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

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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

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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

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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

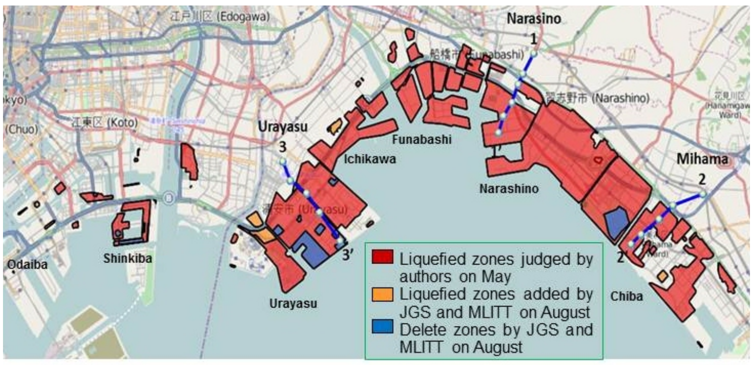

Figure 1 Liquefied area from Odaiba in Tokyo to Chiba City (Joint research by Kanto Regional Development Bureau of the Ministry of Land, Infrastructure, Transport and Tourism and JGS)

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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.

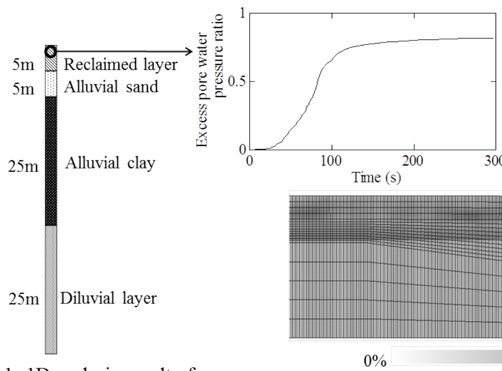

Fig.1: 1D analysis result of excess pore water pressure ratio at the center of the reclamation layer

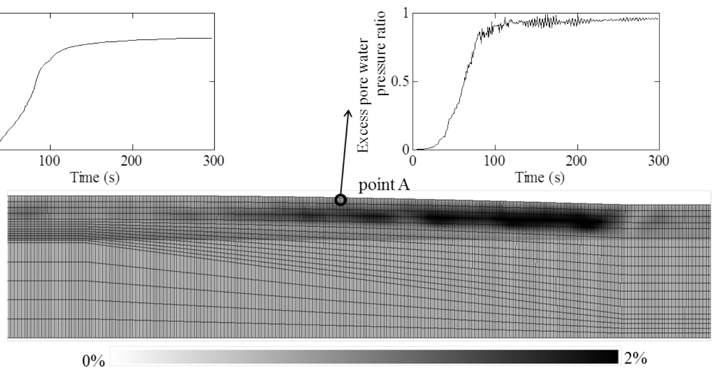

Fig.2: 2D analysis result of shear strain distribution at 150s after earthquake and excess pore water pressure ratio at the center of the reclamation layer at point A

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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.

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

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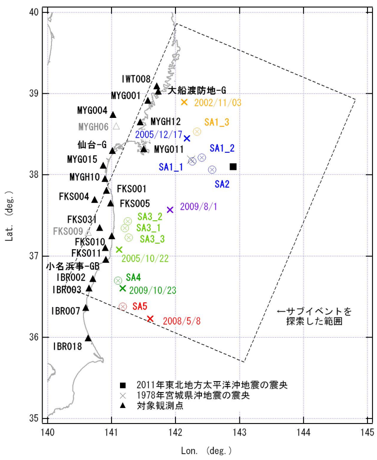
The 2011 off the Pacific coast of Tohoku, Japan, earthquake is obviously the first M9 earthquake which was recorded by dense strong motion networks. The occurrence of the earthquake enabled us to analyze real strong ground motions due to a M9 earthquake for the first time in the history. Before the occurrence 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



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

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

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

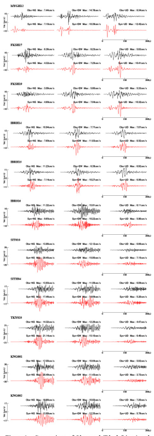

Figure 1 Comparison of Observed (Black Lines) and Calculated (Red Lines) Waveforms for Finite-Difference Simulation (Band Pass Filter: 0.1–0.33 Hz).

