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LONG-PERIOD GROUND MOTION SIMULATION OF OSAKA SEDIMENTARY BASIN FOR A HYPOTHETICAL NANKAI SUBDUCTION EARTHQUAKE

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Abstract: Long-period ground motion simulations for the hypothetical Nankai subduction earthquake are studied. We confirmed the Osaka basin and crustal velocity structure model that covers the source area of the Nankai earthquake and the Osaka basin by modeling of long-period ground motion of the largest aftershock of the 2004 off Kii peninsula earthquake. The simulated ground motions by our velocity model reproduce the observed ground motions well. Then we simulate long-period ground motions for the hypothetical Nankai earthquake using that velocity model and discuss the ground motion characteristics in the Osaka sedimentary basin.

1. INTRODUCTION

Ground motion simulations and predictions based on the source model and the underground velocity structure model are quite important for understanding of the strong ground motion characteristics and related earthquake disaster. Since the 1994 Northridge, USA, and the 1995 Kobe, Japan, earthquakes occurred, strong motion simulations using the heterogeneous source and realistic three-dimensional underground velocity structure models have become successful and quite popular in the research field of applied seismology and earthquake engineering.

In Japan, Kinki area has higher seismic hazard potentials, especially in the Osaka sedimentary basin that has a large population. The Headquarters for earthquake research promotion, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan, reported that occurrence potentials of the next M8-class Nankai and Tonankai earthquakes are high: about 60 to 70 percent within the next 30 years starting from the 2009 (Headquarters for Earthquake Research Promotion 2009). We have already experienced long-period ground motions from the M8-class events rocked facilities on basin or sedimentary sites located at 200-300 km away from the source region, e.g. well known damages in Mexico-city during the 1985 Michoacan earthquake, and in the Tomakomai, Hokkaido, Japan, during the 2003 Tokachi-Oki earthquake. In case of Tomakomai, the long-period ground motions, generated from the source and then amplified and elongated in the Yufutsu basin, damaged the fuel tanks (Koketsu *et al.*, 2005).

The Osaka sedimentary basin is located approximately 250 km away from the source regions of the hypothetical Tonankai and Nankai earthquakes. It is expected that modern mega-cities consisting of a large number of skyscrapers and fuel storage tanks of Osaka and Kobe, located in that basin, will surely be shaken by disastrous long-period ground motions. Therefore, reliable strong motion predictions at those sites are required for reducing earthquake disaster by long-period ground motions.

The velocity structure models for long-period ground motion simulation are already constructed by several organizations and research groups. In this study, first, we demonstrate the applicability of one of the velocity structure models for the strong motion evaluations through simulations of the ground motions observed by the dense strong motion observation network in Kinki area. Next, we simulate long-period ground motions for a hypothetical Nankai earthquake and discuss the ground motion characteristics of the Osaka sedimentary basin.

2. OSAKA SEDIMENTARY BASIN AND CRUSTAL VELOCITY STRUCTURE

In this study, we refer an Osaka basin and crustal velocity structure model given by Iwata et al. (2008). The Osaka sedimentary basin is filled with the late Cenozoic sediments (Ikebe et al. 1970) and surrounded by the Rokko Mountains (northwest), Hokusetsu Mountains (northeast), Ikoma Mountains (east), Izumi Mountains (south), and Awaji Island (west). It has a nearly ellipsoid shape with a length of 60 km in the NE-SW direction and a width of 40 km in the NW-SE direction. The central part of the basin is covered by the Alluvium that is 15–35 m thick. Below the Alluvium, there lie the sedimentary layer mainly composed of the Osaka group that contains marine clay layer in the upper part. The bedrock chiefly consists of granite rocks.

