Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-01 Room:303 Time:May 21 09:00-09:10

2011 Tohoku Earthquake: strong motion and seismic disaster: purpose of the session

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The 2011 Pacific coast of Tohoku Earthquake caused the seismic disaster as well as Tsunami disaster. Seismic Intensity (on JMA scale) of 7 was observed at MYG004 of K-NET where more than 2900 gal was recorded. Strong ground motions such as Seismic Intensity 6 upper or 6 lower distributed at Tohoku and Kanto region. Long duration of the strong ground motions were observed over wide area, and long period ground motions were recorded at Osaka as well as eastern Japan. Liquefaction was occurred and it was significant at Tokyo bay region and along Tone-Gawa River.

It is important to understand the characteristics of the strong ground motions and disaster of the earthquake for the disaster prevention/mitigation of the future large earthquakes.

Based on these backgrounds, this session "2011 Tohoku Earthquake: strong motion and seismic disaster", is proposed from the strong ground motion committee and the program committee of the Seismological Society of Japan.

We will discuss the strong ground motion, seismic disaster and lesson learned from the earthquake.

Keywords: The 2011 off the Pacific Coast of Tohoku Earthquake, strong ground motion, seismic disaster

SSS37-02 Room:303 Time:May 21 09:10-09:25

Characteristics of the 2011 Tohoku-Oki earthquake

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The 2011 M9.0 Tohoku-Oki earthquake is the largest earthquake that occurred in and around Japan since the beginning of the recorded history, and is the first M9-class earthquake that is closely recorded by a dense seismograph network. The ground motions from this major event were recorded by 1223 K-NET and KiK-net stations. The peak ground accelerations (PGA) exceeded gravity at 20 sites; the largest PGA, of 2933 gals, was observed at the K-NET Tsukidate station (MYG004). The area where the observed JMA seismic intensities exceeded 6+ spans for about 300 km along the east coast of Honshu and intensities larger than 5- were observed for most prefectures in the Tohoku and Kanto districts. Strong motions of this earthquake are characterized by large seismic intensities and PGAs, long durations, and wideness of the area that experienced intense shaking. Although the tsunamis were the primary cause of damage, the strong shaking, liquefaction and landslides also brought serious destruction. However, it was reported that the damage ratios of houses and buildings directly due to shaking were not as high as for the former earthquakes having comparable seismic intensities and PGAs. The recorded ground motions at most stations where the seismic intensities and PGAs were large had dominant periods shorter than 0.5 s and relatively poor power in the 1 - 2 s period range which has strong influence on the damage of few-stories wooden houses. The main reason for the short-period predominance is the amplification due to the low-velocity superficial layer and can be roughly explained by empirical amplification factors for 0.1 - 0.5 s periods rather than 1 - 2 s.

Keywords: 2011 Tohoku-oki earthquake, seismic intensity, PGA, PGV, K-NET, KiK-net

SSS37-03 Room:303 Time:May 21 09:25-09:40

Phase velocities of long period waves in the Tokyo bay area from the 2011 off the Pacific coast of Tohoku Earthquake

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The propagation velocities of seismic waves are important for study of ground motion characteristics and verification of underground structure model. The evaluation of the propagation velocities of long period ground motions from the records of the 2011 off the Pacific coast of Tohoku Earthquake give the knowledge to prepare for the long-period ground motions from mega thrust events of Nankai Trough. The Tokyo Electric Power Company has been carrying out seismic observation at 13 sites around the Tokyo bay using the broadband velocity type strong-motion seismographs (VSE-355G3). The ground motion during the 2011 off the Pacific coast of Tohoku Earthquake was observed at every station. A long-period (approximately 20 s) pulse wave with large amplitude is recognized in record section. This pulse wave is most clear in the up-and-down component. In addition, this pulse wave seems to propagate from the northeast direction.

We performed frequency-wave number spectrum analysis for the up-and-down motion records of six sites located at around the Kawasaki thermal power station and estimated the phase velocities and propagation directions. The phase velocity at frequency 0.04Hz and 0.05Hz are about 4.0 km/s and 3.6km/s, respectively. The waves propagate from the epicenter direction (N40E). These characteristics coincide with the propagation characteristics of the wave packets recognized in velocity waveforms. Estimated phase velocity disperses from 0.06Hz to 0.17Hz and phase velocity varies from 4.3km/s at 0.06 Hz to 3.4km/s at 0.17Hz. To examine the relation between this dispersion characteristics and underground structure, we extracted the underground structure model for the grid near the Kawasaki site from the underground structure model for trial version of the long-period ground motion prediction map 2009 and calculated phase velocities of the Rayleigh waves. The phase velocities evaluated from the observation record are faster than phase velocity of the fundamental mode and near to the velocities of first higher mode. The results of frequency-wave number analysis may be affected non-stationary wave propagation. We performed semblance analysis using a narrow-band pass filtered waveforms and evaluated the phase velocity for each time sections. The center periods of the filters are 5, 6, 7, 8, 9, 10, 12, 15, and 20 s. The time window length for analysis is 40 s. The phase velocities in period of 12, 15 and 20 s correspond to the velocities of fundamental mode. In period of 5, 6, 7, 8, 9 and 10 s, the estimated phase velocities correspond to the velocities of 1st higher mode. In addition, the comparison of the phase velocity evaluated from transverse component with the theoretical phase velocity of the Love waves show the correspondence with the 1st higher mode in period range from 5 to 10 s, also.

These results suggest that the higher mode surface waves were predominant over the fundamental mode in the long period ground motions of the Tokyo Bay area during the 2011 off the Pacific coast of Tohoku Earthquake. Since the fundamental mode surface waves show big amplitude usually, we need further examination.