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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[1]Graduate School of Engineering, Tohoku University

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

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

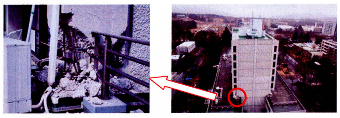

Photo 1 One of damaged four corner columns of THU building

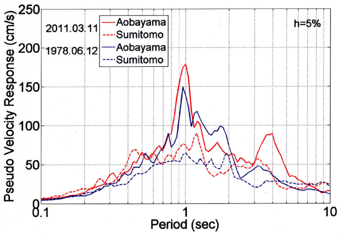

Fig.1 Site specific spectral ground motion amplification in Aobayama hill, Sendai

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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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[1]Kogakuin University, [2]NKSJ Risk Management, Inc., [3]Japan Meteorological Agency

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

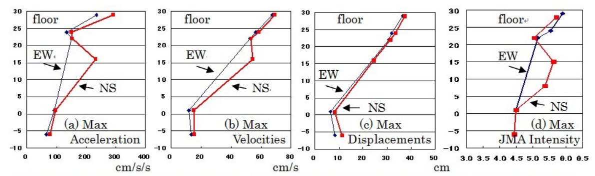

Fig.1 Maximum Accelerations, Velocities, Displacements, and the JMA Intensities of Kogakuin Univ.

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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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[1]Dept.of Architecture, Univ. of Tokyo

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

Japan Geoscience Union Meeting 2012
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SSS37-15 Room:303 Time:May 21 14:33-14:48

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

MAEDA, Takahiro[1*], MORIKAWA, Nobuyuki[1], AOI, Shin[1], FUJIWARA, Hiroyuki[1]

[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

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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

FURUMURA, Takashi[1*], MAEDA, Takuto[1]

[1]CIDIR/ERI Univ. Tokyo

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.

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SSS37-P01 Room:Convention Hall Time:May 21 15:30-17:00

Distribution of seismic motion in the Niigata-ken Chuetsu area of the 2011 off the Pacific coast of Tohoku Earthquake

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[1]Tokyo Electric Power Company

It is well known that the seismic bedrock in Niigata-ken Chuetsu area is deep and it is pointed out that long-period seismic motion is outstanding in this area. In this area, the seismic observation network consisting of 40 stations is operated for the study of seismicity around the fault zone of western margin of Nagaoka plain [Sekine et al.(2010)]. The servo-type accelerometers are installed at ground surface and 100 m in depth. The observation record of this network will be useful for the study of seismic ground motion for wide period range. We report the characteristics of the 2011 off the Pacific coast of Tohoku Earthquake observed in this network and the relation between spatial distribution of seismic motion and topography or underground structure.

The envelope shape of the acceleration waveform is like a spindle shape and shows peak acceleration at around 100 seconds from the onset of shaking. The PGA shows 10-20cm/s/s in a hill part and 30-40cm/s/s in the plain part. In the Fourier spectrum of the EW component, the common peak is recognized at 0.08Hz. The common peak at 0.05Hz is seen in the Fourier spectrum of the UD component, too. The spectrum amplitude of 0.1-1 Hz in plain part shows approximately five times in comparison with the hill part. Two clear pulses with period of approximately 20 seconds are recognized at the interval of 40 s in the velocity waveforms of EW and UD components at the observation site of the hill part. The velocity waveforms at the observation point in the plain are overlapped with successive waves of frequency 0.1-1 Hz and the amplitude is bigger than waveforms at the hill part. In addition, two pulses propagate from the epicenter direction of N80E with approximately 3.3 km/s evaluated from semblance analysis using the UD component of velocity waveforms.