Geophysical investigation of the underground velocity structure by exploration surveys started as early as 1960 in

Osaka area (Kagawa *et al.* 2004a), which enabled several groups of researchers to construct basin structure models. Kagawa *et al.* (1993) incorporated the bedrock depth information obtained from refraction surveys, reflection surveys, gravity anomaly surveys, microtremor array measurements, down-hole logging, etc., and interpolated them using a two-dimensional third-order B-spline function (*e.g.* Koketsu and Higashi 1992) to model the bedrock geometry. They divided the sedimentary layer into three layers according to seismic wave velocities and densities estimated from the results of the reflection surveys and microtremor array measurements. As the spline model, composed only of a set of spline coefficients, can be easily modified by adding new control points, they have been continuously adopting new exploration information to improve their basin velocity structure model (Miyakoshi *et al.* 1997, 1999; Kagawa *et al.* 1998, 2004a). Iwata *et al.* (2008) introduced the improved basin structure model that includes new additional bedrock depth control points from exploration survey information, such as gravity anomaly data and microtremor survey results, in areas where those data were coarse in Kagawa *et al.* (2004).

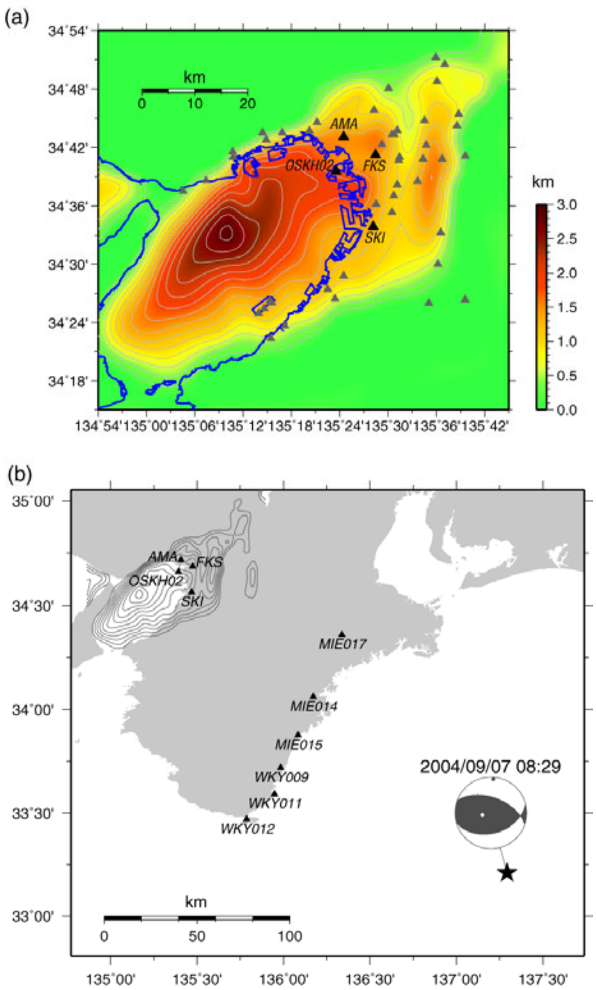

Figure 1 (a) Map of strong motion observation stations used in this study. Color and contour lines indicate the bedrock distribution of the Osaka basin model by Iwata et al. (2008). (b) Model area of for the ground motion simulation. The epicenter determined by JMA and mechanism by F-net, NIED, are shown. The triangles denote the observation stations.

The crustal velocity model by Iwata et al. (2008) covers the crust from the seismic bedrock and Moho discontinuity as well as the subducting Philippine-Sea plates. It was constructed by compiling great amount of data available such as OBS (Ocean Bottom Seismometer) velocity models, deep seismic profiles, receiver function inversion results, and 1D velocity models used for routine-work hypocenter determinations. They modeled the crustal velocity model as the stack of uniform velocity layers, same as the basin. The geometry of the interface depth of each layer is also represented using a two-dimensional third-order B-spline function.

3. VELOCITY STRUCTURE MODEL VALIDATION BY LONG-PERIOD GROUND MOTION SIMULATION

To validate the basin and crustal velocity structure model, we conduct a long-period ground motion simulation for the observed records during the largest aftershock 2004/09/07 08:29JST, M_{JMA}6.5) of the 2004 off the Kii peninsula earthquake (2004/09/05 23:57JST, M_{JMA}7.4). The reason we try to analyze the largest aftershock records is that the source time functions of the mainshock and the foreshock are complex (*e.g.* Yamada and Iwata 2005) and that of the largest aftershock is relatively simple.