Keywords: Phase Velocity, Long-period Seismic Motion, The Tokyo Bay Area, the 2011 off the Pacific coast of Tohoku Earthquake, Frequency-Wavenumber Spectrum Analysis, Semblance Analysis

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-04 Room:303 Time:May 21 09:40-09:55

Attenuation characteristics of peak motions during the 2011 Tohoku earthquake using EHD based on different fault models

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The M_w9.1 Tohoku earthquake, occurred on 2011 March 11, caused over 15,000 people dead and over 3300 people missing. The earthquake, ruptured all the segments from off-Iwate to off-Ibaraki along the Japanese trench, for a total distance of about 480 km (e.g., Yokota et al., 2011), with a moment magnitude of 9.0 - 9.1, is one of the largest mega-thrust earthquakes in the world.

During the earthquake, abundant strong motion datasets have been derived. These datasets indicated that the observed PGAs and PGVs are generally less than the predictions by the existing attenuation models using fault distance (e.g., Boore, 2011; Si et al., 2011). On the other hand, it is also indicated that, by using equivalent hypocentral distance (EHD), the observations are generally consistent the predictions by Si and Midorikawa (1999)(e.g., Kanda et al., 2011; Nishimura et al., 2011; and Ohno, 2011). Since arguments on the appropriateness of EHD as a distance measurement still remain (e.g., Fukushima, 1994), it is needed to confirm the calculated EHDs and their variation.

In this study, considering that the EHD generally depends on the fault model used in the calculation, the variation of EHDs and its impact on attenuation characteristics of PGA and PGV are discussed based on 3 typical slip models proposed for the Tohoku earthquake. The first two models are the models proposed by Yokota et al. (2011) based on the joint inversion of teleseismic, strong motion, geodetic and Tsunami datasets, and Shao et al. (2011) based on the inversion of teleseismic datasets, relatively. The two models are characterized by the location of most ruptured area, around (Yokota et al., 2011) or easterly (Shao et al. (2011)) of the hypocenter. The third model is a uniformly distributed slip model, in which the slips are normalized to unit slips.

Using the EHDs calculated by the 3 fault model, The attenuation characteristics of PGAs and PGVs observed are compared with those predicted by Si and Midorikawa (1999). The results indicated that, (1) there are difference between the results based on different slip models, and the fitting is generally better by using the model by Yokota et al.(2011); (2) for part of the stations around Kanto area there are large differences between EHDs calculated from the uniformly distributed slip model and the inverted ones, leading to the differences in the attenuation characteristics for PGAs and PGVs.

Acknowledgement The strong motion data recorded by K-NET and KiK-net are used in this study.

Keywords: Equivalent hypocentral distance, Attenuation characteristics, 2011 Tohoku earthquake, Fault model

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-05 Room:303 Time:May 21 09:55-10:15

Soil liquefaction in Tokyo Bay area during the 2011 Great East Japan Earthquake

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The 2011 Great East Japan Earthquake caused severe liquefaction in the Tokyo Bay area. Immediately after the earthquake, the authors investigated the liquefied sites for about 10 days. A tentative map of liquefied zones was drawn based on this first stage investigation. As the liquefaction-induced damage were serious, Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, intended to make joint research with JGS to identify liquefied sites. Figure 1 is the map of liquefied zones thus estimated which is slightly modified from the tentative map. As shown in this map, severe liquefaction occurred in reclaimed lands from Shinkiba in Tokyo through Urayasu, Ichikawa, Funabashi and Narashino cities to Chiba City. Total liquefied area from Odaiba to Chiba City reached about 41 km2 which is wider than the liquefied area in Christchurch during the 2011Christchurch, New Zealand earthquake. These lands were constructed after around 1966 by soils dredged from the bottom of the bay. The dredged and filled soils must have been liquefied by the earthquake.

Seismic intensities in the liquefied zones were not high, 5- to 5+ by the JMA scale or 160 to 230 cm/s2 in peak surface acceleration, though the liquefied ground was covered by boiled sands. According to the questionnaires to inhabitants, starting time of the boiling of muddy water are quite different at place. This must imply the depths of liquefied layer and/or water table are different at place. Some inhabitants testified boiling did not occur during main shock but occurred during aftershock. It can be said that very long duration of the main shock and an aftershock 29 minutes later should have induced the severe liquefaction.

Two remarkable characteristics of the liquefied grounds were observed: i) much boiled sand and large ground subsidence, and ii) the buckling of sidewalks and alleys. The former must have occurred because the liquefied soils were very fine. The latter might have been induced by a kind of sloshing of liquefied ground. Sewage pipes meandered or were broken, joints were extruded from the ground, and pipes were filled with muddy water. Many manholes were sheared horizontally and filled with muddy water, whereas few manholes were uplifted. This remarkable damage to buried pipes and manholes might have occurred due to a kind of sloshing of liquefied ground.

