Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-01 Room:302 Time:May 23 16:30-16:39

Seismic Hazard Maps in Japan : purpose of the session

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After Hyogo-ken nanbu Earthquake (Kobe Earthquake), Headquarters for Earthquake Research Promotion was established as a national government body. The headquarters has promoted the researches of active faults and historical seismic activity, and also evaluated potential of large earthquakes and the strong ground motion by the earthquakes. Based on the knowledge, seismic hazard map is edited, in which information of strength of the strong motion and their probabilities are compiled. The seismic hazard map was published tentatively in 2005, and its full version was in 2009. On the other hand, many local government bodies also have promoted the local version of the seismic hazard map taking their local characteristics into account.

These seismic hazard maps are based on the recent results and progress of researches, such as prediction of strong ground motion, models construction of subsurface structure, survey of active faults and the source model of potential large earthquakes. The seismic hazard maps are considered the comprehensive output of the earthquake researches.

What methods are used for the seismic hazard maps? What is current situation of the researches? How are the maps applied for disaster mitigation? What are new tasks to be solve? And how do we solve them? Based on these backgrounds, this session ”Seismic Hazard Maps in Japan”, is proposed from strong ground motion committee of Japan Seismological Society, Japanese Society for Active Faults Studies, and Society of Exploration Geophysicists of Japan.

On following issues, invited lectures are planned; how has seismic hazard map of national government constructed? How the maps are applied in our life? These topics will be reviewed.

In this session, we will discuss on the hazard map, development of its technology and application, as well as the future prospects.

Keywords: prediction of strong ground motion, hazard map, active faults, subsurface structure, strong ground motion, disaster prevention

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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The National Seismic Hazard Maps for Japan published by The Headquarter for Earthquake Research Promotion (HERP)

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The HERP was established based on a Special Measures Law on Earthquake Disaster Prevention, which took the lessons of the Great Hanshin-Awaji Earthquake on January 17, 1995. The executive office of the HERP is set up at the MEXT. The HERP is promoting researches into earthquake with the goal of strengthening disaster prevention measures, particularly for the reduction of damage and casualties from earthquakes. The HERP carries out many projects to achieve the goal.

One of our products is the National Seismic Hazard Maps for Japan. It consists of two types of maps. One is the Probabilistic Seismic Hazard Maps, and the other is the Seismic Hazard Map for a Specified Seismic Source Fault (the scenario map). It was first published in 2005 and updated annually by including added / updated long-term evaluation result & yearly update of the probability of earthquake occurrence. In 2009, a major revision was published. 250m grid is employed for probability (or ground motion) estimation.Landform type classification and amplification factor of surface soil layers were reconsidered and updated. As for the probabilistic maps, maps showing the 'impact' of each category of earthquakes were added. As for the scenario maps, the detailed distribution of seismic intensity was created for all major active fault zones though it was published for limited faults in the past. In 2009, the HERP published another type of experimental scenario maps called long-period ground motion maps (experimental). Targets of the maps are currently the presumed Tokai, Tonankai, and Miyagi-ken-oki earthquakes. The products include distributions of velocity response spectra (periods are 5, 7, 10 sec. with the damping factor 0.05.), maximum velocities, and durations of ground motions.

Keywords: HERP, National Seismic Hazard Maps, New Promotion of Earthquake Research, evaluation of long-term earthquake occurrence

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Toward utilization of the National seismic hazard maps for Japan

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The Headquarters for Earthquake Research Promotion of Japan (HERP) published the National Seismic Hazard Maps for Japan in July 2009, which was initialized by the earthquake research committee of Japan (ERCJ) on a basis of long-term evaluation of seismic activity, and on a basis of strong-motion evaluation. The hazard maps consist of two kinds of maps. One is a probabilistic seismic hazard map (PSHM) that shows the relation between seismic intensity value and its probability of exceedance within a certain time period. The other one is a scenario earthquake shaking map (SESM).

