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STRONG GROUND MOTION PREDICTION FOR HUGE SUBDUCTION EARTHQUAKES USING A CHARACTERIZED SOURCE MODEL AND SEVERAL SIMULATION TECHNIQUES

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SUMMARY

In Japan, the Central Disaster Prevention Council in Japan has opened the seismic intensity map due to future huge subduction earthquake linked by Nankai and Tonankai earthquakes occurred on the Nankai trough. In this study, we tried to predict broad-band strong ground motions of engineering interest during future subduction earthquakes using the empirical Green's function method. Furthermore, to understand the effects of the 3-dimensional deep underground structure of the Osaka basin to the long period ground motions, we carried out the 3-D finite difference simulation. We basically use the characterized source model composed of asperities based on the recipe for predicting strong ground motions from the subduction earthquakes by Irikura et al. [1]. In mega-city Osaka located inside basin, the long period ground motions (4 ~ 6 seconds) with very long duration have been predicted for both huge earthquakes. The amplitude of the predicted response spectrum is over the design spectrum around period of five second. These results suggest that we need to investigate the seismic safety of high-rise buildings and base-isolated buildings and so on.

INTRODUCTION

In Japan, long-term probabilities of several huge subduction earthquakes have been evaluated by the Headquaters for Earthquake Research Promotion (HERP). The huge subduction earthquakes along the Nankai trough have the high potential for the next occurrences. On the other hand, the Central Disaster Prevention Council in Japan has recently opened the seismic intensity map due to future huge subduction earthquake linked by Nankai and Tonankai earthquakes occurred along the Nankai trough. In order to mitigate the disaster caused by such earthquakes, it is very important to predict not only the seismic intensity but also the broad-band strong ground motions of engineering interest before events. A methodology has been proposed to estimate the strong ground motions from scenario earthquakes (inland earthquakes as well as subduction earthquakes) by Irikura et al. [1]. They call it the recipe for strong ground motion prediction of future earthquakes. In this study, we try to predict broad-band strong ground

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motions from the hypothetical Nankai (M8.4) as well as the Tonankai (M8.1) earthquakes based on the recipe. In particular, we concentrate the prediction of strong ground motions inside the Osaka basin with very complicated underground structure. Broad-band strong ground motions have been estimated by the empirical Green's function method. Furthermore, the characteristics of long period ground motions have been preliminarily investigated by the 3-D finite difference method considering 3-D underground structure of the Osaka basin.

SOURCE MODEL

We basically use the characterized source model proposed by the HERP. Such a model is based on the recipe for strong ground motion prediction by Irikura et al. [1]. Fig.1 shows the source model composed of three asperities on the fault for the Nankai and the Tonankai earthquakes. The area of the largest asperity and the area of the combined asperities for each source model are basically determined from the self-similar scaling relations of asperities with respect to seismic moments derived statistically from the source inversion results for actual earthquakes. The main source parameters for each earthquake are summarized in Table 1. In case of estimating individual occurrence of the Nankai and the Tonankai earthquakes, the rupture starting points for both earthquakes were put at symbol ★1 and ★2, respectively. We assumed the rupture propagates radially. Furthermore, in case of estimating linked one of both earthquakes, we assumed the rupture starts at the symbol ★2 and the rupture restarts at ★1 after S-wave reached at ★1 and each rupture propagates radially.