About 27,000 houses were damaged in the Tohoku and Kanto districts of Japan due to liquefaction caused by the earthquake. About half of the damaged houses are located in the Tokyo Bay area. In Urayasu City, where houses were seriously damaged, 3,680 houses were more than partially destroyed. Houses settled substantially and tilted seriously

Keywords: Great East Japan earthquake, Liquefaction, reclaimed land, house, sewqage pipe

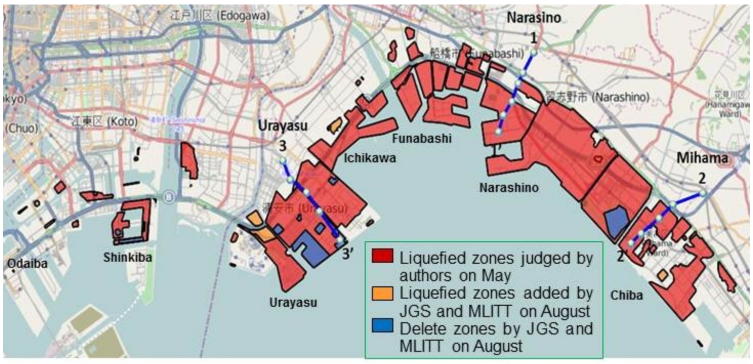

Figure 1 Liquefied area from Odaiba in Tokyo to Chiba City (Joint research by Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism and JGS)

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-06 Room:303 Time:May 21 10:15-10:30

Non-uniformity of Surface Layer Liquefaction Damage Caused by Layered System Organization and Dip of Deeper Layer

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During the Tohoku Region Pacific Coast Earthquake, extensive liquefaction damages were occurred in Urayasu and over a wide range of reclaimed coastal land. The characteristics of this liquefaction include the following. (1) It occurred approximately 450 km away from the epicenter, although K-net and other ground level observations recorded intensities of up to approximately 100-200 gal, but there was continuous relatively long-period ground motion. (2) Liquefaction occurred over a wide range of soils that also included intermediate soils with large fine fraction content. The latter is frequently ascribed to the long duration of the seismic motion. Previously, the authors focused on the stratum organization, with a thin layer of soft alluvial clay located directly under the alluvial sand on the inland side, where liquefaction damage was small, and this clay layer increasing in thickness as you approach to the coast, where liquefaction damage was severe. Based on the results of 1D elasto-plastic seismic response analysis, the authors indicated that in addition to the long duration of the seismic motion, the presence of a soft clay layer below the liquefied layer can amplify seismic waves over a range of longer periods, and the resulting large plastic strain may cause large damage even in clayey sand that normally resists liquefaction. Here, the authors newly focused on the dip of the boundary between the clay layer and the diluvial layer located below it and conducted 2D analysis. The analysis, performed using the ***GEOASIA*** soil-water coupled finite deformation analysis code incorporating an elasto-plastic constitutive model (SYS Cam-clay model) that contains sand, intermediate soil and clay within the same theoretical framework, showed that the presence of this inclined boundary produces non-uniform liquefaction even when liquefaction does not occur in 1D analysis.

Fig. 1 presents the analysis results from a 1D soil model showing layered system organization of soils in the analysis and the change of the excess pore water pressure ratio at the top part of the reclaimed layer with time using the same input seismic motion as Asaoka et al. (2011), except that the model uses a sequence of layers that more closely matches the actual conditions. As a result, the excess pore water pressure ratio of the reclamation layer was only approx. 0.8 at most, and liquefaction did not occur. Fig. 2 shows the results from 2D analysis. It shows the shear strain distribution 150 sec after the start of the earthquake and the change of the excess pore water pressure ratio of the reclamation layer at point A with time. The figure demonstrates that particularly large shear strain appeared near point A. The excess pore water pressure ratio exceeded 0.95, and liquefaction occurred. This was due to amplification of the input seismic waves by the alluvial clay layer and the boundary between the alluvial clay layer and diluvial layer being inclined. The calculations show generation of an SV component of seismic motion and also multidimensional propagation of seismic waves due to reflection by the inclined diluvial layer. It is also stated that large localized plastic shear deformation of the surface layer appeared at various other points in addition to point A (Fig.2).

This recent earthquake was characterized by spatial non-uniformity of liquefaction damage and the large variation therein. Although the heterogeneity of geomaterials is frequently pointed out as a possible cause, the results of this analysis showed that there was large variation in soil deformation caused by an inclined/heterogeneous layered system even with homogenous geomaterials. This is a matter that cannot be considered with 1D analysis and underscores the need for multidimensional analysis.

Asaoka, A. et al. (2011): The effect of stratum organization on the occurrence of liquefaction in silty sand, the Seismological Society of Japan 2011, fall meeting, p.56.

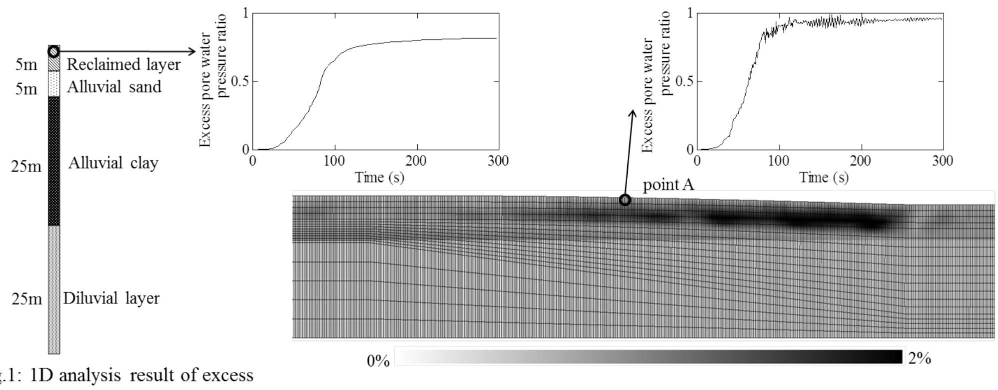

Fig.1: 1D analysis result of excess pore water pressure ratio at the center of the reclamation layer

Fig.2: 2D analysis result of shear strain distribution at 150s after earthquake and excess pore water pressure ratio at the center of the reclamation layer at point A

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-07 Room:303 Time:May 21 10:45-11:00

Rupture processes of the 2011 Tohoku-Oki earthquake sequence on the curved fault derived from strong-motion records