The examples of PSHMs are maps of probabilities that seismic intensity exceeds the JMA scale 5-, 5+, 6- and 6+ in 30 or 50 years, and maps of the JMA seismic intensity corresponding to the exceedance probability of 3% and 6% in 30 years and of 2%, 5%, 10% and 39% in 50 years. We classify earthquakes in and around Japan into three categories such as the characteristic subduction zone earthquakes, subduction zone earthquakes, and crustal earthquakes. PSHMs for three earthquake category are also evaluated.

The SESMs are evaluated for 490 scenario earthquakes of all major faults in Japan. For the SESMs, based on the source modeling for strong-motion evaluation we adopt a hybrid method to simulate waveforms on the engineering bedrock and peak ground velocity. The hybrid method aims to evaluate strong-motions in a broadband frequency range and is a combination of a deterministic approach using numerical simulation methods, such as the finite difference method, for low frequency range and a stochastic approach using the empirical or stochastic Greens function method for high frequency range. A lot of parameters on source characterization and modeling of underground structure are required for the hybrid method. The standardization of the setting parameters for the hybrid method is studied. We summarized the technical details on the hybrid method based on the ”Recipe for strong-motion evaluation”, which are published by the ERCJ.

The National Seismic Hazard Maps for Japan are a comprehensive integration from all of the research aspects conducted by ERCJ. It contains information of all necessary data for producing the maps. We have developed an open web system to provide seismic hazard information interactively, and named this system as Japan Seismic Hazard Information Station, J-SHIS (http://www.j-shis.bosai.go.jp/). We aim to distribute a process of uncertainty evaluation and to meet multi-purpose needs in engineering fields. The information provided from J-SHIS includes not only results of the hazard maps but also various information required in the processes of making the hazard maps, such as data on seismic activity, source models and underground structure.

In April 2009, HERP compiled ”New Policy for Earthquake Research: The second basic comprehensive policy for the promotion of earthquake observation, measurement, surveys and research.” The new policy sets out, as its basic objectives, to promote various research for further advancing seismic hazard maps as well as ”strengthening bridge functions to promote engineering and sociological research for disaster prevention and mitigation.”

In order to mitigate earthquake damage, it is essential to raise each individual’s awareness of earthquakes and to encourage them to be prepared for future earthquakes. The first necessary step to this end is to prepare highly realistic, detailed hazard maps and risk information covering earthquakes that occur in all parts of Japan, based on which each individual can consider earthquake risk as own personal issue. Therefore, the next stage of our research is planned to expand its target from conventional seismic hazard to also cover seismic risk evaluation.

Keywords: National Seismic Hazard Maps, strong-motion, seismic hazard, seismic risk, J-SHIS

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-04 Room:302 Time:May 23 17:11-17:28

The application cases of seismic hazard maps of japan in private enterprises

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Keywords: Japanese seismic hazard maps, The headquarters for earthquake research promotion, business continuity plan, risk finance

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(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-05 Room:302 Time:May 23 17:28-17:45

Application of Seismic Hazard Map in Chiba prefecture

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Chiba Prefecture published seismic hazard maps in 2008, and developed an open web system, named Earthquake Damage Estimation in Chiba (http://www.bousai.pref.chiba.lg.jp/portal/higaisoutei/index.html), in 2009. This web system provided not only the hazard maps, but also the date of making the hazard maps and underground geological structure.

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-06 Room:302 Time:May 23 17:45-18:00

Seismic risk analysis on building damages and human casualties based on seismic hazard of National Seismic Hazard Maps

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1. Introduction

To contribute to effective disaster mitigation in response to changes in seismic risk over the next few decades, we conducted a seismic risk analysis on building damages and human casualties, using seismic hazard curves of National Seismic Hazard Maps for Japan. To consider the changes of the social environment in the future, we calculated not only the seismic risk in 2010 but also that in 2025 and in 2040.

2. Estimation of the buildings and the population distribution data for the seismic risk evaluation

We estimated the distributions of the buildings and the population as of 2010, 2025 and 2040 in Japan, for the seismic risk evaluation as follows.

