Progress towards a Japan Integrated Velocity Structure Model and Long-Period Ground Motion Hazard Map

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ABSTRACT :
The Japan islands are in a complex tectonic setting with various subducting plates, and most of their urban areas are located on sedimentary basins. These lead to three-dimensionally complicated velocity structures, which cause significant effects on the propagation of seismic waves from an earthquake to the urban areas. Accordingly, it is important for the simulation of long-period ground motion and its seismic hazard to determine the three-dimensional (3-D) velocity structure of the whole Japan islands. We have already proposed a standard procedure for modeling a regional 3-D velocity structure in Japan, simultaneously and sequentially using various kinds of datasets such as the extensive refraction/reflection experiments, gravity surveys, surface geology, borehole logging data, microtremor surveys, and earthquake ground motion records. We applied the procedure to the Tokyo metropolitan area for constructing a reference 3-D velocity structure model. As the last step of the procedure, we calibrated the model by comparison of observed and synthetic ground motions, since this modeling is carried out mainly for long-period ground motion hazard map. As this application confirmed the validity of the standard procedure, it is then applied to the central and western parts of Japan in 2006 to 2008, to construct a Japan integrated velocity structure model. Long-period ground motions from future Tokai, Tonankai, Miyagi-oki, and Nankai earthquakes and their response spectra will be computed and combined into a Japan hazard map in 2008 and later by using this model.

KEYWORDS:
3-D velocity structure, sedimentary basin, modeling procedure, long-period ground motion, hazard map

1. INTRODUCTION

Metropolitan areas are usually located over large-scale sedimentary basins. For example, Tokyo, the capital city of Japan, and its metropolitan area are located in the largest sedimentary basin, which is called the Kanto basin with an area of about 17,000 km^2 and the maximum thickness of about 4 km. The basement rocks are almost exposed in mountain ranges, which surround the basin on the west and north sides. The Kanto basin is mostly bounded by the Pacific ocean on the other sides as well, so its velocity structure of the Kanto basin is three-dimensionally complicated. Most other sedimentary basins in earthquake-prone countries are in similar situation to this for the Tokyo metropolitan area (TMA). The damage in TMA itself from the 1923 Kanto earthquake, in Mexico City from the 1985 Michoacan earthquake, and in the Marina district of San Francisco from the 1989 Loma Prieta earthquake has clearly illustrated the risks for population centers located in basins (e.g., Olsen et al., 1995). The sediments filling the basins amplify ground motions and their velocity structures complicate the propagation of seismic waves (e.g., Koketsu and Kikuchi, 2000), so it is important for the prediction of strong ground motion and seismic hazard to determine the three-dimensional (3-D) velocity structures of these urban basins.

This importance motivated various kinds of explorations carried out in and around the urban basins. However, a study on a single exploration dataset cannot completely define the 3-D velocity structure of an urban basin. We have to simultaneously or sequentially use several kinds of exploration datasets for modeling the 3-D velocity structure of an urban basin, because none of single datasets have sufficient resolving power. It is also necessary to verify a resultant model by seismic waveform studies, since this modeling is carried out mainly for strong ground motion prediction (e.g., Sato et al., 1999; Magistrale et al., 2000). In particular, long-period ground motion has become an increasingly important consideration because of the recent growing number of large-scale structures, such as high-rise buildings, oil storage tanks, suspension bridges, off-shore oil drilling platforms, and base-isolated structures (Koketsu and Miyake, 2008). We can calibrate velocity structure models by comparison of observed and synthetic dominant periods of spectral ratios and time history waveforms of long-period ground motion (e.g., Suzuki et al., 2005). Based on these experiences, we have proposed a standard modeling procedure (Koketsu et al., 2008), because extensive geophysical experiments and geological investigations have been carried out and velocity structure models are being constructed all over Japan. We are then applying it to the central and western parts of Japan in 2006 to 2008, toward building a Japan integrated velocity structure model. Long-period ground motions from future Tokai, Tonankai, Miyagi-oki, and Nankai earthquakes, their response spectra, and some index parameters will be computed and combined into a Japan hazard map in 2008 and later by using this model.