Spatial distributions of PGA, PGV and acceleration responses at period of 1, 5, 10 seconds with 5 % damping are evaluated and compared with the topography and the seismic bedrock depth [AIST (2010)]. In perspective, the shape of the amplitude distribution shows relation with the topography. The amplitude is big on plains and small in the hill part. The amplitude is small in particular at the observation point located foot of Kakuda-Yahiko Mountain. The contrast between plain part and hills part in case of acceleration response of 1 s show more clear than in case of PGA. It is because the PGA affected relatively low frequency waves. In the hill area of the south side, PGV and the acceleration responses of 5, 10 s are relatively large and distribution characteristics correspond to the depth of seismic bedrock not to the topography. It is thought that the amplification of long-period seismic motions is affected from deep ground structure.

We thank to Dr. Sekine of ADEP for his support to use the network data. We thank to NIED for providing K-NET and KiK-net data.

Keywords: Spatial variation of seismic motion, Depth of seismic bedrock, Niigata-ken Chuetsu area, the 2011 off the Pacific coast of Tohoku Earthquake, Long-period seismic motion

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SSS37-P02 Room:Convention Hall Time:May 21 15:30-17:00

Rupture propagation during the 2011 Tohoku Earthquake deduced from an array of the Fukushima Daiichi Nuclear Power Plant

AOKI, Shigeki[1*], YOSHIDA, Yasuhiro[1], HOSHIBA, Mitsuyuki[1], NAKAHARA, Hisashi[2], KATSUMATA, Akio[1]

[1]Meteorological Research Institute, [2]Graduate School of Science, Tohoku Univ.

1. Introduction

The source region of the 2011 off the Pacific coast of Tohoku Earthquake (Tohoku Eq.) was about 450km by 200km [Yoshida et al., 2011]. The high-frequency energy radiation sources (HFSs) of this great earthquake were estimated using the empirical Green's function method [Kurahashi and Irikura, 2011] and the back-projection methods by teleseismic P waves [Wang and Mori, 2011] and by regional strong motion records [Aoki et al., 2011]. In these studies, the following common features about the HFSs were pointed out: In the first stage of the rupture (0-100 s), the HFSs are located in the area between the epicenter and the coastline of northern part of the source region (off Miyagi). In the next stage (100-140 s), the HFSs move from off Fukushima to off Ibaraki along the coastline.

Nakahara et al. (2011) performed semblance analysis [Neidell and Tarner, 1971] using a small array at the Oshika peninsula in order to estimate the back-azimuths of incident wave packets from the rupture area of the Tohoku Eq. The temporal changes in the azimuthal angles at the Oshika array are almost comparable to those expected for the S wave packets radiated from the HFSs estimated by Aoki et al. (2011).

In this study, we apply the semblance analysis to accelerograms of a dense array installed at the Fukushima Daiichi Nuclear Power Plant for imaging the rupture propagation of the Tohoku Eq.

2. Data and method

The epicenter determined by JMA is located 178 km away in the direction of N64E from the array. The array comprises 20 three-components accelerometers (two of them were broken due to the tsunami), which were located on the surface with a spacing of 100 - 500m in the area of 2 km (NS) by 1 km (EW). Strong ground motions were recorded with a sampling rate of 100Hz, with a resolution of 24 bits, and with a full scale range of 2000 Gal. Because the peak ground accelerations were about 1000 Gal at the array, no recorder was clipped during the Tohoku Eq.

In consideration of the array geometry, a frequency band of 0.5 - 2Hz is selected. For the calculation of temporal changes in semblance, time windows of 5.12 s are used sliding by 0.5 s interval for each component. In this study, we discuss the result calculated using seven stations with high coherence for one another, which are located in northern area of the power plant. However, when the peaks of semblance appeared, the differences between the back-azimuths estimated from seven stations and those from all stations were inconsiderable.

3. Results

After the P arrival, the semblance became high in each component. Especially in the UD component, the semblance reached about 0.98 around the P onset, and remained high until the S arrival. The back-azimuth was estimated to be about N60E, and the direction almost corresponded to that of the epicenter. After the S arrival, some repeating peaks appeared in the time series of semblance calculated by the horizontal components. Also, there were clear temporal changes in the estimated back-azimuth. Since the S onset, the back-azimuth had been estimated to be about N60E for 60 s. After that, the back-azimuth gradually began to rotate clockwise, and reached about N180E at times of about 110 s from the S onset. After 110 s, the semblance value dropped.