As of 2010

We estimated the number of buildings for each construction age group and for each structure group and the amount of population for each age group at grid cells of 250m*250m each in size for all of Japan, using "Grid Square Statics of 2005 Population Census" and "Building Structure Database" developed by National Research Institute for Earth Science and Disaster Prevention.

As of 2025 and 2040

We estimated the distributions of buildings and population by correcting the estimated 2010 data according to changes in future population, using "Population Statistics of Japan 2008" by National Institute of Population and Social Security Research.

3. Seismic risk evaluation method

We selected appropriate methods from the existing relatively simple methods considering the vast calculations for all of Japan. Then we tested several methods for the seismic intensity distributions estimated by spatial interpolation method from the recent observed records in actual destructive earthquakes, and compared the estimated amount of damages with the actual amount of damages. In order to conduct the future risk evaluation accurately, we revised the selected seismic risk evaluation methods so as to reflect the effects of aged deterioration of wooden buildings and aging of population.

4. Results

We calculated the risk curves for the number of the completely damaged buildings and the death toll at grid cells of 250m*250m each in size and estimated expected values based on the risk curves. As a result, we estimated that 500,000 buildings will be damaged completely and 7,000 people will be killed by destructive earthquakes as expected values within the next 50- year period for all of Japan as of 2010. And 420,000 buildings will be damaged completely and 6,700 people will be killed as expected values within the next 50-year period as of 2025 and 330,000 buildings will be damaged completely and 6,100 people will be killed as expected values within the next 50-year period as of 2040. In these estimations the expected values are dependent on the variations of seismic hazard and it is important for seismic risk evaluation to deduce the variations of seismic hazard as much as possible.

5. Next approach

We are planning to conduct a seismic risk analysis on building damages and human casualties for all of Japan as of 1890, 1920, 1950 and 1980 for the purpose of verifying the seismic risk evaluation method and understanding changes in the seismic risk during 150 years in Japan to contribute to effective disaster mitigation.

Keywords: National Seismic Hazard Maps for Japan, Seismic Risk

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Study of Building Seismic Risk Evaluation Method Based on Response Analysis to Support Seismic Disaster Prevention measu

Ippei Kondo[1*], Yoe Masuzawa[1], Kaoru Mizukoshi[1], Hiroyuki FUJIWARA[2], Shinichi Kawai[2], Nobuyuki Morikawa[2], Hisanori Matsuyama[3], Yuzuru Hayakawa[3]

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Building damage evaluation methods based on damage rate curves are effective for determining seismic risk distributions and total damage for each local government or for each earthquake based on nationwide seismic hazard information, distribution of buildings, etc. On the other hand, in order to progress from nationwide macro seismic risk evaluation to the establishment of specific seismic disaster prevention strategies by local governments and to the development of practical disaster prevention and disaster reduction activities by local governments and local residents, it is considered that building damage evaluation methods that are capable of visualizing detailed seismic risk information for building units in local areas such as wards are necessary.

To evaluate damage to building units, it is necessary to consider the following points.

?The building damage greatly depends on the ground amplification properties, so it must be possible to take into consideration the frequency properties of the seismic motions (ground frequency properties) and the building frequency properties.

?It must be possible to appropriately reflect the elastic plastic properties (reduction in stiffness, increase in damping due to hysteretic damping) up to collapse of the building.

?It must be possible to comprehensively explain to a certain extent building damage from past earthquakes.

Taking the above into consideration, the outline of a damage evaluation method was demonstrated based on seismic response calculations, as a seismic risk evaluation method for specific scenario earthquakes, with the objective of supporting effective and rational seismic disaster prevention measures by local governments and local residents. Using this method a study was carried out in which building damage was calculated from the Niigata-Ken Chuetsu Earthquake (2004) based on individual building data for Nagaoka City and Ojiya City, and the calculated damage was compared with the actual damage, and tasks for the future were identified.