2. STANDARD MODELING PROCEDURE

In seismology, two kinds of basement (bedrock) are defined in a velocity structure model. 'Seismic basement (bedrock)' is usually assigned to the uppermost part of the crust, whose S-wave velocity (V_S) is around 3 km/s, while 'engineering bedrock' with a V_S of 400 to 700 m/s is located just below surface layers. Regions between seismic basement and engineering bedrock are greatly influence long-period ground motion, so our modeling procedure targets these parts of subsurface velocity structures. Models for the crustal structures from the seismic basement to the Moho discontinuity and the velocity structures of subducting plates must also be included to simulate strong ground motions from subduction-zone earthquakes. If there are various kinds of exploration datasets and observed seismograms in such basins as the Kanto basin, the following standard procedure proposed by Koketsu et al. (2008) is applicable for modeling their velocity structures in common.

Step 1: Assume an initial layered model consisting of seismic basement and sedimentary layers from comprehensive overview of geological information, borehole data, and exploration results.

Step 2: Assign P-wave velocities to the basement and layers based on the results of refraction and reflection surveys, and borehole logging. Assign S-wave velocities based on the results of borehole logging, microtremor surveys, spectral-ratio analyses of seismograms, and empirical relationships between P- and S-wave velocities.

Step 3: Obtain the velocity structure right under engineering bedrock from the results of microtremor surveys referring to the results of borehole logging, since among 2-D or 3-D surveys only microtremor surveys are sensitive to shallow velocity distributions and the shapes of shallow interfaces.

Step 4: Compile data and information on faults and folds. Convert time sections from seismic reflection surveys and borehole logging into depth sections using the P- and S-wave velocities in Step 2.

Step 5: Determine the shapes of interfaces between the layers and basement by inversions of geophysical-survey data (e.g., refraction traveltimes and gravity anomalies). In case of insufficient data, forward modeling is carried out. The depths of faults and folds in Step 4 are introduced into the inversions as constraints, or additional data to the forward modeling.

Step 6: Calibrate the P- and S-wave velocities in Step 2 and the interface shapes in Step 5 by inversion or forward modeling of spectral features of observed seismograms such as dominant periods of H/V (horizontal/vertical) spectral ratios.

Step 7: Adjust the velocities and interface shapes using inversion or forward modeling of time history waveforms of observed seismograms.

We start from the result of Steps 1 to 2 calling it a 0th-grade model. This model is then revised into a 0.5th-grade model through Steps 3 to 5, as the final result after Steps 6 to 7 is called a 1st-grade model. Although sufficient exploration data may not be available except for major metropolitan areas, sufficient observed seismograms are always available for all the important sedimentary basins in Japan, thanks to the K-NET and KiK-net arrays. In this case, stronger emphasis should be placed on Steps 6 to 7 than on Steps 3 to 5, and the result after Step 6 is called the 0.5th-grade model. Earthquake Research Committee (2008) has already adopted this standard procedure as a recipe of constructing velocity structure models for "National Seismic Hazard Maps for Japan (2008)."

3. JAPAN INTEGRATED VELOCITY STRUCTURE MODEL

Figure 1 shows the areas of 3-D velocity structure models, which have been built or are now under construction. The red squares indicate the 1st-grade models constructed by the DaiDaiToku Project (Special Project for Earthquake Disaster Mitigation in Urban Areas) of MEXT, whose 3-D image and cross section are shown in Figure 2. The green squares and blue squares are those by the Itoigawa-Shizuoka Tectonic Line and Miyagi-oki Earthquake Research Projects of MEXT, and Integrated Velocity Structures Database Project of the Special Coordination Funds for Promoting Science and Technology, respectively. The National Institute of Advanced Industrial Science and Technology constructed the 1st-grade models denoted by pink circles. For the National Seismic Hazard Maps for Japan (2009), the National Research Institute for Earth Science and Disaster Prevention (NIED) has made the 1st-grade models denoted by orange squares. The NIED also built many velocity structure models denoted by yellow squares, for the National Seismic Hazard Maps for Japan (2005) (Earthquake Research Committee, 2006).