These changes in back-azimuth are comparable to those expected for the rupture propagation estimated in the previous studies. Aoki et al. (2011) found five HFSs during the Tohoku Eq. First three HFSs were located in off Miyagi (#1:38 s from initial rupture, #2:57 s, #3: 74 s), and the rest were located in off Fukushima (#4: 105 s) and off Ibaraki (#5: 131 s). The arrival times of S wave radiated from these HFSs almost corresponded to the local peaks in the time series of semblance. Moreover the back-azimuths of these HFSs were within 30 degrees of the estimated back-azimuths at time of the local peaks.

Acknowledgements.

We would like to thank TEPCO for providing the data of dense seismic array.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Rupture propagation, High-frequency energy radiation sources, Semblance analysis, Near-real-time processing

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SSS37-P03 Room:Convention Hall Time:May 21 15:30-17:00

Strong Ground Motions during the 2011 Tohoku Earthquake at the Vertical Array inside Onagawa Nuclear Power Plant

SAGUCHI, Koichiro[1*], KURAHASHI, Susumu[2], MASAKI, Kazuaki[2], IRIKURA, Kojiro[2]

[1]Nihon Emsco Co., Ltd., [2]Aichi Institute of Technology

Strong ground motions during the 2011 off the Pacific Coast of Tohoku Earthquake occurring on March 11, 2011, were observed in the Onagawa Nuclear Power Plant. The maximum acceleration of 692gal (the NS direction) was obtained during the main shock. It is necessary to evaluate the non-linear behavior of the surface layers in order to clarify the characteristics of thestrong ground motions on the important structures. In this study, the non-linear effects of the strong ground motions at the vertical array inside Onagawa Nuclear Power Plant are estimated using the one-dimensional reflection method with nonlinear coefficient.

First, we identified the underground structural model from aftershock records obtained in the borehole arrays using the simulated annealing method. Spectral ratios between surface and underground data are used for the inversion. Based on numerical experiments it is identified that P-wave velocity, S-wave velocity and Q values of individual layers are inverted very well.

Next, Strong motion records of main shock observed by the bore hole seismometers were simulated by using one-dimensional multiple reflection method. In this study, non-linear effect is considered by introducing non-linear coefficient c (f) for down-going waves from surface and P and S-wave velocities B(i) for in the non-liner soil layer during main shock. The simulated waveforms obtained from this method show good agreement with the observed seismograms in the borehole stations.

In conclusion, the results indicate that non-linear effects of surface layers on the main shock motions are limited in shallow depths of 5 meters, in Onagawa Nuclear Power Plant.

Keywords: 2011 off The Pacific Coast of Tohoku Earthquake, Strong ground motions, Simulated annealing, Non-linear coefficient, Identification

Japan Geoscience Union Meeting 2012
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SSS37-P04 Room:Convention Hall Time:May 21 15:30-17:00

A high Density Questionnaire Seismic Intensity Survey in Oshu City of Iwate Prefecture, for the aftershock occurred at A

YAMAMOTO, Hidekazu[1*], SANO, Tsuyoshi[1], Rohei Saito[1]

[1]Faculty of Engineering, Iwate University

A vibration characteristics for strong motions of earthquakes depends on not only the source but also subsurface geological structures. To clarify the vibration characteristics at Oshu of Iwate Prefecture, the survey of seismic intensity was done using questionnaires for the earthquake occurred at April 7, 2011. This earthquake was the aftershock of the 2011 off the Pacific coast of Tohoku Earthquake. JMA reported that the seismic intensities at the Maesawa Town of Oshu City were 6 weak for the main shock and same for the aftershock.