Keywords: Seismic Risk Evaluation, Building Damage Evaluation, Response Spectra, Seismic Response Calculation, Ground Amplification Spectrum Evaluation Method

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(May 22-27 2011 at Makuhari, Chiba, Japan)

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Development of disaster damage anticipation tool for local community using seismic hazard or risk information

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Local community must autonomously handle large-scale disaster, such as earthquake. Management of natural disaster risk by social network of local communities and collaboration named as "disaster risk governance" is important to improve local coping capacity against disasters. To improve this capacity, the local community must reasonably evaluate disaster risk through risk communication.

To evaluate natural disaster risk, most recent scientific findings should be utilized by local community. Recently, natural disaster risk or hazard information, such as seismic hazard maps, has been created as geo-spatial information. These data have big potential in disaster prevention activities of local communities.

In order to utilize seismic hazard or risk map, there are two points. The first is the method of getting these data. The second is methodology of risk evaluation. In this presentation, interoperability of geo-spatial information as method of getting seismic hazard or risk map and the concept of web based information tool for risk evaluation are introduced through demonstration experiments.

Keywords: risk evaluation, geographic information system, hazard map

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Validation of probabilistic seismic hazard maps for Japan

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1. Introduction

The authors have tested and validated the probabilistic seismic hazard maps for Japan by comparing them with the observed seismic intensity at the strong ground motion observation sites [1], and by comparing with the estimated spatial distribution of seismic intensity based on the earthquake catalog [2,3].

In this paper, probabilistic seismic hazard maps (probabilistic maps) are estimated for time period of 30 years starting from 1890, 1920, 1950 and 1980, respectively, as well as that from 2010. In addition, spatial distribution maps of the maximum seismic intensity due to past earthquakes (experienced maps) are evaluated for the corresponding time period. These two types of seismic hazard maps are compared and examined for the validation of the national seismic hazard maps.

2. Method

Probabilistic seismic hazard maps for 30 years starting from 1890, 1920, 1950, 1980 and 2010 are evaluated. The earthquake occurrence model and ground motion attenuation model are identical to those adopted for the national seismic hazard maps [4], except for the probability of occurrence of earthquakes modeled with the non-stationary model, e.g., the large inter-plate earthquakes and the earthquakes on major active faults.

Experienced seismic hazard maps are evaluated based on the earthquake catalog. Earthquakes with magnitude 6.0 or greater are selected for Earthquake Category I and II, and 5.5 or greater for Category III. The data are divided into every 30 years starting from 1890, and the maximum seismic intensity in 30 years due to these earthquakes is estimated probabilistically.

3. Results

We compare the expected number of sites in Japan where the strong earthquake shaking (i.e., JMA Intensity 6W) is observed within 30 years for both probabilistic seismic hazard maps and experienced hazard maps. The expected number of sites is calculated by simply summing up the probability of exceedance at all the sites placed with approximately 250m spacing, and is considered as a simple measure of the total seismic hazard of Japan. The probabilistic and expected seismic hazards are consistent with each other except that the expected hazard is greater than the probabilistic one for the period starting from 1890.

Then, we check whether the strong shaking is really experienced or not at the site where the seismic hazard is estimated as high based on the probabilistic hazard map. It became clear that at the sites where the seismic hazard is dominated by the Category I earthquakes (large inter-plate earthquakes) or by the Category II earthquakes (large to medium size earthquakes in subduction zone), the ratio that the strong shaking is observed is high. On the other hand, at the sites where the Category III earthquakes (shallow inland earthquakes) dominate the seismic hazard, only weak correlation is observed between the probabilistic hazard and experienced hazard. These suggest that the strategy for the seismic risk management needs to be changed depending on the earthquake type dominating the seismic hazard for the site.

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Keywords: probabilistic seismic hazard map, disastrous earthquake, earthquake category, risk management

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(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-10 Room:302 Time:May 24 08:45-09:00

Multivariate statistical analysis for seismotectonic zonation by the use of earthquake, active fault and crustal structu

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A new seismotectonic province map is presented here, that is especially useful for the seisimic hazard assessment of blind earthquakes with Mw around 6.5. The 2nd order mesh with ca.10x10 km covering all over Japan by GIS is adopted for statistical analysis, such as the principal component analysis and cluster analysis. The parameters used in this study are the data of gravity anomaly, width of seismogenic layer, distribution of active faults and observed seismicity. The result shows the quantitative spatial similarities and new borders between seismically active and inactive regions.