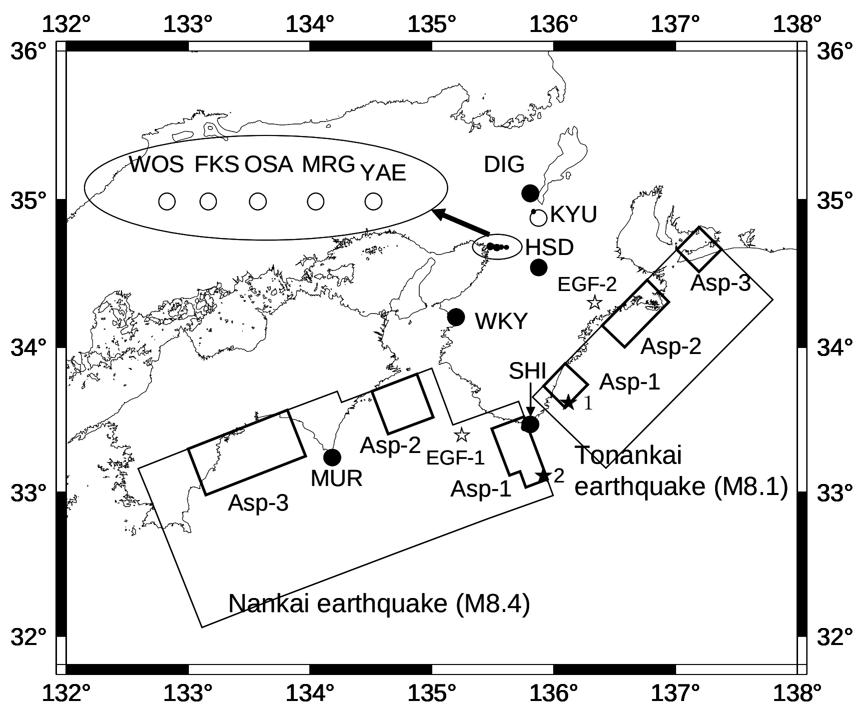


Fig. 1 Map showing the source model composed of three asperities on the fault for the Nankai and the Tonankai earthquakes and site locations. EGF-1 and EGF-2 are the epicenters of earthquakes used as the empirical Green's functions for the Nankai and the Tonankai earthquakes, respectively.

Table 1 Source parameters for the Nankai and the Tonankai earthquakes

	Nankai earthquake	Tonankai earthquake
Magnitude	8.4	8.1
Fault Area (Km^2)	35800	14500
Seismic Moment (N・m)	8.34E+21	2.15E+21
Averaged Stress Drop (Mpa)	3	3
Rupture Velocity (km/sec)	2.7	2.7

	Asperity			Asperity		
	1	2	3	1	2	3
Area (km^2)	2672	1336	1336	1082	541	541
Averaged slip (cm)	1141	954	954	850	601	601
Seismic Moment (N・m)	1.46E+21	5.16E+20	5.16E+20	3.76E+20	1.33E+20	1.33E+20
Stress Drop (MPa)	20.1	20.1	20.1	20.1	20.1	20.1

	Back Ground	Back Ground
Area (km^2)	30457	12336
Averaged slip (cm)	470	299
Seismic Moment (N・m)	5.85E+21	1.51E+21
Stress Drop (MPa)	2.7	2.7

SYNTHETICS BY THE EMPIRICAL GREEN'S FUNCTION METHOD

Firstly, we predicted broad-band strong ground motions at several sites by the empirical Green's function method by Irikura [2]. The locations of sites are shown in Fig.1, together with the epicenter of the earthquakes (EGF-1 and EGF-2) used as the empirical Green's functions.

The symbols ○ and ● showing site locations depict the sediment sites inside basin, rock outcropping sites or hard sediment sites, respectively. Table 2 shows the information of the earthquakes as the empirical Green's functions and its source parameters estimated roughly from the displacement source spectra computed as vectorial summation of two horizontal components of the recordings at hard sediment sites. Fig.2 shows the empirical Green's functions at 5 sites (OSA, WOS, WKY, MUR and SHI) for the Nankai earthquake. You can easily see that the waveforms represent the characteristics due to each site condition. Fig.3 shows the synthesized ground motions at 5 sites from the Nankai earthquake. When we concentrate the synthetics at OSA and WOS inside basin, we can point out the long duration affected by the long path as well as the effect due to 3-dimensional underground structure of the basin. Furthermore, as you can see in Fig.4 depicting pseudo velocity response spectra, the synthetics are predominant in long period range (4 ~ 6 seconds). These amplitudes are over the safety regulation of the standard design spectra in Japan. This result suggests the strong effect to high-rise buildings and base-isolated buildings with long natural period. Fig.5 and Fig.6 show the synthesized ground motions and these pseudo velocity response spectra at 6 sites (FKS, MRG, YAE, DIG, HSD and KYU) for the Tonankai earthquake. The peak horizontal accelerations and velocities as well as the predominant periods of the synthetic motions inside basin are almost the same as those predicted for the Nankai earthquake, although the site locations for both earthquakes are slightly different each other. Finally, the synthesized ground motion and the pseudo velocity response spectra at OSA in Osaka city in case of the linked occurrence of both earthquakes are shown in Fig.7 and Fig.8 together with the synthetics in case of the individual occurrence. These figures show the amplitude of the predicted ground motions in case of the linked earthquake becomes slightly larger than the individual earthquake. From these results, we can emphasize the necessity of the more advanced prediction of long period ground motions in mega-city Osaka located inside the Osaka basin. In next section, we carry out a preliminary theoretical calculation for long period ground motions during the Tonankai earthquake to investigate the effects of the 3-dimensional basin structure as well as the rupture propagation.

