Japan Integrated Velocity Structure Model Version 1

Kazuki Koketsu & Hiroe Miyake
Earthquake Research Institute, University of Tokyo, Tokyo, Japan

Haruhiko Suzuki
Engineering Division, OYO Corporation, Tsukuba, Japan

15 WCEE
LISBOA 2012

SUMMARY:
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 assessment 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 (Koketsu et al., 2009). We then applied this procedure to northeastern and central Japan in 2009, and to southwestern Japan in 2011. We have now constructed the Version 1 of the Japan Integrated Velocity Structure Model by combining these regional models. Long-period ground motions from future Tokai, Tonankai, Nankai, and Miyagi-oki earthquakes and their response spectra were computed by using this model, and hazard maps were published in 2009 and 2012 based on the results of the computation.

Keywords: 3D velocity structure, long-period ground motion, seismic 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 of Japan, which is called the Kanto basin with an area of about 17,000 km^2 and the maximum sediment 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., 2009), because extensive geophysical experiments and geological investigations have been carried out and velocity structure models are being constructed all over Japan. We then applied this procedure to northeastern and central Japan in 2009, and to southwestern Japan in 2011. We have now constructed the version 1 of the Japan integrated velocity structure model by combining these regional models. Long-period ground motions from future Tokai, Tonankai, Nankai, and Miyagi-oki earthquakes and their response spectra were computed by using this model, and hazard maps were published in 2009 and 2012 based on the results of the computation.

2. STANDARD MODELING PROCEDURE

In earthquake engineering and engineering 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 greatly influence long-period ground motion, so our modeling procedure mostly 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. (2009) 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 this is a reason for calling the result before Step 6 only a 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 three target regions of the 1st-grade modeling, where all the steps of the standard procedure were carried out (e.g., Petukhin et al., 2012). For northern Japan, Earthquake Research Committee (2006) constructed 0.5th-grade models for the National Seismic Hazard Maps for Japan (2005). Therefore, the Japan islands are now covered by the 1st- and 0.5th-grade regional models. We then combined these regional models into the Version 1 of the "Japan Integrated Velocity Structure Model."

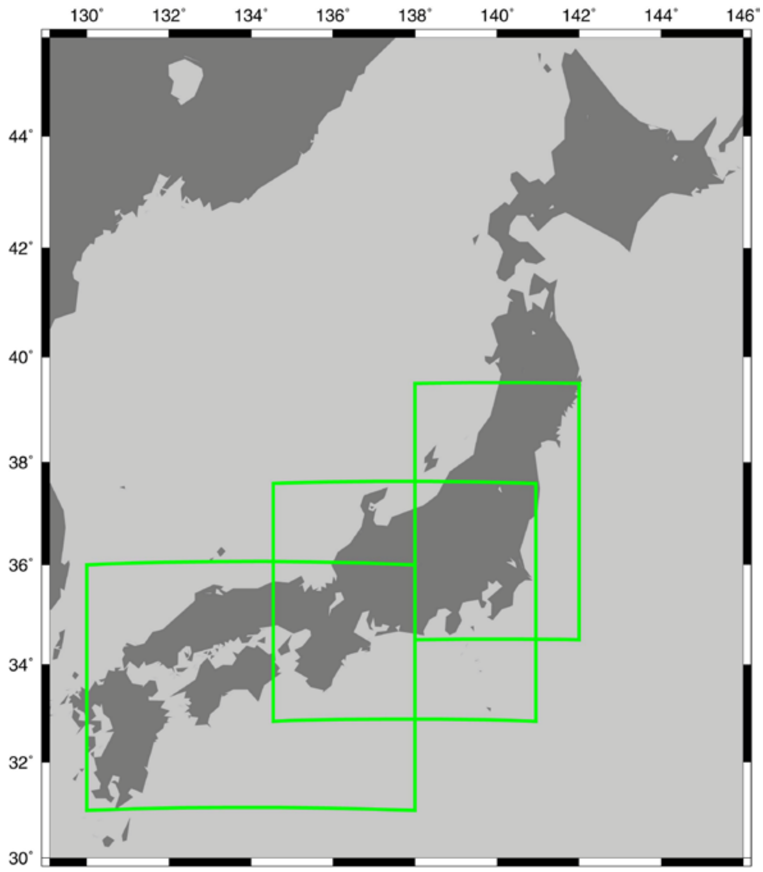

Figure 1. Target regions of the 1st-grade modeling by the standard procedure.