Keywords: active fault, magnitude, seismotectonic zonation

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Significance of detailed active fault maps for better seismic hazard map- a case study on Kikukawa fault in Yamaguchi pr

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Based on interpretation of 1:10,000-scale air-photographs, we are preparing detailed active fault maps all over Japan, expecting that these maps will serve as fundamental data for so-called 'Official Active Fault Map of Japan'. The maps enables us to find not only to find minor active faults, but also accurate geometry of earthquake-source faults that may allow us to discuss more precisely on prediction of strong ground motion. We present a result of case study on Kikukawa fault in Yamaguchi prefecture, showing how largely the newly-found short active fault traces change the image of future earthquakes and ground motion prediction.

Keywords: geometry of active fault, detailed information of active faul, seismic hazard map, Kikukawa fault

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Probable epicenters of future M7 earthquakes in the southern Kanto region, central Japan

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The Earthquake Research Committee, Government of Japan reported that an earthquake with magnitude around 7.0 (M7) has a 70% chance of occurring in southern Kanto in 30 years, which had been estimated based on the five past earthquakes in the region. Probable hypocenters of M7 earthquakes are crucial factors to refine seismic hazard maps for the region. However, it must be a difficult matter to configure probable hypocenters of these earthquakes since the mechanisms of the past earthquakes have not been elucidated in detail. Our approach to the problem is an empirical one to derive probability models of M7 epicenters with possible assumptions based on reliable evidences. In the present study, we assume that M7 earthquakes may occur around inter plate earthquakes in this region. Incorporating this assumption into a model, the seismicity associated with the Pacific plate is smoothed with a pair of two dimensional normal density functions with different wave lengths and the smoothed seismicity with the shorter wave length is subtracted from the longer one. Five different wave lengths are considered and in total ten models are constructed. Likelihood of each model is tested with five past M7 earthquakes. The best model performs by 1.3 times better in an average probability gain than that of the model used in the current national seismic hazard maps for Japan.

Keywords: M7 earthquakes, Earthquake forecasting model, Seismic hazard, Southern Kanto

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HDS028-13 Room:302 Time:May 24 09:30-09:45

Study on source characteristic of great inland-earthquakes (Mw>7) generated by the quasi-dynamic multi-cycle simulation

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A set of large inland earthquake (Mw>7) rupture scenarios is generated using two-step dynamic rupture modeling approach. In the first step, a set of different-size earthquakes with dynamic input parameters is produced by quasi-dynamic multi-cycle simulation (Hillers et al., 2006; Hillers et al., 2007) governed by rate- and state-dependent friction low. In the second step, single-event full-dynamic modeling under the slip-weakening friction law (Ida, 1972; Andrews, 1976) is performed using the input parameters generated by the multi-cycle simulation.

A spatial coherence analysis method (Song and Somerville, 2010) is employed in order to examine cross-coherence structures between key kinematic source parameters (e.g. final slip, peak slip velocity, and rupture velocity) of the generated spontaneous dynamic rupture models. Through this analysis, several important features of spatial cross-coherence structures are found. For great earthquake with Mw >7, the peak slip velocity distributions correlate well with the high rupture velocity distributions with almost zero distance, but the correlation distances of both peak slip velocity and rupture velocity with respect to the final slip range between 5 and 20 km toward rupture propagation direction.

These results give important information for the RECIPE of the strong ground motion prediction. According to the existing RECIPE for construction of the characteristic source models, we assume that asperity areas generating strong ground motions are the same as large slip areas on the fault. However, from the spatial coherence results in this study it is recognized that the asperity area for great inland crustal-events (Mw>7) are not always coincident with the large slip areas.