Table 2 Source parameters for the earthquakes used as the empirical Green's functions

	EGF-1	EGF-2
Date	1991/10/20	2000/10/31
Latitude (deg)	33.395	34.2
Longitude (deg)	135.248	136.4
Depth (km)	37	40
Magnitude (JMA)	5.1	5.7
Seismic Moment (N･m)	3.00E+16	1.70E+17
Fault Area (km2)	1.5	4
Stress Drop (MPa)	40	50

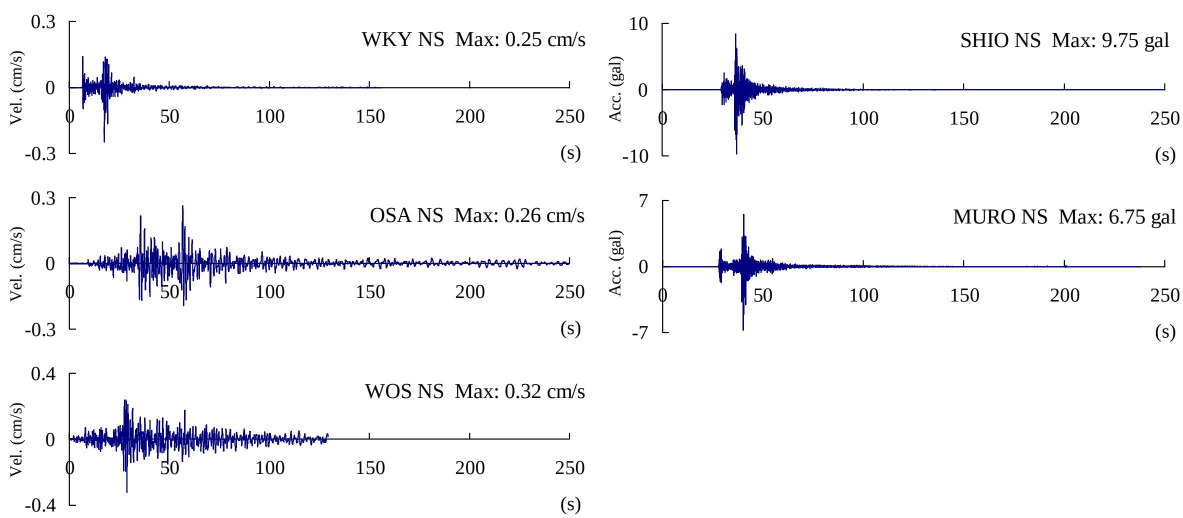


Fig. 2 Acceleration and velocity waveforms used as the empirical Green's functions