We use the strong motion records of this event provided by the Committee of Earthquake Observation and Research in the Kansai Area (CEORKA; Kagawa *et al.* 2004b), K-NET (Kinoshita 1998) and KiK-net (Aoi *et al.* 2001) maintained by the National Research Institute for Earth

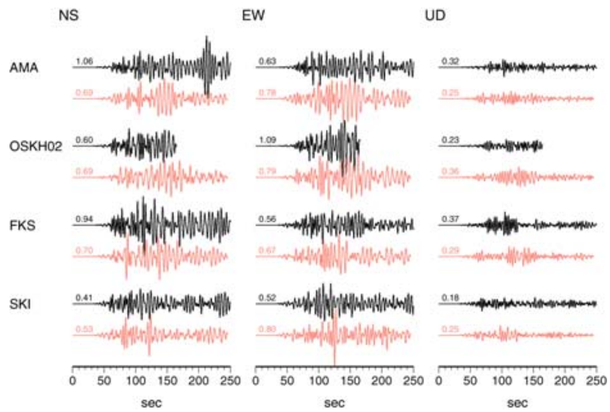

Figure 2 Comparison of the observed (black trace) and synthetic (red trace) velocity waveforms at stations inside the Osaka basin. The waveforms are band-pass filtered at 3 – 10 sec.

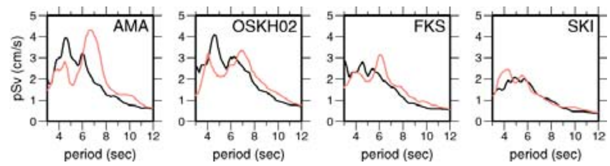

Figure 3 Comparison of the observed (black trace) and synthetic (red trace) pseudo velocity response spectra with 5% damping factor.

Science and Disaster Prevention (NIED), the seismic intensity observation network of Japan Meteorological Agency (JMA), and the strong motion network project of 10 electric power companies (Denkyo-net). In addition to the seismograms listed above that had been open to researchers, we have also collected the seismograms of two organizations: the Osaka City Waterworks Bureau (OCWB) and Kansai International Airport Co., Ltd (KIAC). In total, we use data from as many as 54 strong motion stations in and around the Osaka basin shown in Figure 1(a). The computation of seismic wave propagation is performed by a fourth-order 3D finite-difference method (FDM) using staggered grids with non-uniform spacing (Pitarka 1999). The model area size of the computation is 280 km (EW) × 250 km (NS) × 70 km (depth). The basin model is included in the northwest corner of the model with a volume of 105 km (EW) × 93 km (NS) × 3 km (depth). The model area is illustrated in Figure 1(b).

The source is modeled as a double couple point source, using the epicenter determined by JMA and the source mechanism by F-net of NIED. The source time function is represented by a bell-shaped function $f(t) = [1 - \cos(2\pi t/T_d)]/T_d$ with a duration time T_d. The source duration T_d as well as the source depth is estimated so as to fit the waveforms observed at K-NET stations outside of the Osaka basin in Kii peninsula. The source duration and source depth are estimated to be 4.5 s and 11 km, respectively.

We then simulate long-period ground motions and validate the basin model by comparing the observed and the synthetic waveforms in terms of velocity waveforms and pseudo-velocity response spectra (pSv). Figure 2 shows examples of the observed and synthetic velocity waveforms. AMA, OSKH02, FKS, and SKI are the stations in the central bay area where the bedrock depth is represented as 1.4 – 1.7 km in the model (see Figure 1(a)). In Figure 3, we show 5% pseudo-velocity response spectra of horizontal component. Not only waveforms but also peak periods and levels of ground motions in pSv are well reproduced. Iwaki and Iwata (2010) pointed out the simulations fairly well reproduced the observations except those at some stations at North-Eastern area of Osaka basin.