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Rupture processes of the interplate earthquake sequence of the 2011 Tohoku-Oki mega-thrust event have been derived using the strong-motion records. To construct fault models which approximate the geometry of the large fault zones as precisely as possible, we express the upper boundary of the subducting Pacific plate (Nakajima and Hasegawa, 2006; Nakajima et al., 2009; Kita et al., 2010) using NURBS (Non-Uniform Rational B-Spline). This mathematical expression of the plate geometry enables us to reproduce the fault models of the interplate earthquakes flexibly. Source inversion method using the curved fault expressed by NURBS is based on the method proposed by Suzuki et al. (2010). The derived rupture process of the mainshock indicates three main features related to the waveform radiation: 1) The shallow large slip area located far off Miyagi prefecture ruptured 60 seconds after the initial break for at least 40 seconds, generating the seismic waves rich in the very-low-frequency content. 2) The area between the hypocenter and the coastline of Miyagi prefecture experienced two rupture events, which seem to be responsible for the two large acceleration phases observed in and around Miyagi prefecture. 3) The rupture after 100 seconds proceeded to the south, off Fukushima prefecture, generating the large velocity phase that has similar onset time to the large acceleration phase observed in the Kanto district. The rupture process of the M7.6 largest aftershock, which occurred approximately 30 minutes after the mainshock near the southern edge of the mainshock fault, indicates that the large slip area extends to the east, shallower part of the fault plane. The velocity waveforms of the aftershock show the pulse, duration of which is longer than 10 seconds. This phase is well reproduced by the slip located in the shallower part. These features for the Tohoku-Oki earthquake sequence are essentially the same as those derived by the source inversion using the rectangular fault. It is considered better, however, for examining the characteristics of the strong-motion generation to approximate the geometry of the ruptured fault as precisely as possible.

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-08 Room:303 Time:May 21 11:00-11:15

Construction of a source model for the 2011 Tohoku, Japan, earthquake with special reference to strong motion pulses

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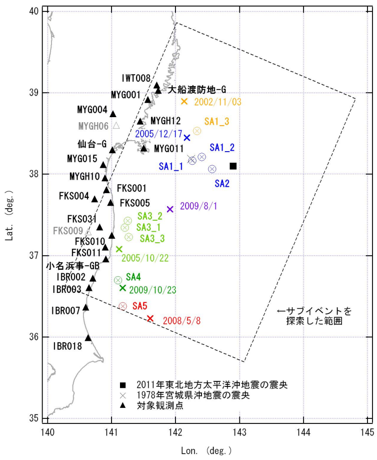
The 2011 off the Pacific coast of Tohoku, Japan, earthquake is obviously the first M9 earthquake which was recorded by dense strong motion networks. The occurrence of the earthquake enabled us to analyze real strong ground motions due to a M9 earthquake for the first time in the history. Before the occurrence of the earthquake, the author proposed the following for the evaluation of strong ground motions due to a large subduction earthquake (Nozu, 2010):

1) To use a source model composed of asperities with relatively small size.

2) To calculate strong ground motions based site amplification and phase characteristics.

In the past study, the applicability of the above strategy was fully investigated for M8 class earthquakes. In the present study, to investigate the applicability of the strategy for a M9 earthquake, a source model with asperities was newly developed for the 2011 Tohoku earthquake. The constructed source model involves 9 asperities with relatively small size, located off-the-coast of Miyagi through off-the-coast of Ibaragi. The strong ground motions due to the earthquake were calculated based on site amplification and phase characteristics, using the constructed source model. The agreement between the observed and calculated ground motions was quite satisfactory, especially for velocity waveforms (0.2-2.0 Hz) including near-source pulses. The result definitely shows the applicability of the strategy for a M9 earthquake. The asperities with small size introduced in this study are equivalent to the concept of super asperity proposed by Matsushima and Kawase (2006), because the size of the rupture area used in this study is much smaller than the size of the asperities or SMGAs conventionally assumed for a huge subduction earthquake. More elaboration is required, however, in terms of terminology, because the concept of asperity itself is currently ambiguous.

Keywords: the 2011 off the Pacific coast of Tohoku earthquake, strong ground motion, strong motion pulse, source model, super asperity



Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS37-09 Room:303 Time:May 21 11:15-11:30

Postdiction of Source Model for the 2011 Tohoku Earthquake

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There are many studies on strong ground motion validation for past earthquakes, applicability of the methodology of strong ground motion prediction, and strong ground motion prediction for forthcoming earthquakes. We here define postdiction (= prediction after the fact) as a method of ground motion prediction posterior to the earthquake based on the knowledge prior to the earthquake. We examined the postdictability of the source model for the 2011 Tohoku earthquake. The postdiction will be validated for the observed ground motions using the empirical Green's function method and other techniques.

<Parameters available prior to the earthquake>

The fault plane was considered to be a multiple rupture involving the Miyagi-oki, southern Sanriku-oki, Fukushima-oki, and Ibaraki-oki regions as a single megathrust event. We excluded the central Sanriku-oki region due to the aseismic information and the offshore regions from northern Sanriku-oki to Boso-oki due to the tsunami earthquakes and normal faulting information. The rupture area was estimated to be 35,000 km^2 with Mw 8.3 (after Murotani et al., 2008) and 8.5 (after Sato, 1989). The earthquake magnitude was limited to around the size of the 869 Jogan earthquake, and did not reach to that for the Tohoku earthquake.