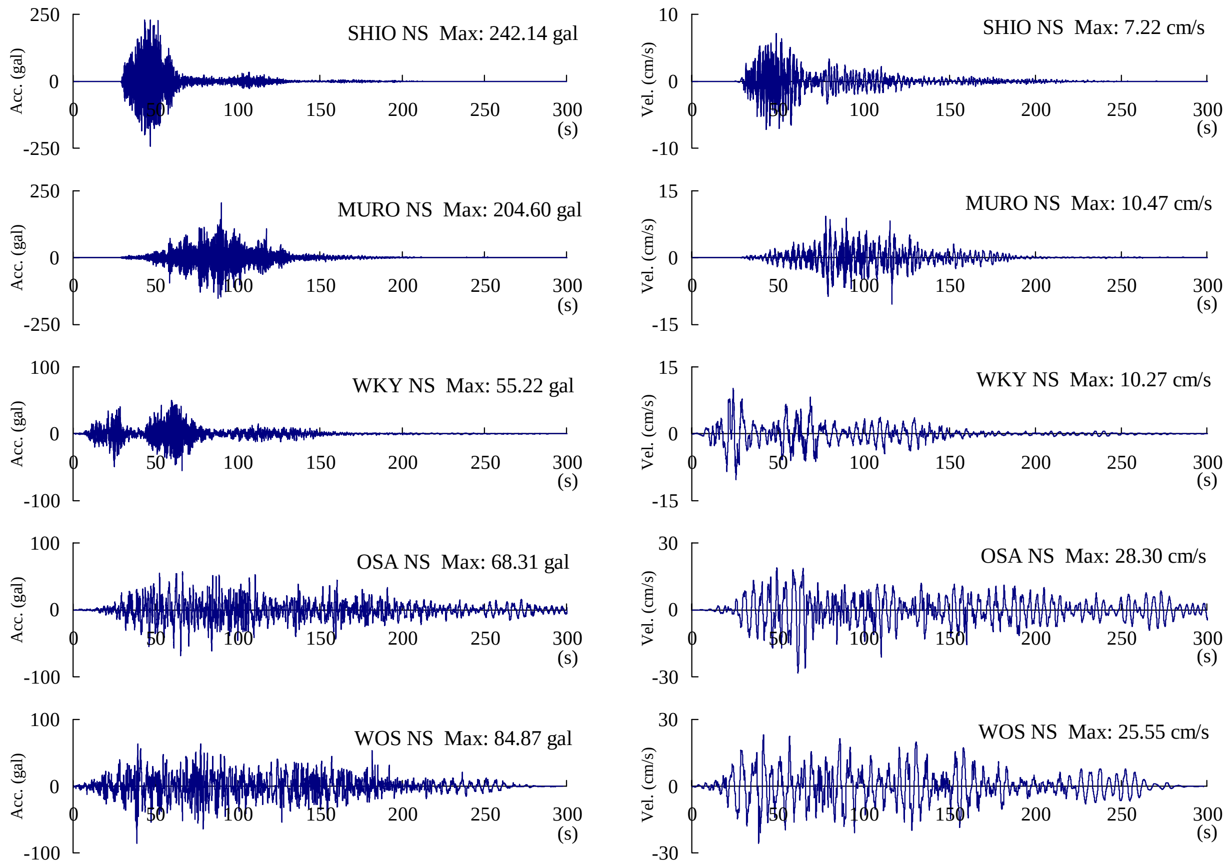


Fig. 3 Predicted acceleration and velocity motions at 5 sites for the Nankai earthquake.

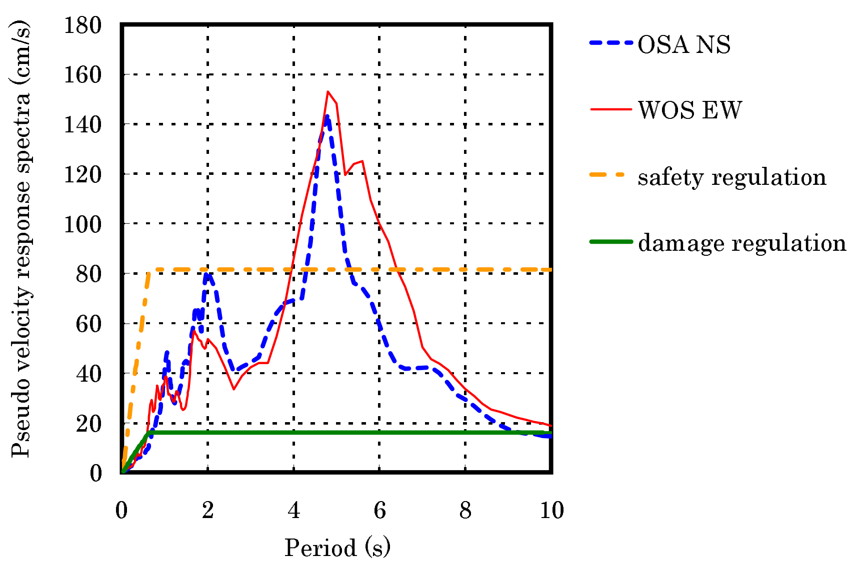


Fig. 4 Pseudo velocity response spectra of the predicted ground motions for the Nankai earthquake at OSA and WOS sites located inside the Osaka basin. A couple of the design spectra are depicted in this figure.