The questionnaire revised by Ohta et al.(1998) was used for calculating seismic intensity. 6,727 questionnaires were distributed for parents of students of 31 elementary schools of Oshu City, 347 were distributed for those of Maesawa junior high school, and 200 were distributed for residents in the central Maesawa Town of Oshu City. The seismic intensities estimated from questionnaires were averaged for 1 km square meshes to clarify the distribution of seismic intensity for Oshu City. To avoid differences among individuals for questionnaire survey, the effective mesh where the number of the questionnaire was more than three was used for analysis. The number of the effective mesh was 1079. The seismic intensities were ranging from 4.0 to 6.3, and the average was 4.9. As a result, the seismic intensity at the south area of Oshu City was large, namely, 6 weak, and the one at east area was also large. On the other hand, the one at the north area to the west area was small. The results shows that the seismic intensity was large at the area where houses were damaged.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, aftershock at April 7 in 2011, high density Questionnaire Seismic Intensity Survey, Instrument seismic intensity, earthquake damege, Oshu City, Iwate Prefecture

SSS37-P05 Room:Convention Hall Time:May 21 15:30-17:00

Estimation of site amplification from observation of aftershocks and microtremor explorations near KiK-net Haga station

YAMANAKA, Hiroaki[1*], TSUNO, Seiji[2], CHIMOTO, Kosuke[1], NIIRO, Ryuji[1]

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Strong shaking was experienced in the wide area of the northern part of Japan during the 2011 off the Pacific coast of Tohoku Earthquake of 11 March, 2011. Seismic intensities at some of the sites reached the maximum value of 7 in the intensity scale of Japan Meteorological Agency (JMA). K-NET Tsukidate in Miyagi prefecture is one of these sites where the observed PGA is more than 2G. Several studies investigated the reasons for the large PAG and distribution of the ground motion features in the vicinity (Hayakawa et al., 2011; Matsushima et al., 2011; Yamanaka et al., 2011). The Kik-net Haga (TCGH16) in Tochigi prefecture is also the site with a seismic intensity of seven during the main shock. Tanaka and Nobata (2011) compared strong motion data at the sites around the Haga station to know effects of shallow and deep soils.

In this study we investigated site amplifications of S-waves in shallow soils near the KiK-net Haga station. We first conducted aftershock observations in the vicinity of the site by installing temporary 8 stations within 1 km. One on the sites is located with relatively good soil conditions in a hill. This site is used as a reference site in this study. The other sites are situated in plain area. We also conducted microtremor array explorations to deduce shallow S-wave velocity profiles at the aftershock observation stations. From the observed data we estimated the local site amplifications of S-waves in the shallow low-velocity layers.

It is found from analysis of aftershock records during moderate events with magnitudes less than 5.3 that the predominant period of the amplification for all the sites are 0.2 to 0.3 seconds except for the reference site. This predominant peak can be identified in strong ground motion records at the TCGH16 station. The SPAC analysis of the array records from the microtremor explorations revealed S-wave velocity profiles down to 20 meters at all the sites. The average S-wave velocity of top 30 meters in the S-wave velocity profile was compared to know the differences of shallow soil amplifications. The average velocity distributes from 220 to 300 m/s at the sites except for the reference site. The reference site has an average S-wave velocity of 500m/s. We concluded from the investigations that the site amplifications due to shallow soils in the vicinity of the TCGH16 station are characterized by a dominant peak at a period from 0.2 to 0.3 second. The site effects can be also expected during the main shock in the area.

Keywords: 2011 off the Pacific coast of Tohoku Earthquake, strong ground motion records, aftershock observation, microtremor exploration, site amplification, shallow soil

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Gravity survey around Furukawa, Osaki, Japan, where is severly damaged by 2011 Tohoku earthquake

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The 2011 off the Pacific coast of Tohoku earthquake have bought destructive damage to huge area of Japan. Sever damage were found in huge area around Kanto and Tohoku region, where are mid and northern area of Japan, respectively. Tsunami has attacked to the Pacific coast of Tohoku region and the damage caused by liquefaction were found at very large area around Kanto and southern Tohoku region.

On the other hand, damage caused by earthquake ground motions was fewer than damage by Tsunami and liquefaction, though very large accelerations were recorded at many sites. They seem to pay few attention to damage by ground motions. However, sever damage by motions was recognized at some limited areas, such as Furukawa, Tome, and so on.

After the earthquake, we have carried out the detailed survey of damage in Furukawa, where is located in northern part of Miyagi prefecture. Although the downtown of Furukawa is not so large, that is, only about 2 km x 2 km, the damage distribution was not uniform. Severe damage of wooden structures was found mainly in the southern part of the downtown and few damage in northern part. Of course, we have to consider the differences of structural ages, but the anomaly of damage distribution had enough persuasive to suggest anomaly of earthquake ground motions.