4. SIMULATION OF LONG-PERIOD GROUND MOTIONS FOR THE HYPOTHETICAL NANKAI EARTHQUAKE

Based on the simulation results discussed in the previous section, the Osaka basin and crust velocity structure model by Iwata *et al.* (2008) could be used as a reference velocity model for long-period ground motion simulations. We would like to conduct the prediction of the ground motion during a hypothetical Nankai earthquake. We use the hypothetical Nankai earthquake source model proposed by Sekiguchi *et al.* (2008), Their source model is based on the characterized source model (Irikura and Miyake 2001) by Central Disaster Management Council of Japan (2003) that consists of five asperities and a background area. They applied multi-scale heterogeneity to the slip and rupture velocity distributions so as to be fit for more realistic simulation in a broadband frequency range. Each of the six areas slips according to a slip velocity time function by Nakamura and Miyatake (2002) with different maximum slip and duration time.

The simulation is carried out by the 3D FDM (Pitarka 1999) at the periods 3s and longer. The size of the velocity structure model is 400 km (EW) × 344 km (NS) × 70 km (depth) that includes the entire source model and the Osaka basin area (Figure 4).

The source model by Sekiguchi et al. (2008) is composed of subfaults distributed every 1.5 km over the

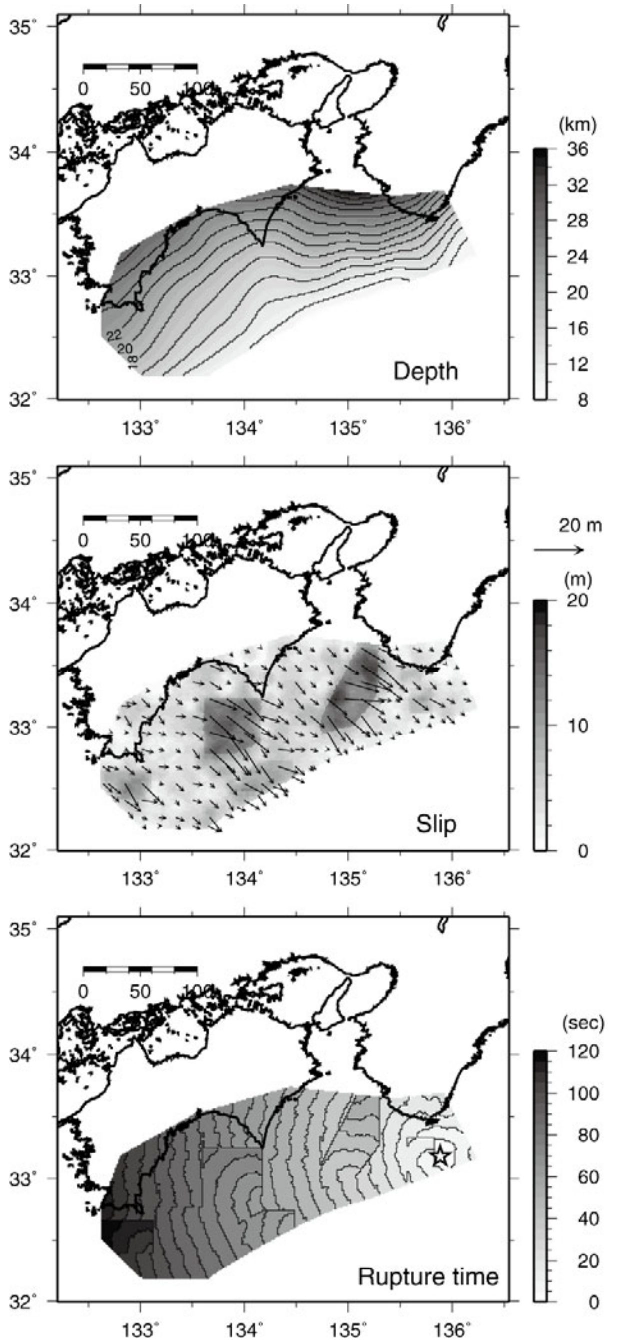

Figure 4 Source depth distribution (top), slip distribution and direction (middle), and rupture time distribution (bottom) of the hypothetical Nankai earthquake source model used in this study.