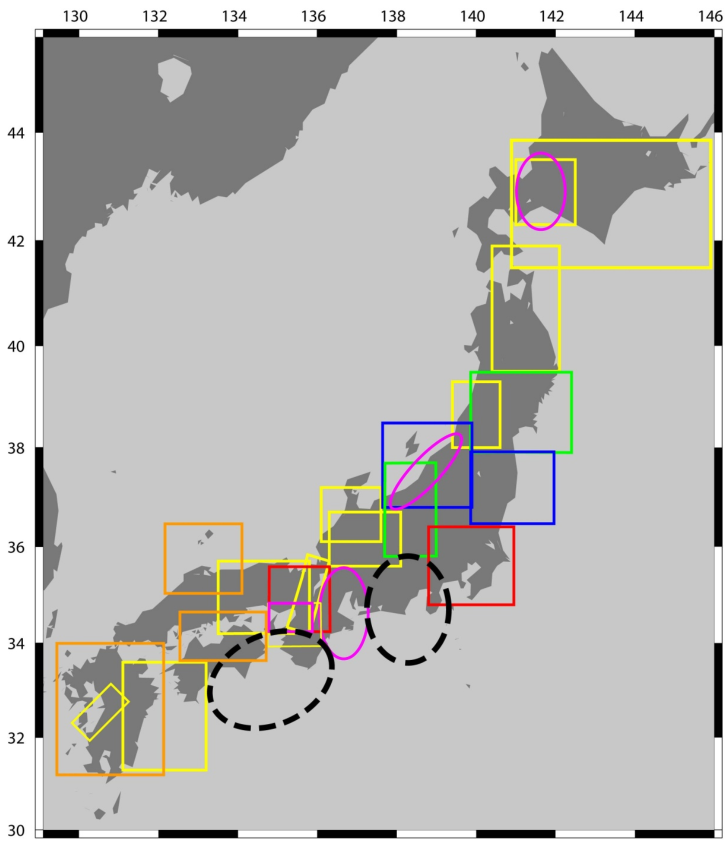

Figure 1. Areas of 3-D velocity structure models in Japan.

We have validated the constructed velocity structure model by comparison of observed and synthetic waveforms, since this modeling is carried out mainly for strong ground motion prediction. The proposed procedure including the joint inversion and validation with ground motion simulations works well for TMA, and the applicability of the standard procedure has been confirmed for regions with substantial data of experiments and earthquake records in Japan. We are applying the standard modeling procedure mentioned in the previous section to the central and western parts of Japan shown by dashed black circles. If this application is completed and the velocity structure models for the National Seismic Hazard Maps for Japan (2005) are assumed to be 0.5th-grade models, the Japan islands are covered by the 1st and 0.5th-grade models except for northern Hokkaido and Yamaguchi prefecture. We then combine these 1st- and 0.5th-grade models into the "Japan Integrated Velocity Structure Model."