To understand the anomaly of damage distribution, we began observation of earthquake ground motions using very dense sensors in Furukawa. In the area of 2 km x 2 km of downtown, we have installed 19 sensors by the end of 2011. As a result, the anomaly of ground motions is large beyond our consideration. It is very difficult to explain them using a simple physical model such as one-dimensional ground model.

The anomaly of ground motion must be caused by anomaly of ground structure. Thus, to know it, we carried out the gravity survey around the Furukawa area. In this area, it seems to be estimated that soft soil sediments is not so thick: the depth to engineering basement is less than 50 m. This means that very high resolution of gravity anomaly is required. The intervals of observations are less than a few hundred meters in the downtown.

The Bouguer anomaly shows different features from anomaly of ground motion and predominant period of response spectra. This suggests that the ground structure seems to be very complicated in Furukawa area.

For the further study, we have to carry out the gravity survey with shorter interval of sites. Furthermore, other kind of physical parameters may be necessary to obtain more accurate model of ground structure, such as magnetic survey and so on.

Keywords: Furukawa, Osaki, Miyagi, 2011 Tohoku earthquake, gravity survey, ground structure, dense seismic array observation

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Very Dense Seismic-Array-Observation in Furukawa District, Miyagi, Japan

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On March 11, 2011, off the Pacific coast of Tohoku Earthquake (Mw9.0) hit eastern part of the main land, Japan, and killed more than ten thousand of persons mainly due to great Tsunami. On the other hand, strong ground motions during the earthquake were observed in almost the whole region in Japan by K-NET, KiK-net organized by NIED, and the other seismometer networks. At least 17 of K-NET and KiK-net stations observed over 980 cm/s2 of PGA in horizontal components, and two stations observed over 6.5 of seismic intensity on JMA scale. However, damaged areas due to the ground motion do not correspond to either the large PGA or seismic intensity sites.

We focus on Furukawa district of Osaki city, where severe residential damages occurred at the downtown. Ground motion records are available at two stations, MYG006 (K-NET) and JMA Furukawa (JMA), located in the area. They observed about 550 cm/s2 of PGAs, whereas the peak value of pseudo-velocity response spectra with 5% damping are about 250 cm/s at 1.5s of period, which were almost similar to JMA Kobe and JR Takatori records during 1995 Kobe earthquake. The damage level was different between the areas within several hundred meters from MYG006 and JMA Furukawa stations, which are about 1 km away from each other. The severe damages were concentrated within the area about 1x1 km2 including the JMA station. This implies that the ground motion characteristics were not uniform in sub-kilometer scale, and the existing two stations are not enough to clarify the distribution.

We scattered dozens of low-cost seismometers, namely ITK sensor, around the area about 2x2 km2 in Furukawa district. The observed data are sent to the remote server through the Internet connection in real time. The seismometers were installed beside the volunteer's houses introduced by Osaki city office. The volunteers can access the interactive information service, e.g. real-time seismic intensity.

In this study, we analyze the ground motion data of aftershocks, and show the differences of ground motion characteristics. We also performed gravity survey and microtremor observations in order to identify the underground structures. The mechanism causing difference of the ground motion characteristics is discussed based on the survey results.

Keywords: off the Pacific coast of Tohoku Earthquake, Ground motion, Furukawa, Seismic array observation

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Long-period Ground Motion Characteristics of the Osaka Sedimentary Basin during the 2011 Great Tohoku Earthquake

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Seismic risk by long-period ground motion is one of important issues in mega-cities in the large sedimentary basin because the resonances of long-period structures such as oil tanks, long bridges, and high-rise buildings would cause the seismic disaster. For example, strong long-period ground motion cause a fire in Tomakomai, 200km away from the epicenter, in the 2003 Tokachi-oki earthquake. In this study, we analyze long-period ground motions of the 2011 great Tohoku-Oki earthquake (Mw9.0). Its long-period ground motions are well-recorded at about 100 strong motion stations by many organizations in and around the Osaka sedimentary basin. This data set could help detail feature of the ground motion propagation characteristics in the Osaka sedimentary basin.