Long-period ground motion simulations were performed using this version of the Japan Integrated Velocity Structure Model and the finite difference schemes of Pitarka (1999) and Hayashi and Hikima (2000). Such indexes as peak ground velocities, response spectra at various periods, and ground motion duration were retrieved from simulated ground motions, and they were mapped onto the

"Long-Period Ground Motion Hazard Maps 2009 and 2012" of the Earthquake Research Committee (Koketsu et al., 2008; Kagawa et al., 2012).

AKCNOWLEDGEMENT

This study was supported by the MEXT Program for Long-Period Ground Motion Hazard Maps and Grants-in-Aid for Scientific Research (A) No. 19201034 from the Japan Society for the Promotion of Science.

REFERENCES

Earthquake Research Committee (2006). National Seismic Hazard Maps for Japan (2005), Headquarters for Earthquake Research Promotion, http://www.jishin.go.jp/main/chousa/06mar_yosoku-e/index-e.htm.

Earthquake Research Committee (2008). National Seismic Hazard Maps for Japan (2008), Headquarters for Earthquake Research Promotion, Tokyo, Japan.

Hayashi, K. and Hikima, K. (2000). Three dimensional, finite difference, viscoelastic seismic modeling (Part 2) Inclusion of earthquake source and parallel processing by PC cluster, *2000 Seismological Society of Japan Fall Meeting*, Abstract P016 (in Japanese).

Kagawa, K., Petukhin, A., Koketsu, K., Miyake, H. and Murotani, S. (2012). Source modeling for long-period ground motion simulation of the 1946 Nankai earthquake, *Proceedings of the 15th World Conference on Earthquake Engineering*, in press.

Koketsu, K., Miyake, H., Fujiwara, H. and Hashimoto, H. (2008). Progress towards a Japan integrated velocity structure model and long-period ground motion hazard map, *Proceedings of the 14th World Conference on Earthquake Engineering*, Paper No. S10-038.

Koketsu, K. and Kikuchi, M. (2000). Propagation of seismic ground motion in the Kanto basin, Japan, *Science* **288**, 1237-1239.

Koketsu, K. and Miyake, H. (2008). A seismological overview of long-period ground motion, *J. Seismol.* **12**:**2**, 133-143.

Koketsu, K., Miyake, H., Afnimar and Tanaka, Y. (2009). A proposal for a standard procedure of modeling 3-D velocity structures and its application to the Tokyo metropolitan area, Japan. *Tectonophysics* **472:1-4**, 290-300.

Magistrale, H., Day, S., Clayton, R. and Graves, R. (2000). The SCEC southern California reference three-dimensional seismic velocity model version 2, *Bull. Seism. Soc. Am.* **90**, 565-576.

Olsen, K., Archuleta, R. and Matarese, J. (1995). Three-dimensional simulation of a magnitude 7.75 earthquake on the San Andreas fault, *Science* **270**, 1628-1632.

Petukhin, A., Miyakoshi, K., Kagawa, T., Koketsu, K., Miyake, H. and Masuda, T. (2012). Construction and waveform testing of the crustal and basin structure models for southwest Japan, *Proceedings of the 15th World Conference on Earthquake Engineering*, in press.

Pitarka, A. (1999). 3D elastic finite-difference modeling of seismic motion using staggered grids with nonuniform spacing. *Bull. Seism. Soc. Am.* **89**, 54-68.

Sato, T., Graves, R. and Somerville, P. (1999). Three-dimensional finite-difference simulation of long-period strong motions in the Tokyo Metropolitan area during the 1990 Odawara earthquake (M_J 5.1) and the great 1923 Kanto earthquake (M_S 8.2) in Japan, *Bull. Seism. Soc. Am.* **89**, 579-607.

Suzuki, H., Morino, M., Iwamoto, K., Liu, Y., Fujiwara, H., Hayakawa, Y., 2005, 3D subsurface structural model for strong motion simulation around Lake Biwa, southwest Japan, *Zisin* **58**, 91-106 (in Japanese with English abstract).