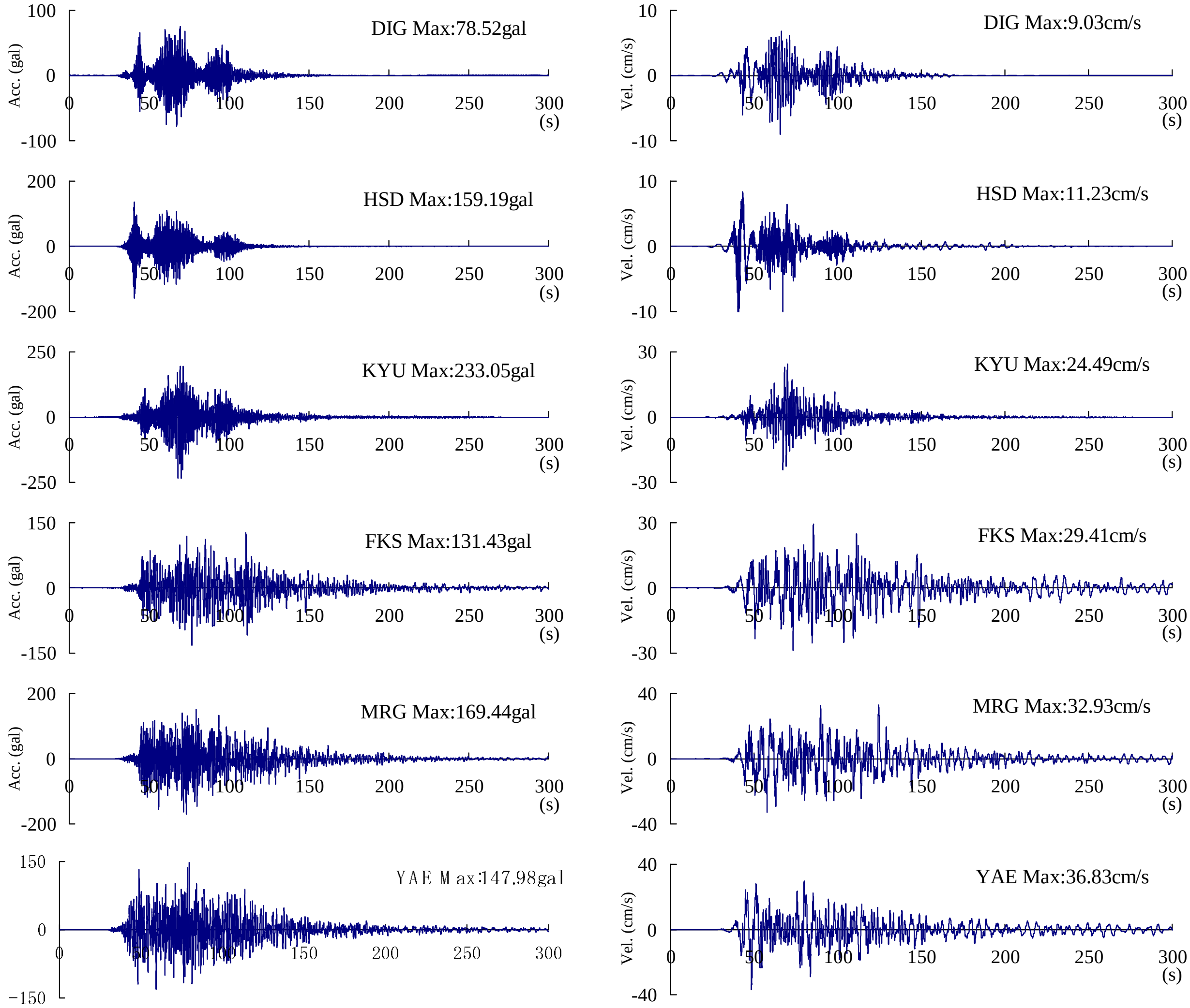


Fig. 5 Predicted acceleration and velocity motions at 6 sites for the Tonankai earthquake.

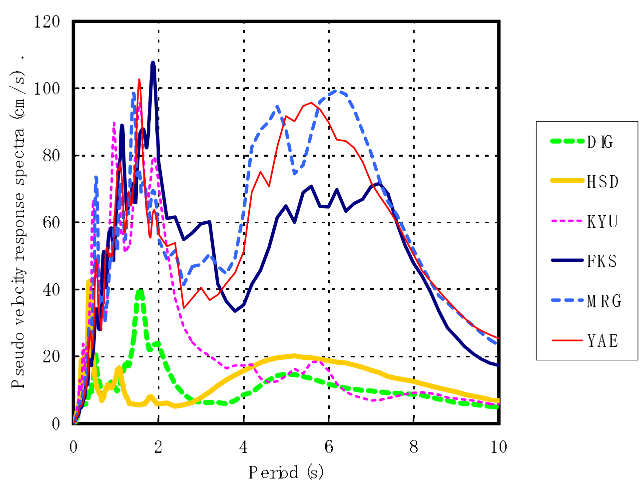


Fig. 6 Pseudo velocity response spectra of the predicted ground motions for the Tonankai earthquake at 6 sites located inside (FKS,MRG,YAE) and outside (DIG,KYU,HSD) the Osaka basin.