Firstly, we compared horizontal components of reference site's record and each site's record in the long period range, 30 to 50s, and calculated its cross-correlation. We estimated difference in orientations and delay time to give a maximum cross-correlation. Second, we calculated the Fourier amplitude spectrum for S-wave portion of each horizontal record. Horizontal spectral ratio between vector-summed two components of amplitude spectra at the sedimentary site and the average of those at six rock sites are estimated. Predominant period of each spectral ratio in the long period range (10-1s) is obtained. Theoretical 1-D resonance period of S-wave for each sedimentary site is estimated from the Osaka sedimentary basin model by Iwata et al.(2008) and Iwaki and Iwata (2011), and is compared to the observed predominant period.

Observed predominant period distribution in the sedimentary basin is obtained. The observed predominant period of the spectral ratio is comparable or shorter than the theoretical resonance period at each site. Two- or three-dimensional basin effect could affect the observed predominant periods. Spectral ratio in the coda part, HV sprctral ratio, and azimuthal spectral characteristics will be analyzed.

We used ground motion data of seismic intensity observation network in Osaka prefecture, K-NET, KiK-net and F-net of NIED, CEORKA network, and BRI network.

Keywords: Long-period Ground Motion, Osaka Sedimentary Basin, 2011 Great Tohoku Earthquake

SSS37-P09 Room:Convention Hall Time:May 21 15:30-17:00

Long-period strong motion simulation of the 2011 Tohoku earthquake based on revised empirical attenuation relations

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Satoh et al.(2010) proposed the method to calculate long-period strong motions in the period range from 0.1 to 10 seconds based on empirical attenuation relations of the acceleration response spectra with 5% damping and the average and variance of the group delay time for development of the design long-period ground motion for long-period buildings. In this study we revise the empirical relations and simulate the long-period strong motions of the 2011 Tohoku earthquake (Mw9.0).

In the revised empirical relations we add 18 subduction-zone earthquakes with M_J>6.5 and focal depth < 60km from August 2007 to May 2011 including foreshocks and aftershocks of the Tohoku earthquake. The JMA 95-type records in the Kanto plane, the Nobi plane and the Osaka plane are added with K-NET and KiK-net records.

The empirical relation of the acceleration response spectra by Satoh et al.(2010) was modeled by only Mw as the source term. In addition the average characteristics of all earthquakes in Japan were modeled in the attenuation factor and the amplification factor at each station. In this study we first develop six cases (case-1 to case-6) of empirical relations. We regard the case-4 as the best case by comparing the long-period strong motions simulated based on six cases of the empirical relations with the restored records of the 1944 Tonankai earthquakes (Midorikawa et al.,2006;Furumura and Nakamura,2006) and the previous long-period strong motions simulated based on the theoretical method or the empirical Green's function method. In the case-4 Mw^2 term and the difference of the amplification factor at each station on deep sediments in the Kanto plane and the attenuation factor and between earthquakes on the boundary of the Pacific plate and the Philippine sea plate are considered and the main shock records are not included. The stations of deep sediments in the Kanto are defined as stations where the natural period of the one-dimensional amplification factors from the seismological bedrock to the engineering bedrock calculated from the model structure by HERP(2009) are greater than 4 seconds based on the study by Satoh et al.(2011). Here we use the revised empirical relations of the average and variance of the group delay time considering the difference of the amplification factor at each station on deep sediments in the Kanto plane and the attenuation factor between earthquakes on the boundary of the Pacific plate and the Philippine sea plate. The simulations by the case-5 and case-6 including the main shock records tend to underestimate the records and the previous simulated waves.