Based on the RECIPE, we assume that the horizontal locations of large surface-displacement estimated from the active fault survey are corresponding to those of large final-slip distributions during past earthquakes. However, it is suggested that the asperity areas, which generate the strong ground motions (e.g. the area with large slip velocity), might not be directly corresponding to large surface-displacement estimated from the active fault survey.

The RECIPE has been made based on the analysis of inversion results by Somerville et al. (1999), they mainly used intermediate size events less than Mw 7. So it is necessary to examine whether cross-coherence structures of kinematic source parameters are same between Mw < 7 and Mw > 7 events, carrying out additional multi-cycle simulation for smaller events with Mw < 7.

This study was supported by Japan Nuclear Energy Safty Organization (JNES).

Keywords: multi-cycle simulation, dynamic source parameters, cross-coherence structures, RECIPE for the prediction of the strong ground motions

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

HDS028-14 Room:302 Time:May 24 09:45-10:00

Comparison of long-periods ground motion in Tokyo Bay area calculated from Tokai and Tokai-Tonankai coupled earthquake

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The evaluation of the long-period ground motions from great earthquakes occurred in the Suruga trough and the Nankai trough is important for seismic design or earthquake disaster prevention of long-period structures in Tokyo Bay area. Recently, the next Tokai earthquake is said to become an Aansei Type event that the focal region of Tokai earthquake and the focal region of Showa Tonankai earthquake will be outbreak in succession. However, there are few examples of the long-period ground motion simulations of the Ansei type event, and the influence of focal region coupling is unknown. Generally the response of long-period structure with low damping factor grows big if the duration time of vibration is long. When we thought about Tokyo Bay area, the region of the Tonankai earthquake may give a small influence because its distance from Tokyo bay area is longer than the region of Tokai Earthquake. Therefore, in this study, we calculated the long-period ground motion of Tokai-Tonankai coupled event and compared it with Tokai earthquake and evaluated the influence of coupled event.

The source fault model was made based on the model of Central Disaster Prevention Council. The start point of slip of Tokai event part and the Tonankai event part and the time lag (72.31 seconds) of slip start were the same as the model of Central Disaster Prevention Council too. The velocity structure model made by the Headquarters for Earthquake Research Promotion was used for calculation. We evaluated the long-period ground motion in period range more than 3.5 s using three dimensional finite difference methods. 17 points in Tokyo bay area were selected for wave evaluation.

Waveforms calculated from Tokai-Tonankai coupled event showed almost the same shape and amplitude as the waveforms of Tokai event. In the Tokyo Bay area, the influence of the Tonankai region is small and the influence of the Tokai earthquake region is big. The peak ground velocities of the horizontal motion are 20-30cm/s in west side and 40-60cm/s in the east side of the Tokyo Bay. There was the point where the case of the coupled event was about 30% bigger than Tokai event but there was the point where Tokai event was bigger. The peak ground velocity of coupled event was about 3% big on the 17 points average. The peak ground velocities of vertical motion are 10-30cm/s and coupled event case was almost the same as Tokai event case.

Comparing the response velocity spectra of 1% damping factor, coupled event and single event are almost same in period range shorter than six s. As for the peak of response spectra in period of 6-10 s, the coupled event was about 20-40% bigger than Tokai event at many evaluation points, but Tokai event was bigger than coupled event at some points. In period range over 10 s, the case of coupled event is bigger at almost evaluation points but there are the periods where the Tokai event case is bigger than coupled event case.

The ground motion during the Tokai-Tonankai coupled event was the results of the complex interference between the wave from Tokai region and Tonankai region.

Keywords: Long-Period Ground Motion, Tokai Earthquake, Tokai-Tonankai Coupled Earthquake, Finite Difference Method, Tokyo Bay Area

Japan Geoscience Union Meeting 2011
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Preliminary Study on Ground Motion Prediction Equation of Response Spectra on Seismic Bedrock

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Prediction of the response spectra for the strong motion on seismic bedrock based on an attenuation relationship is very important for the earthquake mitigation and the nuclear power plant safety. So far, since the data are rarely derived on seismic bedrock, it remains many difficulties to develop an attenuation relationship on seismic bedrock directly.