We set a characterized source model based on the recipe for strong ground motion prediction. We also incorporated with the double-corner source spectral model (Miyake and Koketsu, 2010) for plate-boundary earthquakes. In this model, size and stress drop for strong motion generation areas are respectively half and double of those for asperities. The 20%-sized asperities were located to be the same position of the historical earthquakes. The stress drop for 10%-sized strong motion generation area was 14 (after Murotani et al., 2008) and 30 MPa. (after Sato, 1989). The rupture starting point was set to the central eastern edge of the southern Sanriku-oki region. The rupture was assumed to propagate radially from the hypocenter as well as the rupture starting points of asperities and strong motion generation areas.

<Parameters unavailable prior to the earthquake>

After the Tohoku earthquake, we learned different locations and sizes between asperities for long-period components and strong motion generation areas for short-period components. In this postdiction, the strong motion generation areas were located inside the asperities. The model did not allow multiple ruptures and reverse propagation as seen in the Tohoku earthquake.

<Problems>

Based on the knowledge prior to the earthquake, the source model for the Tohoku earthquake seems to be limited to the Jogan earthquake size. To assume a M9-class earthquake, we need a rupture area over the Tohoku region; from northern Saniku-oki to Boso-oki including the off-shore regions. It is unlikely to model this size prior to the earthquake. The rupture area for the Tohoku earthquake resulted in a standard deviation of Murotani et al. (2008), therefore, we propose the rupture area with variability for a given magnitude toward megathrust source modeling.

Keywords: Tohoku earthquake, source model, scaling, validation, prediction, postdiction

SSS37-10 Room:303 Time:May 21 11:30-11:45

GPU-accelerated large-scale simulation of seismic wave propagation from the 2011 Tohoku-Oki earthquake

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The Tohoku-Oki earthquake on March 11, 2011 (MJMA 9.0) generated strong shaking reaching the maximum intensity (seven) on the JMA's scale and caused devastating tsunamis with run-up heights exceeding 30 m. Such mega-thrust earthquake was not expected to occur along the plate interface off the northeastern Japan. Thus it is very important to study this event for understanding the geophysical condition of the generation of mega-thrust earthquake, the characteristics of the induced strong ground motions, and the mechanism of the excitation of the large tsunamis.

The ground motion records of this event are quite important data for the quantitative studies on the earthquake source and the induced damages. However, modeling of the ground motions is not a simple task because of the strong lateral heterogeneity in and around the Japan trench: all of steeply varying topography, oceanic water layer, thick sediments, crust with varying thickness and subducting oceanic plate can affect the seismic waves radiated from suboceanic earthquakes [1,2]. Thus the structural model is an important factor in the study of waveform modeling.

The modeling of the ground motion induced by this event is a computational challenge: large memory size and fast computing devices are required because the huge fault size of the earthquake (about 500 km x 200 km) imposes a very large domain size for the simulation. For example, for a finite-difference domain of 960 km long, 480 km wide and 240 km deep and for a grid spacing of 0.15 km, a quite large grid size of 6400 x 200 x 1600 or 33 billion of grid points are necessary.

Therefore, we need to develop numerical methods that can precisely incorporate the effects of the heterogeneous structure including the land-ocean topography. Further, we need to confirm the feasibility of the methods in the case of large-scale problem: the computation must be done within a tolerable time.

Thus, in this paper we use a 3-D finite-difference time domain (FDTD) method [3,4]. In the method we implement the schemes to incorporate the land and ocean-bottom topography, oceanic layer and other lateral heterogeneity. In order to simulate the wave propagation with a large grid size, we adopt the GPU (graphics processing unit) computing to our finite-difference program. We use the TSUBAME supercomputer in Tokyo Institute of Technology which has a peak performance of 2.4 peta-flops. Currently, we have succeeded to simulate the wavefield from the whole fault of 2011 Tohoku-Oki earthquake by using 1000 GPUs of the TSUBAME supercomputer with 33 billion of grid points and a grid spacing of 0.15 km. We present the results of the simulation of the wave propagation based on a preliminary source model of the 2011 Tohoku-Oki earthquake.

[1] Okamoto, Earth Planets Space, 54, 715-720, 2002.
[2] Nakamura et al., submitted paper.
[3] Okamoto et al. Earth Planets Space, 62, 939-942, 2010.
[4] Okamoto et al., in GPU Solutions to Multi-scale Problems in Science and Engineering, Yuen, D. et al. (Eds.), 250 p., Springer, due February 29, 2012. (ISBN 978-3-642-16404-0)

Keywords: 2011 Tohoku-oki earthquake, strong ground motion, finite-difference, FDTD, multi-GPU

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Long Period Ground Motion Simulation of the 2011 off the Pacific coast of Tohoku earthquake (Mw9.0)

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[1]RRI, Kyoto University

1. Introduction

On 11 March 2011, Japan was struck by a massive Mw 9.0 subduction zone earthquake whose epicenter was off Miyagi Prefecture in the Tohoku region (the 2011 off the Pacific coast of Tohoku earthquake).The seismic ground motions of this earthquake caused severe damage and casualties over a wide area from Tohoku into the Kanto region. The long-period ground motions associated with this earthquake had less effect on high rise buildings than one would expect from the scale of the event. Nevertheless, skyscrapers suffered some ceiling collapses and damage to internal furnishings, elevators and other equipment. It is important to estimate the amplification characteristics, attenuation characteristics and other propagation parameters of the long-period ground motions associated with this earthquake to investigate measures that can be taken against such ground motions in future huge earthquakes. Our objective of this study is to investigate how well the observed long-period ground motions during the earthquake are reproduced using our source model (Kawabe et al., 2011) and the 3D subsurface structure model proposed by the Headquarters for Earthquake Research Promotion (HERP).