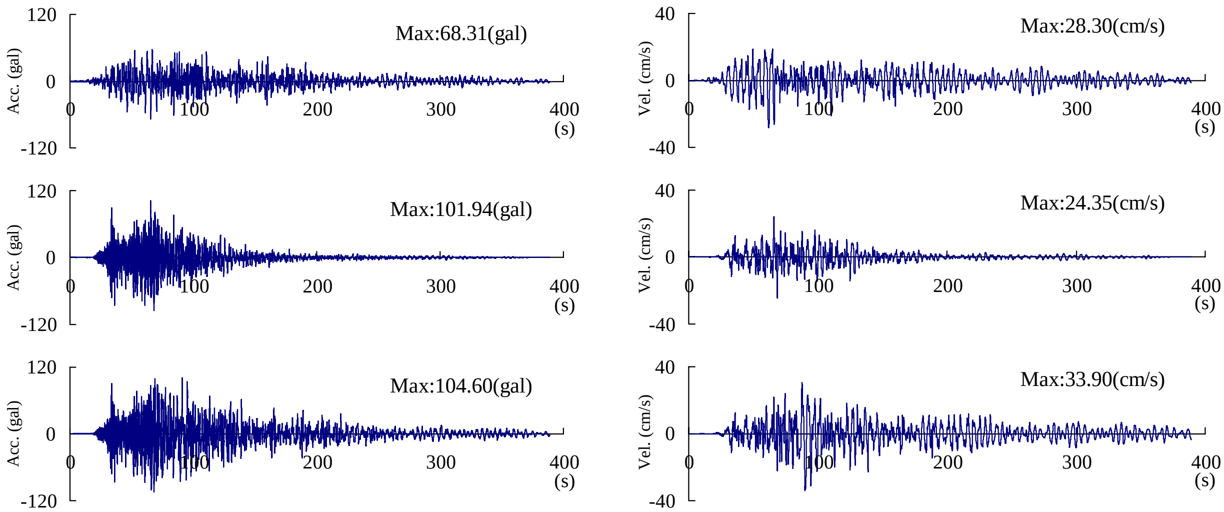


Fig. 7 Predicted acceleration and velocity motions at OSA site in case of the linked occurrence of the Nankai and the Tonankai earthquakes.

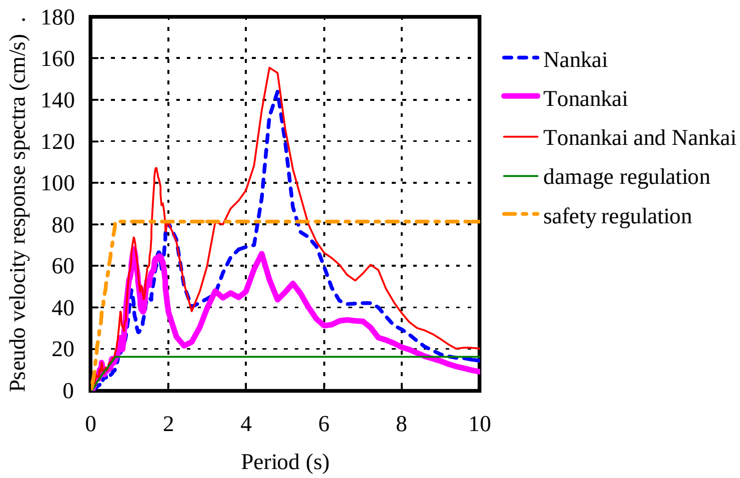
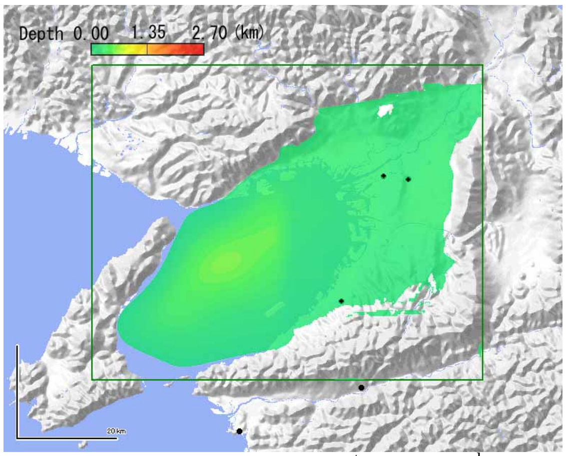


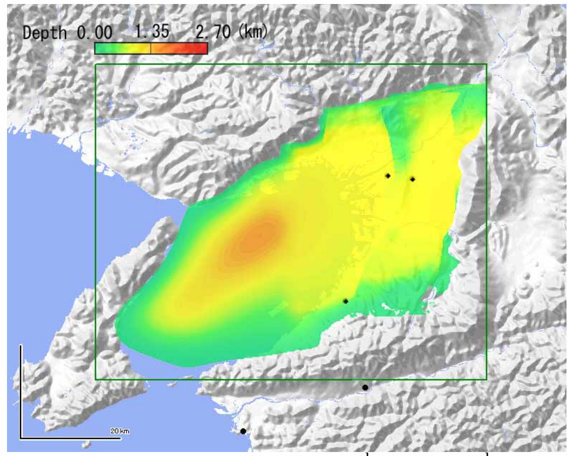
Fig. 8 Pseudo velocity response spectra of the predicted ground motions at OSA site in cases of the individual occurrence of the Nankai and the Tonankai earthquakes and the linked occurrence of both earthquakes. A couple of the design spectra are depicted in this figure.