In this study, we constructed a response spectra database on seismic bedrock including the following data: (1) Data directly estimated from the recordings derived at the vertical array at KiK-net stations at which the bottom seismograph is located on seismic bedrock with Vs over 2km/sec; (2) Recordings derived at hard rock sites in RK-NET and dam sites; (3) Near source data estimated using the substructure model and an equivalent linear method for records at K-NET and KiK-net sites.

Based on this database, we developed a new attenuation relationship for response spectra on seismic bedrock, including the effects of focal depth, earthquake type.

Comparison with the other studies shows that our results are generally consistent with the recent previous studies.

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Keywords: Seismic Bedrock, Ground Motion Prediction Equation, Response Spectra

Japan Geoscience Union Meeting 2011
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Large-scale Wave Propagation Simulation using Multi GPU on TSUBAME2.0

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Ground motion simulation using FDM is one of the key techniques for seismic hazard assessment. Huge computation resources are required to perform large-scale wave propagation simulations using realistic models for high accuracy assessment. To estimate the uncertainty of the assessment caused by uncertainty of the assumptions of the source models for future earthquakes, thousands of various simulations are necessary. To overcome this difficulty, we developed, by using CUDA, the multi GPU version of GMS (Ground Motion Simulator) and performed the large-scale simulation on TSUBAME2.0 which is the Japanese fastest supercomputer operated by Tokyo Tech. The original code (CPU version) of GMS (Aoi et al., 2004) is a total system for seismic wave propagation simulation based on 3-D FDM using discontinuous grids (Aoi&Fujiwara, 1999), which includes the solver as well as the preprocessor tools (parameter generation tool) and postprocessor tools (filter tool, visualization tool, and so on). The computational model is decomposed in two horizontal directions and each decomposed model is allocated to a different GPU. Because the values on the grid at the boundary of the neighbor decomposed models are necessary for the calculations, two grids from the boundary are overlapped each other and the values on these grids are exchanged by MPI. Relative time required for the communication compared to the time for the calculation is longer for GPU than for CPU, because the calculation speed is much faster for GPU. Moreover, the overheads for the communication are larger for GPU because direct communications are not available and values are transmitted to the target GPU via CPU using MPI. Therefore the time for the communication is not negligible and the concealment technique of the communication by overlapping the calculation and the communication is essentially important for achieve high performance parallel computation using GPU. Popular technique for concealing the communication is follows: Values on the overlapped grids are calculated first and then the communication of those values between neighbor decomposed models are performed during the calculation of rest grids. This technique is not efficient because it requires discontinuous memory accesses which are hard for GPU. Considering that our discontinuous grids have two regions having different size of grid spacing, exchanges of the values on the overlapped grid in one region are made during the calculation of another region. Our concealment technique makes it possible to avoid the discontinuous memory accesses. We examined the two kind of performance test for parallel computing; weak and strong scaling tests. For the weak scaling test where the model sizes (number of grids) are increased in proportion to the degree of parallelism (number of GPUs), the result showed almost perfect linearity up to the simulation with 256 GPUs. Here we used the model with about 22 million grids as the unit model and the model size for the 256 GPUs case is about 5.5 billion grids. On the other hand, for the strong scaling test where the model size is independent from the degree of parallelism, the speed-up using the unit-model is 3.2 and 7.3 for 4 and 16 GPUs cases, respectively. The reason of the rapid decrease of the parallel performance is that the communication time increases so that it is no longer possible to conceal by calculation time. Moreover, the number of the threads for each GPU decreases because the model size allocated to each GPU becomes too small. Considering that the time steps for most model we use for simulation are up to hundreds thousand, the turn around times are several minutes to a few hours when the GPU resources appropriate to the size of the model is available. Thus, the performance of the GMS on GPU is practically satisfactory for most cases. The turn around times above do no include the time for outputting the result. Efficient parallel output technique maybe necessary for large files.

Keywords: GPGPU, TSUBAME2.0, parallel computing, ground motion simulation, FDM, seismic hazard assessment