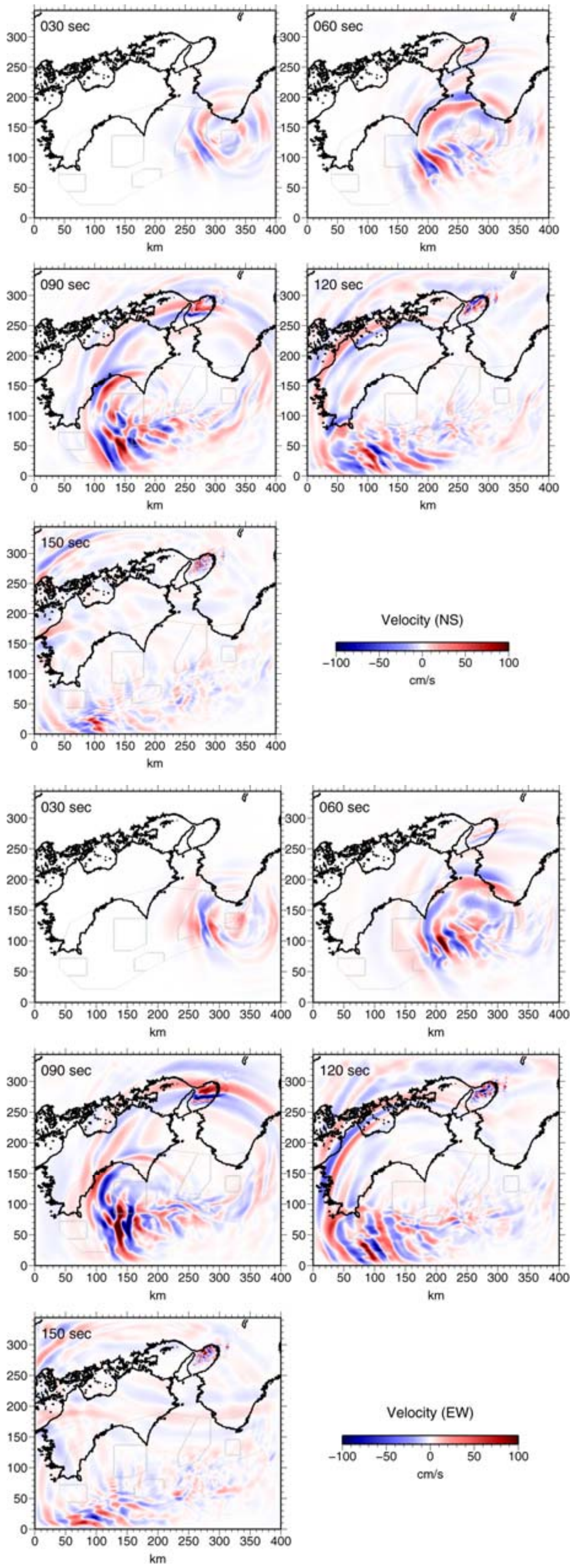

Figure 5 Snapshots of the ground velocity for NS (top) and EW(bottom) components at 30 to 150 seconds after the rupture starting time.

source area. We changed the depth of each subfault so that they are pasted on the upper surface of the Philippine Sea Plate of our crustal model. Consequently, our subfault depths

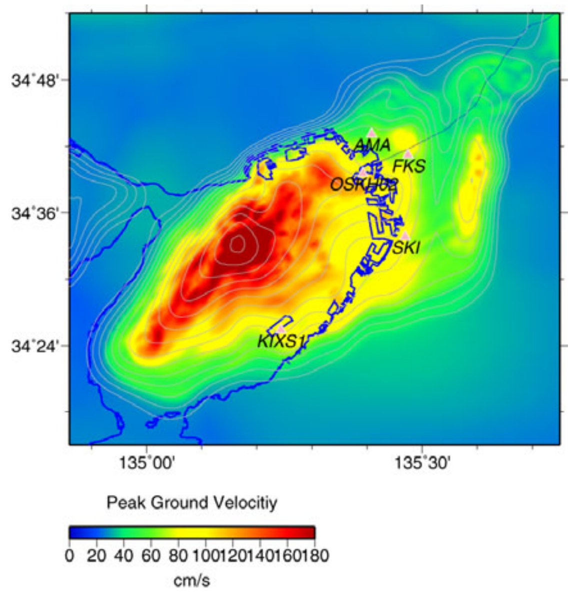

Figure 6 Distribution of the simulated maximum horizontal ground velocity in the Osaka basin.