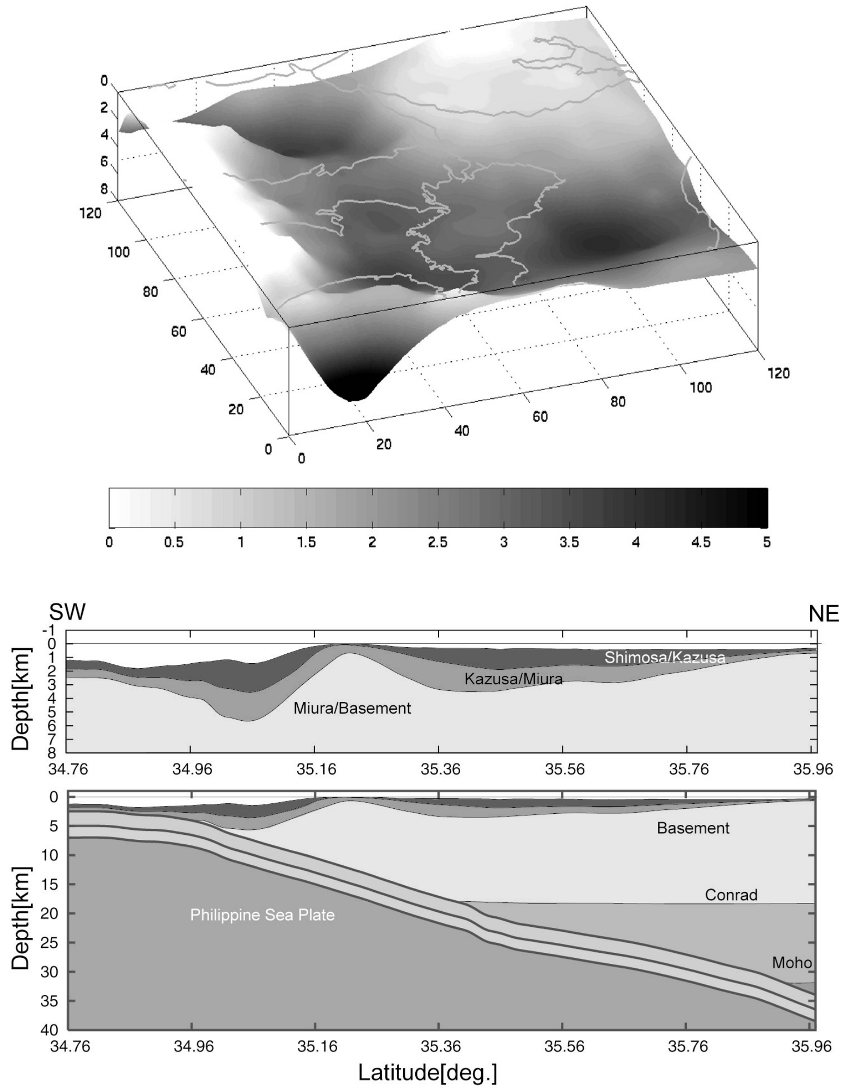

Figure 2. Depth distribution in km of the seismic basement surface (upper) and cross section along the Tokyo bay (lower) of the 1st-grade velocity structure model for the Tokyo metropolitan area (Tanaka et al., 2005; Tanaka et al., 2006).

4. LONG-PERIOD GROUND MOTION HAZARD MAP

We extract three regions from the Japan Integrated Velocity Structure Model as shown in Figure 3. Miyake et al.

(2008) constructed the characterized source models for future Tokai and Tonankai earthquakes, using the modeling procedure of Irikura et al. (2004) and its modifications for subduction-zone earthquakes. We are now carrying out long-period ground motion simulations using these regional velocity structure models, characterized source models, and a finite difference scheme (e.g., Pitarka, 1999; Aoi and Fujiwara, 1999; Hayashi and Hikima, 2000). Such indexes as peak ground velocities, response spectra at various periods, and ground motion duration will be retrieved from simulated ground motions, and they will be mapped onto the "Long-Period Ground Motion Hazard Maps."