2. Ground Motion Simulation

We used our source model (Kawabe et al., 2011) composed of five strong motion generation areas (SMGAs) located on the sea off Miyagi, south Iwate, Fukushima and Ibaraki Prefectures. The effective period of our source model was 0.1 to 10 sec. We used the subsurface structure model presented on the HERP website (HERP model). The subsurface model was used in the 2009 version of the Long-Period Ground Motion Hazard Map published by HERP. Ground-motion simulations were performed using the 3D finite-difference procedure presented by Pitarka (1999). The algorithm is accurate to fourth order in space and second order in time. The finite-difference model covers an area of 412 km (east-west direction) $*$ 471 km (north-south direction), and extends to a depth of 100 km. The grid spacings were 0.3 km horizontally and 0.1 to 0.6 km vertically, and the time step was 0.0075 sec. The effective period of the simulation was 3 to 10 sec. because of the values of the finite-difference grid spacing, the physical parameters of the subsurface structure model and the effective period of our source model.

3. Results

Figure 1 compares the observed waveforms with the synthetic waveforms. Overall, the propagations of seismic ground motion (such as the arrival time and duration) from the north into the Kanto basin were reproduced. A more detailed look at these results indicates that the amplitude of the principal motions and shape of the wave packet are reproduced from station MYGH12 in Miyagi Prefecture to IBR012 in Ibaraki Prefecture, but the amplitude of the later phase of the synthetic waveforms is somewhat lower than that of the observed ones. The synthetic waveforms of the NS component of the principal motions are overestimated for all of the observation stations in the Kanto basin south of the SIT010 station in Saitama Prefecture. However, the velocity amplitudes of the EW and UD components correspond well to the observed values. The later phase amplitudes of the synthetic waveform are lower than the amplitudes observed at the stations in Kanto basin. One possible reason for this is that the source model was composed of only five SMGAs, the radiation of ground motions from the other source region was not assumed. It is also possible that the attenuation parameters in the sedimentary basins might be incorrect. These factors will be investigated in a future study.

Acknowledgment: We thank the National Institute for Earth Science and Disaster Research (NIED) for strong motion records, Japan for strong motion records, and the Japan Meteorological Agency (JMA) for the source data.

Keywords: 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake, strong ground motion, source model, strong motion generation area, finite difference method

SSS37-11 Room:303 Time:May 21 11:45-12:00

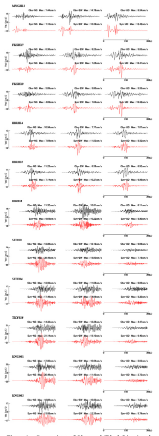

Figure 1 Comparison of Observed (Black Lines) and Calculated (Red Lines) Waveforms for Finite-Difference Simulation (Band Pass Filter: 0.1–0.33 Hz).

SSS37-12 Room:303 Time:May 21 13:45-14:03

Lessons of the 2011 Tohoku earthquake Focused on Characteristics of Ground Motions and Building Damage

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The author addresses firstly the observed high acceleration records with PGA of 2,700 cm/s/s and the corresponding JMA seismic intensity 7 at the K-NET Tsukidate station during the 2011 Tohoku Earthquake (M9.0). Structural damage was quite light in the surrounding area. The relation between high acceleration record and building damage is discussed by referring to the questionnaire intensity by authors and by mentioning unfavorable behavior with partial uplifting and slipping of the foundation of the seismometer based on the non-stationary spectral analysis and particle orbit analysis.

Many long-duration records observed during the earthquake, especially in geological basin, are also discussed. A base-isolation device with lead damper of a building in Osaki city was damaged. Many numbers of displacement cycles may affect on the damage of the seismic elements of structures due to ground motion with long duration.

Next, ground motion characteristics during the 2011 Tohoku earthquake are compared to those during the 1978 Miyagi-ken Oki earthquake (M7.4) at the same observation site. The author addresses observation records at basement floor of Sumitomo building near Sendai station, which is recognized as engineering bedrock motion. The comparison shows that the ground motion during the 2011 earthquake is larger in PGA and response spectra than 1978 earthquake, but the amount of structural damage is smaller in 2011 earthquake due to progress of seismic design and seismic retrofits. Difference of ground motion due to geological conditions is also discussed based on strong motion networks including the authors' DCRC network.

Regarding specific building damage of 8- and 9-story buildings at Aobayama campus of Tohoku University, ground motion amplification in the site was discussed based on the observation records at a 9 story SRC building of Departments of Civil Engineering and Architecture (THU building). During the 2011 earthquake, THU building was resonantly shaken and damaged (Photo 1) by the amplified ground motion compared to more than two times at the period range of 1sec compared to Sumitomo station, which is one of major reasons of the structural damage (Fig.1). The amplification was also recognized during the 1978 earthquake. Dynamic behavior of the damaged THU building due to the amplified ground motion is also discussed.

As other specific building damage, the two pile foundation buildings which were damaged during the 1978 earthquake comparatively discussed. An example of the pile foundation damage of the building constructed after the Japanese Building Code issued in 1981 is addressed. As damage of non-structural elements, the tremendous number of ceiling board dropped during the main shock and the major aftershock. Some of them caused killed persons for the first time. The 400 valley-filled housing lands' failures were caused in Sendai City. These damages are strongly related to the long duration ground motion.

Finally, the following learning and lessons from the 2011 earthquake are addressed for stronger earthquake countermeasures of urban and building structures: 1) Necessity of the seismic microzoning considering ground motion difference due to geological conditions, 2) Necessity of appropriate seismic indices corresponding to objective building damage, 3) Reconsideration of the setting place / setting method of the seismometer, 4) Necessity to evaluate the safety of structural elements for number of displacement cycles due to the long-duration earthquake and repetition by many aftershocks, 5) Consideration of non-stationary of ground motion the nonlinearity of the building for the huge earthquake, 6) Total balance of structural element, non-structural elements, and equipments, and also balance of foundation and superstructure for synthetic seismic performance of the whole building, 7) Evaluation of residue performance of the buildings damaged by past earthquakes and this earthquake.

