near hypocenter 2 taking 68 seconds. Just after the rupture of Tonakai earthquake ends, the rupture of Tokai earthquake starts from hypocenter 2 and reaches the eastern end taking 40 seconds.

Fig.9 shows the snapshots of velocity of Y (N29W) component at 40, 80, and 130 seconds after rupture start. It illustrates that a distinct wave front propagates eastward. The wave front reaches the Kanto plain about 130 seconds after the rupture starts.

Fig.10 shows the velocity waveform at SJK. The first large amplitude arrives at 130s and the principal motion continues more than 4 minutes. Fig.11 shows the pseudo velocity response spectra. They have dominant peaks of 5, 6.5 and 8 seconds.

As discussed in Fig.7, the model has the tendency to underestimate the ground motion in the Kanto plain. Therefore, this result has the possibility of underestimation. We would like to improve the subsurface ground model to obtain quantitatively more accurate prediction.

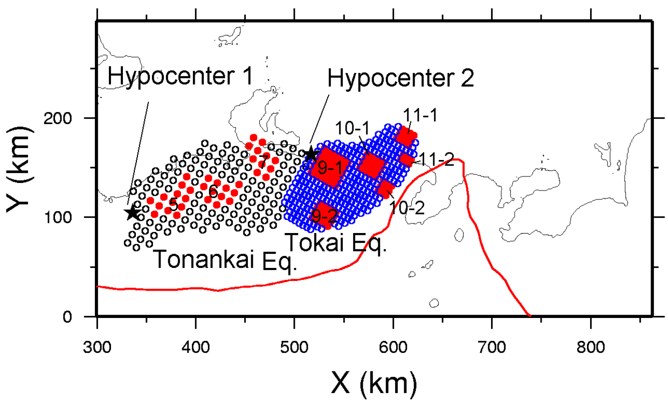


Fig.8 Source Model of Tonakai-Tokai coupled earthquake

Table 3 Source parameters

		Seismic Moment (Nm)	Average slip	Rise time (s)
Tonankai earthquake (Mw 8.2)	asperity 5	4.26×10^{20}	7.9	5.56
	asperity 6	3.31×10^{20}	7.3	5.56
	asperity 7	3.31×10^{20}	7.3	5.56
	back ground	1.21×10^{21}	2.7	5.56
	(total)	2.30×10^{21}		
Tokai earthquake (Mw 8.0)	asperity 9−1	3.09×10^{20}	6.9	5.6
	asperity9−2	1.03×10^{20}	4.8	3.7
	asperity 10−1	1.05×10^{20}	4.8	3.7
	asperity 10−2	3.49×10^{19}	3.4	2.8
	asperity 11−1	5.50×10^{19}	3.9	1.9
	asperity 11−2	2.00×10^{19}	2.8	1.9
	background	1.10×10^{21}	1.8	5.6
	(total)	4.72×10^{21}		