We simulate long-period strong motions of March 9, off the coast of Sanriku foreshock (Mw7.4), March 11, off the coast of Ibaraki largest aftershock (Mw7.8) and the main shock based on the revised empirical relations. The long-period strong motions of both the foreshock and the aftershock are well simulated. For the main shock we set outer-fault parameters based on the source model composed of strong motion generation areas estimated by Satoh(2012) using the empirical Green's function method. Three faults are assumed and the outer-fault parameters are set assuming the cascade model. We first set the static stress drop and calculate the outer-fault area from both the stress drop and the area of the strong motion generation area for each fault. Then the seismic-moment of the outer-fault from the outer-fault area and the static stress drop. As a result the long-period strong motions of the main shock are reasonably reproduced assuming the static stress drop of 3 MPa. However, the strong motions in the period greater than 5 seconds are slightly over estimated. The main reason is that the Mw of three faults are 8.4, 8.8, and 8.1 although the maximum Mw of the data used in the empirical relations is 8.2. We will examine the sensitivities at simulations by considering the upper limit of Mw.

Keywords: long-period ground motions, empirical attenuation relations, the 2011 Tohoku earthquake, simulation, Mw2 term

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The survey of human perception and reaction in high-rise buildings in 2011 off the Pacific coast of Tohoku Earthquake

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I report seismic response, human perception and reaction and indoor situation of high-rise buildings in Tokyo and Osaka area, Japan, for the 2011 off the Pacific coast of Tohoku Earthquake, using strong motion data, and questionnaire/hearing surveys.

The questionnaire/hearing surveys from 43 buildings in Tokyo and Osaka area showed that their seismic response and damage patterns are different by story and location. In tokyo area, the 50% of the residents in the high-rise buildings with thier own natural period 3 second answered their walking is difficult without holding onto something stable or it is difficult to remain standing. On the other hand, the 20% of the residents in the high-rise buildings with their own natural period 5 second answered their walking is difficult without holding onto something stable or it is difficult to remain standing.

In Osaka area, the residents in the high-rise buildings with thier own natural period 6 second answered it is difficult to remain standing, but the residents in thier own natural period 4 second answered the need to hold onto something stable.

Even though there was no severe building damage, many residents in the high-rise buildings find it hard to move. In addition, detailed contents are reported on the day.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, high-rise buildings, response, human perception and reaction

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Distribution of tiled roof damage around Tsukuba and Tsuchiura cities, cased by the 2011 Off the Pacific Coast of Tohoku

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In Tsukuba and Tsuchiura cities and its surrounding area, there were a number of building damages and land disasters induced by the 2011 Off the Pacific Coast of Tohoku Earthquake on March 11, 2011. Among these seismic damages, a large number of roof tiles damages were distributed in a wide area. The roof tiles damages are good indicator to reveal the relationship between seismic intensity and topographical-geological feature. In this study, we mapped 7,142 of tiled roof damages extracted from satellite image (Google Earth image). These damages are distributed not only on an alluvium but also on middle terraces of geology. Furthermore, these damages may deeply depend on subsurface geology as well as surface geology, because various damage ratios of roof tiles are found on the same surface geology. We carried out microtremor survey (H/V spectral ratio) to evaluate the relation between tiled roof damage and subsurface geology. In this presentation, we demonstrate the relationship among the distribution of tiled roof damage, results of microtremor, and subsurface geology based on boring.

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Keywords: tiled roof damage, Google Earth image, 2011 Off the Pacific Coast of Tohoku Earthquake, Tsukuba City, Tsuchiura City

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Investigation of Building Damage near Surface Faults and Estimation of Strong Motion of the 2011 Iwaki Earthquake

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Iwaki Earthquake occurred in Fukushima Prefecture Iwaki City on April 11, 2011. This earthquake is assumed to be induced the Great Tohoku Earthquake, and the Itozawa Fault, the Shionohira Fault, the Yunotake Fault and Fujiwara Fault appeared(Ishiyama et al, 2011). The wooden houses was damaged due to the ground deformation which was caused by these faults.

We investigate the bulding damage on May 29 and 30, 2011, and collect the building damage data near the faults.

As a result, almost all bulding damages were located immediately above the faults.

We estimate the strong ground motion using the result of the source inversion by the observed strong motion(Hikima, 2011), because there is not the observed data near the faults.

We analysis the relationships between the building damages, the strong ground motion and the ground deformation.

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Keywords: Near Surface Fault, Building Damage, Strong Ground Motion Simulation, Complete Enumeration, Iwaki City