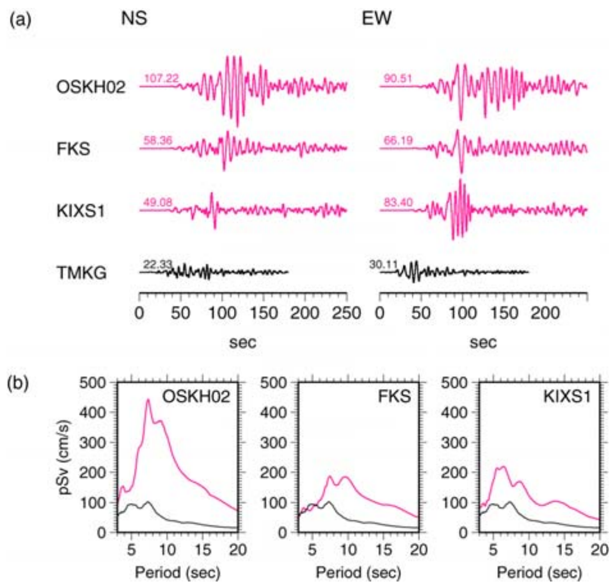

Figure 7 The simulated (a) velocity waveforms and (b) pSv for the hypothetical Nankai earthquake at stations in the Osaka basin (pink traces) compared with the observed pSv during the 2003 Tokachi-oki earthquake at Tomakomaoi port (black traces).

are systematically shallower than those of Sekiguchi *et al.* (2008) because the plate depth of our velocity model is shallower than theirs. The depth, slip, and rupture time distribution of the source model used in this study are shown in Figure 4.

Figure 5 shows the snapshots of the horizontal components of the velocity wavefield (bandpass filtered at 3–20 s). As the rupture starts at off Shionomisaki (southern promontory of Kii peninsula) area and propagates westward, large ground motions can be clearly observed on the west side of the rupture front at 60, 90, and 120 sec after the rupture starting time. On the other hand, the Osaka basin experiences remarkable amplification of the long-period ground motions at approximately 60 sec, which still continues at 150 sec after the rupture starting time. In the Osaka basin area, at 60 second and 90 second, that is approximately the *S* -wave arrival time, the ground motions in the east-west component seems to be larger than that in the north-south component, which would be caused by the slip direction of the source. Figure 6 shows the distribution of peak horizontal ground velocity (PGV), i.e. the vector sum of the two horizontal components, in the Osaka basin area. The PGV value reaches 80 – 100 cm/s in the central area and the eastern area of the basin. In Figure 7, we compare the simulated ground motions and pSv (horizontal component) at OSKH02, FKS and KIXS1 (Kansai air-port island) with the observed ones during the 2003 Tokachi-oki earthquake at Tomakomai port. The maximum velocities at these Osaka coastal are higher than approximately 80 cm/s. The pSv value at period 6 s is approximately 480 cm/s at OSKH02 and higher than 200 cm/s at FKS and KIXS1, They are twice to five times as large as the pSv value observed at Tomakomai port.

4. CONCLUSIONS

We conducted a long-period ground motion simulation during a hypothetical Nankai earthquake using the validated Osaka basin and crustal velocity structure model. The simulated peak ground velocity reached 80 - 100 cm/s at the center and east part of Osaka. The pSv at period 6 s was as high as 480 cm/s at the bay area, which is nearly five times as large as the pSv observed at Tomakomai port during the 2003 Tokachi-oki earthquake. Discussion on plausible source scenarios of the hypothetical earthquake is needed in the future study.

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