PRELIMINARY GROUND MOTION PREDICTION USING THE 3-D FINITE DIFFERENCE METHOD

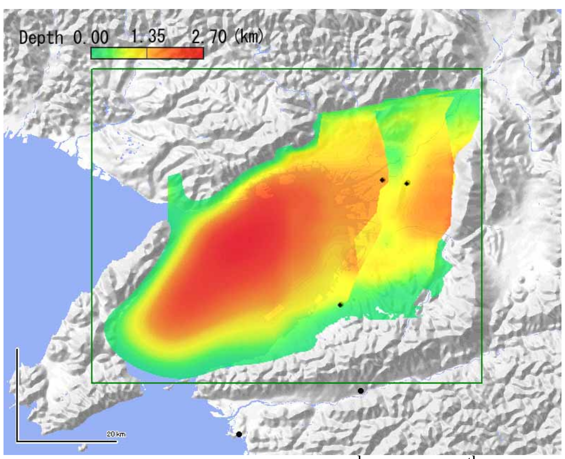
We try to estimate long period ground motions using the 3-D finite difference method (Graves [3], Pitarka [4]). The 3-dimentional underground structure models for the Osaka basin have been proposed by some researchers (e.g., Miyakoshi et al. [5], Horikawa et al. [6]). Here, we constructed a rough three-dimensional velocity model referring to Miyakoshi et al. [5] and Horikawa et al. [6]. The model has three sediment layers on bedrock. The depth of each sedimentary layer is depicted in Fig. 9, and the parameters of the sediment layers and bedrock are shown in Table 3. Fig. 10 shows the region of the finite-difference simulation, together with source model composed of three asperities for the Tonankai earthquake. We calculated velocity seismograms inside the basin from only asperity. All the synthetics are bandpass filtered in the frequency range 0.1 to 0.4 Hz to exclude the numerical errors in higher frequencies. Fig. 11 shows synthetic peak velocity distributions for two horizontal components in case of two different starting point shown in Fig.10. In both cases, the area showing large amplitude is appeared along the basin edges. Furthermore, you can see the distributions for both components are drastically changed by the rupture process. We compared the pseudo velocity response spectra by the 3-D simulation for Case-1 with those by the empirical Green's function method. Fig. 12 shows the comparisons at three sites (FKS, MRG and YAE) in Osaka. The fittings in predominant period are not complete except for YAE site. Such discrepancies might come from the preciseness of the 3-D underground structure model as well as the roughness in using an only earthquake as the empirical Green's function. We need to investigate the validation of the 3-D model through some simulations of seismograms.



(a) The boundary depth of the 1st and the 2nd layer



(b) The boundary depth of the 2nd and the 3rd layer



(c) The boundary depth of the 3rd and the 4th layer

Fig. 9 Depth distribution of each sediment layer in 3-dimensional model of the Osaka basin.

Table 3 Physical parameters of each sediment layer and bedrock

Layer	Vs (km/sec)	Vp (km/sec)	Density (kg/m^3)	Qs
1	0.40	1.6	1,700	40
2	0.55	1.8	1,800	60
3	1.00	2.5	2,100	100
4	3.20	5.4	2,700	400

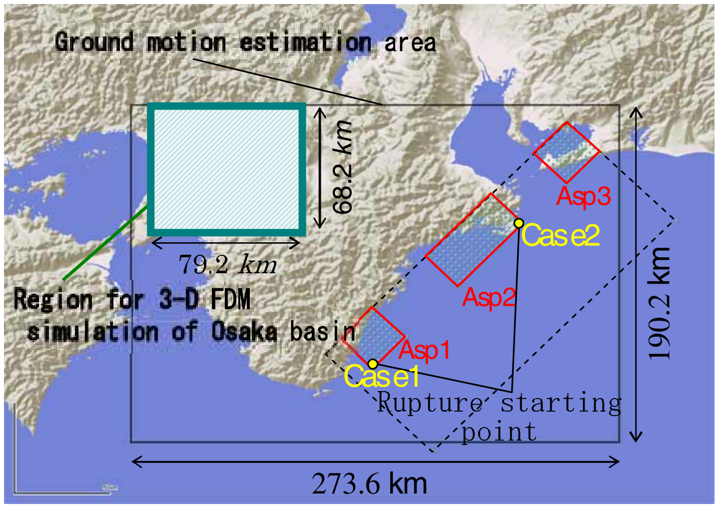
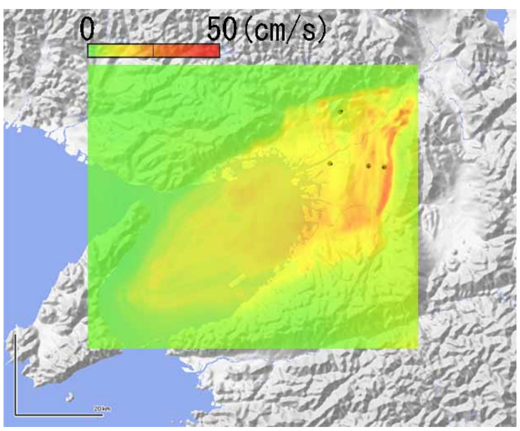
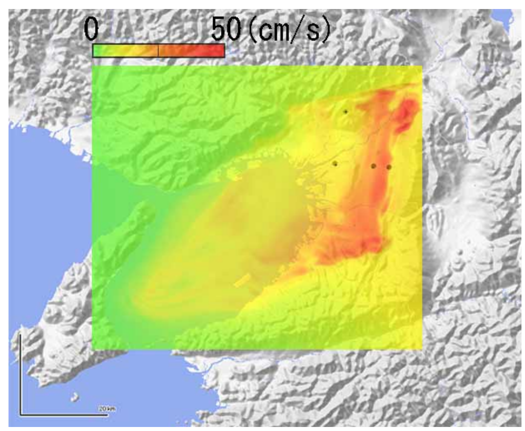