Keywords: 2011 Tohoku earthquake, ground motion characteristics, site amplification characteristics, building damage, resonance, long duration

SSS37-12 Room:303 Time:May 21 13:45-14:03

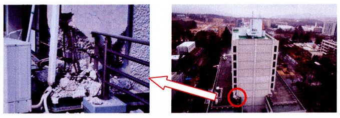

Photo 1 One of damaged four corner columns of THU building

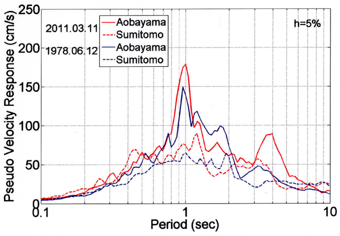

Fig.1 Site specific spectral ground motion amplification in Aobayama hill, Sendai

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SSS37-13 Room:303 Time:May 21 14:03-14:18

Response and Damage of High-Rise Buildings in the Nishi-Shinjuku Area, Tokyo, Japan, during the 2011 Tohoku Earthquake

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We reported seismic response, damage and emergency response of high-rise buildings in the Shinjuku Station area in Tokyo, Japan, for the 2011 Great East Japan Earthquake, using strong motion data, numerical simulations and questionnaire/hearing surveys. The Shinjuku Campus of Kogakuin University of 29-stories showed that the maximum amplitudes of the strong motions during the mainshock are 1 m/s/s, 0.2 m/s, and 0.1 m for accelerations, velocities, and displacements, respectively, at the ground level. And those of the 29th floors are amplified to 3 m/s/s, 0.7 m/s, and 0.37 m, respectively. The JMA intensity also amplified from 4 at 1st floor to 6- at 29th floor. Even though there was no structural damage, nonstructural elements suffered damage at the middle to higher floor: falls of ceiling boards, and deformation of partition walls. An emergency elevator had been stopped for more than 3 weeks, because of twisted cables and broken parts. The questionnaire/hearing surveys from 16 buildings in the Shinjuku area showed that their seismic response and damage patterns are similar to those of Kogakuin University. Even though there was no severe building damage, emergency managers felt difficulty to make an appropriate announcement whether people should stay or evacuate from the building to obtain the damage information immediately after the earthquake. This suggests the effectiveness of RSM (Real-Time Seismic Monitoring system) after an earthquake.

Keywords: 2011 Great East Japan earthquake, Long-Period Strong Ground Motion, High-Rise Building, Numerical Analysis, Non Structural Elements, Emergency Response

Table 1 Max. amplitudes of of the Kogakuin and STEC buildings during 2011 East Japan earthquake

(a) Kogakuin University Building

Floor		29	25	22	16	8	1	B6F	-100m
Relative Displacement to1F (cm)	EW	30.5	28.7	24.8	–	–	0.0		
	NS1	33.7	29.0	25.9	16.9	–	0.0		
	NS2	33.5		25.6	16.4	–	0.0		
Absolute Displacement (cm)	EW	30.6	26.1	25.1	–	–	5.7	6.5	5.8
	NS1	34.7	29.9	26.9	17.9	–	6.2	7.1	6.3
	NS2	35.3		27.4	18.2	–	7.2	7.0	
	UD	3.5	3.7					3.4	3.3
Acceleration (cm/s/s)	EW	234.6	134.7	151.7	–	197.1	91.9	63.3	45.9
	NS1	291.6	151.4	153.4	232.4	198.2	97.5	56.8	49.5
	NS2	340.7		159.2	241.9	–	81.6	55.4	
	UD	183.6	–					37.1	29.1
JMA Intensity		5.9	5.2	5.1	–	–	4.5	4.4	4.1

Note: NS1=West Side, NS2=East Side

(b) STEC Office Building

Floor		28	22	15	8	1	B6F
Relative Displacement to 1F (cm)	EW	32.7	27.3	18.8	7.8	0.0	
	NS1	29.7	23.5	15.3	7.0	0.0	
	NS2	34.9	27.4	17.2	8.7	0.0	
Absolute Displacement (cm)	EW	34.4	28.9	20.5	9.9		
	NS1	29.0	23.2	15.8	8.3		
	NS2	35.2	28.0	18.3	8.9		
	UD	3.5					3.5
Acceleration (cm/s/s)	EW	161.0	124.7	152.2	154.7		
	NS1	246.9	125.8	246.0	190.0		
	NS2	302.1	155.8	228.6	159.3		
	UD	134.2					37.9
JMA Intensity		5.6	4.9	5.5	5.3	4.5	

Note: NS1=East Side, NS2=West Side

The JMA intensities of the shaded cells are calculated using the two horizontal components

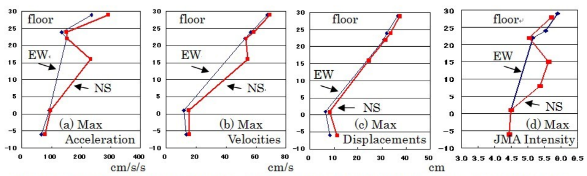

Fig.1 Maximum Accelerations, Velocities, Displacements, and the JMA Intensities of Kogakuin Univ.