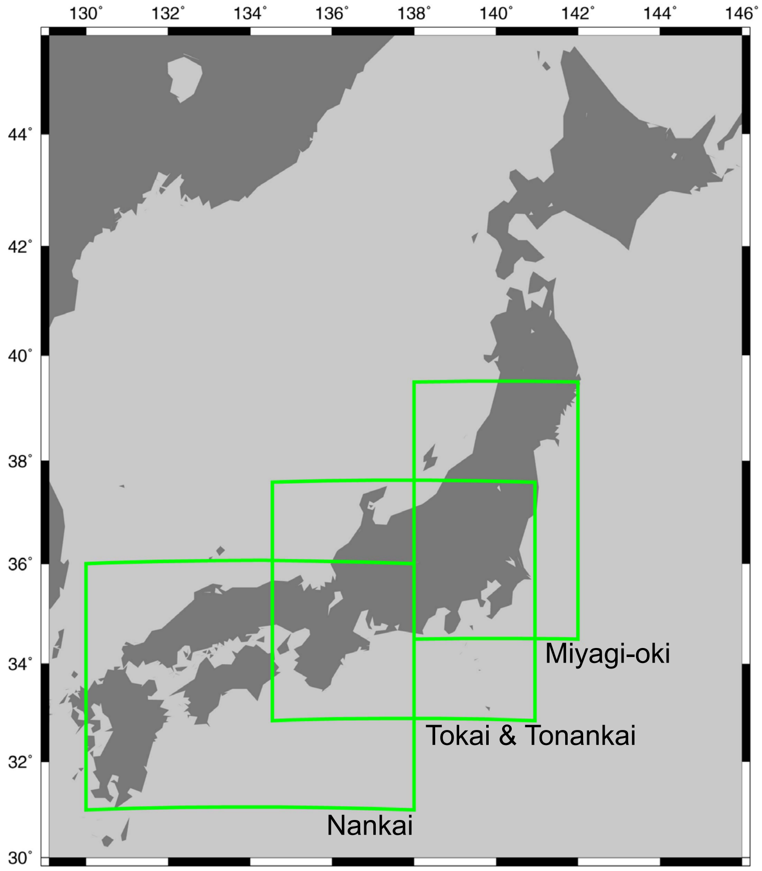

Figure 3. Target areas of long-period ground motion hazard maps for future Tokai, Tonankai, Miyagi-oki, and Nankai earthquakes.

Miyake et al. (2007) constructed 3-D velocity structure and source models, and carried out broadband ground motion simulations for a future Tokai earthquake. They then retrieved distributions of pseudo-velocity response spectra at several periods from simulated ground motions on the engineering bedrock. We can image a long-period ground motion hazard map for this future Tokai earthquake from their result for a period of 7 s, which is shown in Figure 4. Response spectra larger than 100 cm/s were obtained not only in the source region (gray squares) but also in the Tokyo metropolitan area 150 to 250 km away from the epicenter (red star) and earthquake asperities (black squares).

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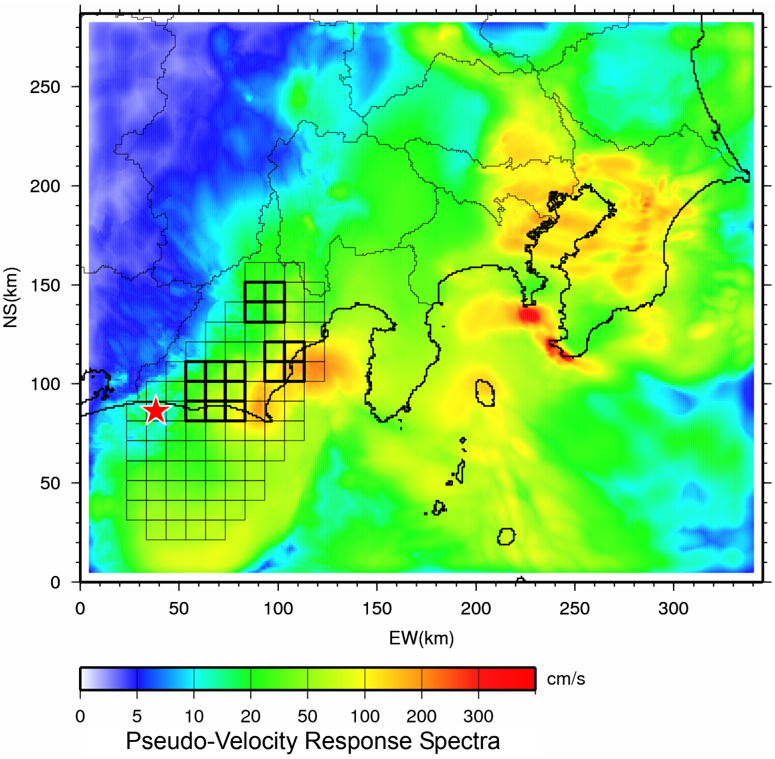

Figure 4. Distribution of pseudo-velocity response spectra for a damping factor of 5% and natural period of 7 s at the engineering bedrock based on the velocity structure and source models for a future Tokai earthquake (Miyake et al., 2007).

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