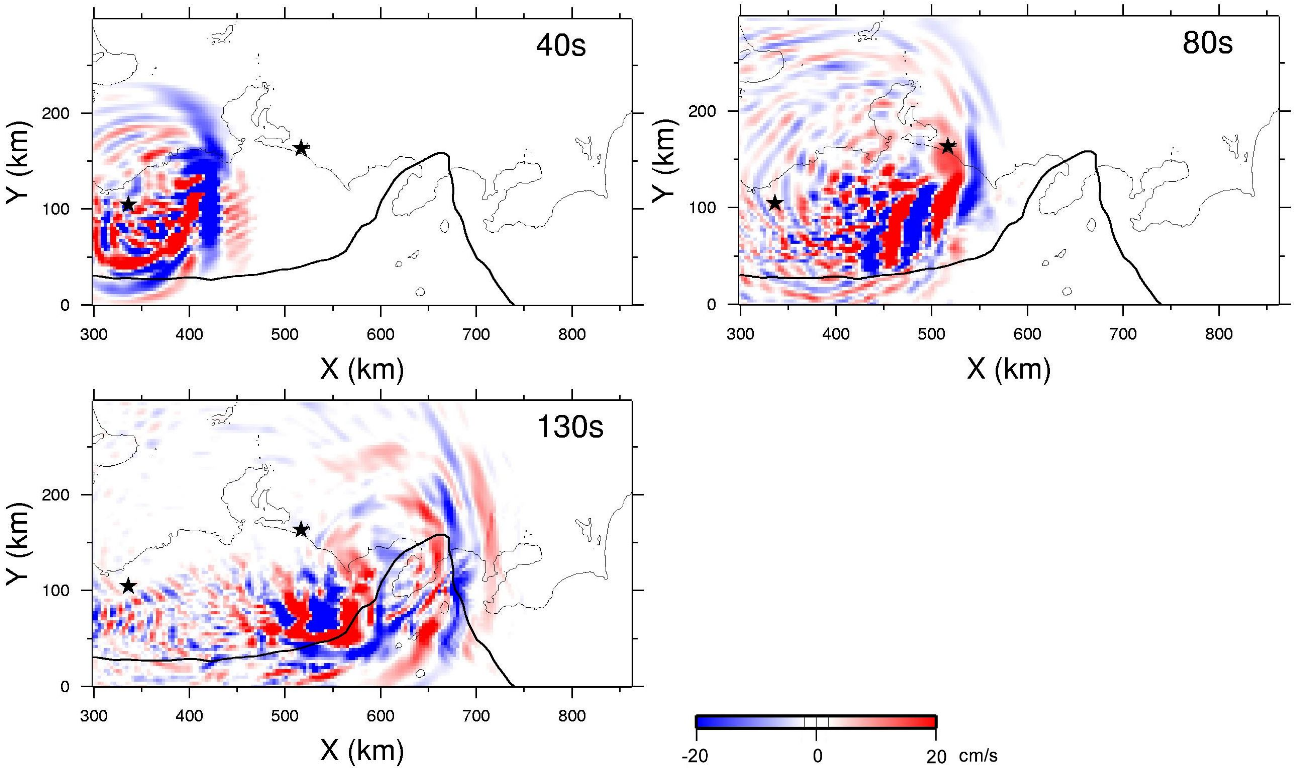


Fig.9 Snapshot of velocity Y (N29W) component of Tonankai-Tokai coupled earthqukae

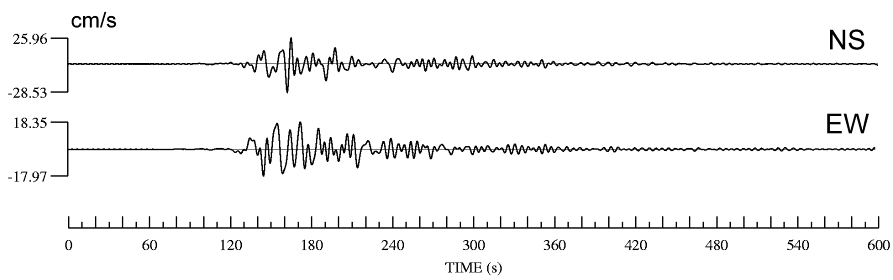


Fig.10 Calculated velocity of Tokai-Tonankai coupled earthquake at SJK

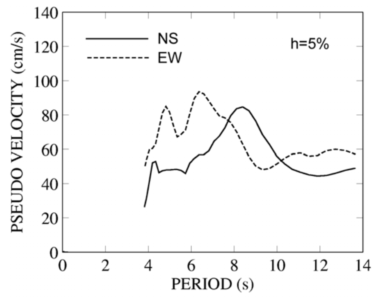


Fig.11 Pseudo velocity response spectra of calculated

5. CONCLUSION

We constructed a three-dimensional subsurface ground model and simulated Off the Kii peninsula earthquake by a large-scale finite element method. The soft layer of the sedimentary wedge along Nankai trough has the effect to elongate the duration of ground motion and lessen the amplitude. We simulated the ground motion of the Tokai-Tonankai coupled earthquake. Long period ground motion reaches Kanto plain about 130 seconds after the rupture starts. The principal motion continues more than 4 minutes. The model shown in this study has a limitation to underestimate the amplified ground motions in the Kanto plain. It is necessary to adjust velocity structure and Q value to obtain a better model.

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