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SSS37-14 Room:303 Time:May 21 14:18-14:33

Fundamental analysis on quantification of aftershock ground motion hazard

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The Aftershocks of the recent giant earthquakes have caused severe societal consequences in terms of fatalities and casualties, and business interruption. For example, in the 2011 Christchurch earthquake and the 2011 Van earthquake, destruction of buildings due to aftershocks caused a number of casualties. Intermittent aftershocks of the 2004 Chuetsu earthquake affected business continuity. As to the Tohoku earthquake in 2011, the influence of aftershocks was widespread, including, e.g. landslides, tsunamis, fires, power failures, and the closure of railroads and highways. Aftershocks also affect decisions on evacuation, recovery, and business continuity activities. The aftershock hazard is the prime point to be considered for rational decision-making process in the post-mainshock environment. Quantitative analysis of aftershock hazard is required to improve rational decision-making capability in the post-mainshock environment, especially for the expected Tokai Tonankai and Nankai earthquakes.

The focus of our research is two-fold: (1) to clarify a probability distribution which can be applied to seismic intensities of aftershock by analyzing the 2011 Tohoku earthquake data and (2)to propose a framework to evaluate a probability model at each site. The aftershock ground motion records that were collected from Kyoshin Network (K-NET) for 142 days from March 11, 2011 were used in our research. A total of 62 observation stations located in Iwate, Miyagi, and Fukushima are selected. Peak Ground Velocity (PGV) is adopted as an index of seismic intensity. The data analysis employing probability paper plot and statistical goodness-of-fit test confirmed that the distributions of aftershock intensity agreed with Type II extreme value distribution (Frechet distribution). Then, a method to evaluate parameters of the aftershock probability distribution was discussed and suggested that the parameters can be evaluated from the main shock intensity at each station. The proposed method is considered useful to evaluate aftershock hazard immediately after mainshock.

Our research is, however, based on aftershock hazard for five months, and do not consider the fact that aftershocks decrease with increasing elapsed time from the occurrence of the mainshock. Integrating a time dependent factor (i.e., the modified Omori law) is considered as a future issue to be tackled. Clarifying periodic features of aftershock by analyzing response spectrum and analyzing aftershocks of other giant earthquakes are also considered future tasks.

Keywords: seismic hazard analysis, aftershock, probabilistic method, the 2011 Tohoku earthquake

SSS37-15 Room:303 Time:May 21 14:33-14:48

Long-period ground motion simulation of great Nankai Trough, Japan, earthquakes

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[1]NIED

The megathrust earthquakes in Nankai Trough in southwest Japan have been occurring with an interval of 100-200 years. For improving seismic hazard map to prepare for the anticipated Nankai Trough earthquake, it is important to understand uncertainty of ground motions caused by different source parameters, such as rupture area, asperity, and hypocenter location. In this study, we evaluate long-period ground motions for the anticipated Nankai Trough earthquake for several scenarios with various possible parameters including rupture area, asperity, and hypocenter. In the possible parameters, we also include the scenario; the large slip near the trough following the lesson from the 2011 Tohoku earthquake. Long-period ground motions are simulated by the finite difference method using characterized source model and recently developed three-dimensional velocity structure model of Japan. The simulation results show the large variation depending on different scenarios. This large variation can help us to understand the level and variability of long-period ground motion due to source effect of the Nankai Trough earthquake.

Keywords: Nankai trough, long-period ground motion, finite difference method, uncertainty, GMS

SSS37-16 Room:303 Time:May 21 14:48-15:03

Re evaluation of the elongation of the long period ground motion due to Nankai Trough earthquake which occurs by linkage

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We examined the characteristic of the long period ground motion expected for future Nankai Trough earthquake by comparison of observed ground motion during the 2011 Off Tohoku Mw9.0 earthquake and comparison in recent destructive Nankai Trough earthquakes in 1944 and 1946.

A large and long-time shaking of long-period ground motion was developed during the 2011 Off Tohoku Mw9.0 earthquake due to the fault rupture in wide area of about 500 km $*$ 200 km and slip of over 20m entirely over the plate interface. In addition, very large slip of more than 50 m occurred near the Japan Trench might cause very long period ground motions with period over 10 sec. Ground motion record from dense seismic array across Japan demonstrated that the large slip occurred at least two or three area on the fault plane with time lag for tens of seconds, leading multiple shocks of strong ground motions with long-time durations more than 10 min.

Mzximum amplitude of the velocity response spectrum of the long-period ground motions observed in central Tokyo (Kanto basin) is about 40 cm/s in wide period band from 0.5 to 40 sec, which is considered to be rather weak for Mw9.0 earthquake since it was almost comparable to those observed during Mid Niigata Mw6.8 earthquake in 2004 and SW Off Kii-Peninsula Mw7.4 earthquake. It is considered that the level of long-period ground motions developed in central Tokyo is usually very weak from the earthquakes occurring in the area off Miyagi because the long period surface waves cannot effectively developed in the structure of Japan Trench. On the other hand stronger long-period ground motion is often developed in the Nankai Trough where thick cover of acritional prism over subducting Philippine-sea plate develop and guide long period ground motion along the trench very effectively.

Therefore it is expected that the development of the long-period ground motion for future Nankai Trough earthquake should be much stronger than those observed during the present Off Miyagi earthquake. In addition, linkage occurrence of the Tokai, Tonankai, and Nankai earthquake segment with time lag of several tens of second between each segment prolong duration of long period ground motions as noted during the present Off Miyagi earthquake. Such effect of long-time shaking should cause significant influence to high-rise building with resonance to the long-period ground motions for long time. Since the duration of the long-period ground motion is not noticed in the present index of shaking such as intensity, peak ground velocity, and response spectrum etc., we need introducing additional index such as cumulative elastic energy etc. to evaluate the possible dangerousness of long-time shaking of the long-period ground motions expecting for linkage earthquake occurences.

This study was conducted under the support from Ministry of Education, Culture, Sports, Science and Technology.