Japan Geoscience Union Meeting 2012
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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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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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Rupture propagation during the 2011 Tohoku Earthquake deduced from an array of the Fukushima Daiichi Nuclear Power Plant

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

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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 downgoing 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

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

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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

Japan Geoscience Union Meeting 2012
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Estimation of site amplification from observation of aftershocks and microtremor explorations near KiK-net Haga station

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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

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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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