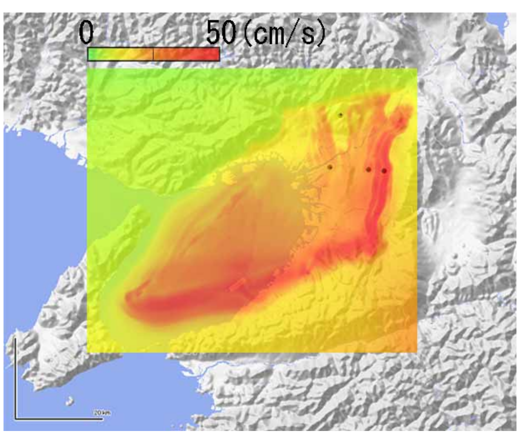
Fig. 10 Map showing the region for calculating long period ground motions from the Tonankai earthquake. The thick rectangular box depicts the region for the 3-D simulations. The dotted line and the red lines indicate fault area and asperities, respectively.



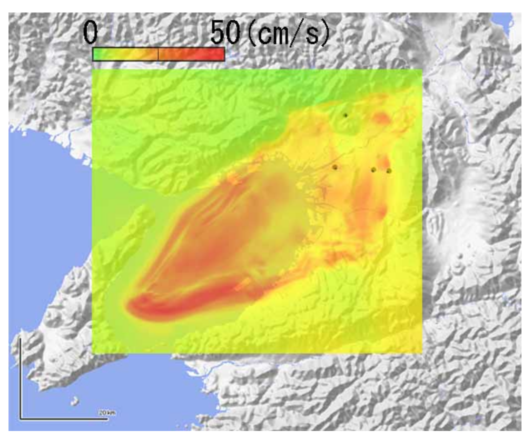
(a) Case1 NS component



(b) Case1 EW component



(c) Case2 NS component



(d) Case2 EW component

Fig. 11 Synthetic peak velocity distributions for two horizontal components in case of assuming two different starting points shown in Fig.10

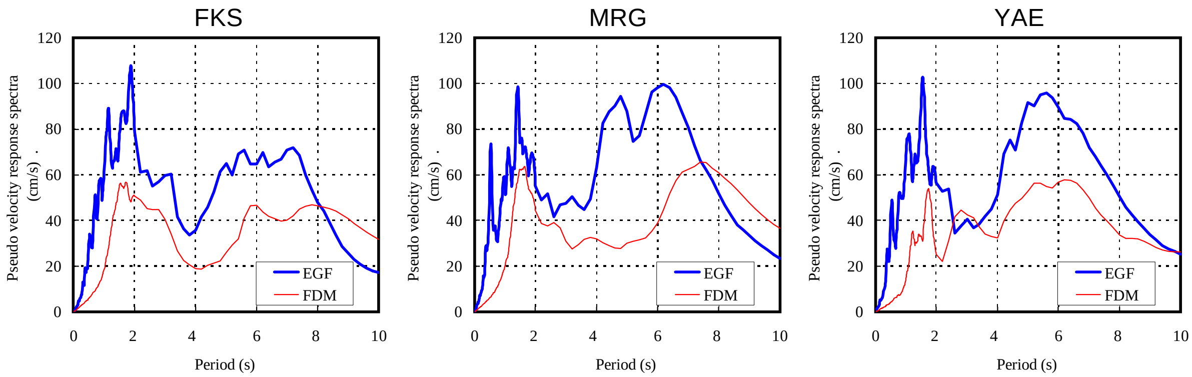


Fig.12 Comparison of the pseudo velocity response spectra of the broad-band ground motions by the empirical Green's function method with those of the long period ground motions by 3-D finite difference method. The effective period range for 3-D simulation is 2.5 to 10 sec.

CONCLUSIONS

We attempted to predict strong ground motions from future huge subduction earthquakes (Nankai and Tonankai earthquakes) using the empirical Green's function method and 3-D finite difference method. In mega-city Osaka located inside basin, the long period ground motions (4 ~ 6 seconds) with very long duration have been predicted for both huge earthquakes. The amplitude of the predicted response spectrum is over the design spectrum around period of 5 sec. These results suggest that we need to investigate the seismic safety of high-rise buildings and base-isolated buildings and so on. Furthermore, we need to increase the accuracies of the predicted strong ground motions inside the Osaka basin.

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