Precise distribution of seismic intensity at the southern area of Iwate Prefecture, Japan, by a high density questionnaire survey - Results of the Iwate-Miyagi Nairiku Earthquake in 2008, the 2011 off the Pacific coast of Tohoku Earthquake and the aftershock occurred at April 7, 2011 -

H. Yamamoto& T. Saito
Iwate University,Morioka

SUMMARY:
This paper aims to clarify two-dimensional precise distribution of seismic intensities in the area where the observation station density of instrumental seismic intensity were low by carrying out a high density questionnaire survey in the southern area of Iwate Prefecture, Japan, for three large earthquakes: the Iwate-Miyagi Nairiku Earthquake in 2008, the 2011 off the Pacific coast of Tohoku Earthquake and the aftershock occurred at April 7, 2011. The results on the 2008 earthquake shows that 4 and 5 week of seismic intensity on JMA scale were distributed in almost area of southern Iwate Prefecture. The estimated questionnaire seismic intensities were in good agreement with instrumental seismic intensity recorded at the station. The seismic intensity distribution map showed that at almost area the seismic intensities were determined at almost area by an epicentral distance, meanwhile, those were determined at a part area by a local site effect.

Keywords: the Iwate-Miyagi Nairiku Earthquake in 2008, the 2011 off the Pacific coast of Tohoku Earthquake, maximum aftershock occurred at April 7, 2011, questionnaire survey, questionnaire seismic intensity, precise distribution of seismic intensity, instrumental seismic intensity, site amplification characteristics

1. INTRODUCTION

An earthquake in the south area of Iwate Prefecture, Tohoku District, Japan, occurred at June 14, 2008. Japan Meteorological Agency(JMA) reported that the JMA magunitude was 7.2, the depth of the hypocenter was 8 km. Strong motions were observed at many cities of Tohoku District of northern Honshu, Japan. The observed instrumental seismic intensities at two observation sites of Oshu City, Iwate Prefecture and Kurihara City, Miyagi Prefecture, were 6 strong on JMA scale. By the earthquake, land slides occurred in mountain area, nevertheless, houses damages were few in urban area.
Because srtong motions on a ground surface are affected by earthquake source characteristics, path effect and subsurface site response effect, often, different seismic intensities were observed at the observation sites with similar epicentral distants in a narrow area.
Figure 1 shows the distribution of instrumental seismic intensities of the Iwate-Miyagi Nairiku Earthquake in 2008 after Japan Meteorological Agency. A left figure is a whole area map and a right figure is a closeup area map of the southern Iwate Prefecture, Japan. In Japan, the instrumental seismic intensity observation stations were operated throughout almost municipalities and the observed instrumental seismic intensities were rapidly reported. However, the distribution density of the observation sites is low in a local area such as Iwate Prefecture while that is high in an urban area such as a metropolitan city. In order to clarify distribution of strong ground motions precisely in a narrow area, a population-based questionnaire survey on seismic intensities is a effective and powerful tool.

2. METHOD ON QUESTIONNAIRE SURVEY

In Japan, a questionnaire survey method developed by Ohta et al (Ohta et al. 1979) had been used by

many researchers for many earthquakes occurred in Japan in order to estimate seismic intensities. In this study the method revised by Ohta et al (Ohta et al. 1979, 1998) was used. Questionnaire sheets on calculating seismic intensities were distributed in whole area of Kitamami City, Oshu City and Ichinoseki City. The sheets were distributed to parents of students of elementary schools because they were distributed evenly across. Figure 2 shows locations of elementary schools where questionnaire sheets were distributed. The number of surveyed elementary schools in Kitakami City was in full, however, the number of those in Oshu City and Ichinoseki City was not in full. This reaseon was that houses of some redidents had been dameged in the two cities. The number of surveyed schools in Kitakami City was 18, that in Oshu City was 28, and that in Ichinoseki City was 7.

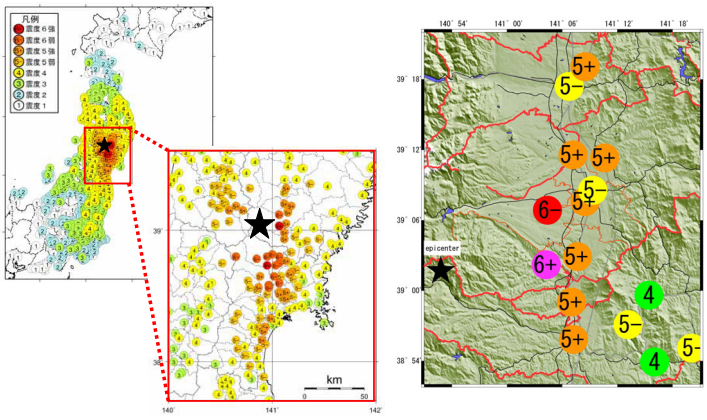

Figure 1. Distribution of instrumental seismic intensities of the Iwate-Miyagi Nairiku Earthquake in 2008 after Japan Meteorological Agency. A left figure is a whole area map and a right figure is a closeup area of the southern Iwate Prefecture, Japan. Numbers indicate JMA seismic intensity. A plus indicates 'strong' and a minus indicates 'weak'. A star indicates a location of epicentre of the Iwate-Miyagi Nairiku Earthquake.

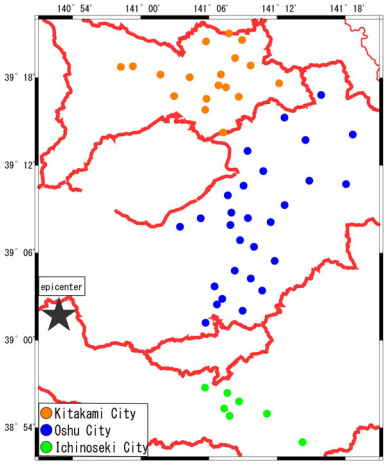

Figure 2. Locations of elementary schools in Kitakami City, Oshu City and Ichinoseki City surveyed for the Iwate-Miyagi Nairiku Earthquake.

Figure 3 shows a flowchart for questionnaire survey and analysis in this study. In Kitakami City, questionnaire sheets were distributed to parents of students of elementary schools at the time of middle of July, 2008, and these were retrived at the time of end of July. In Oshu City and Ichinoseki City, sheets were distributed at the time of end of July and these were retrived at the time of end of August. The number of questions of the questionnaire developed by Ohta et al are 35. The number of questions to ask on locations and environments of answerers is 9, the number of questions to ask on strong motions are 21, and that to ask on other things is 5. We can calculated a value of a seismic intensity

from the answers for one questionnaire sheet. We can estimate seismic intensity on the site from the answer of the address of the question where had an answerer felt strong motions.

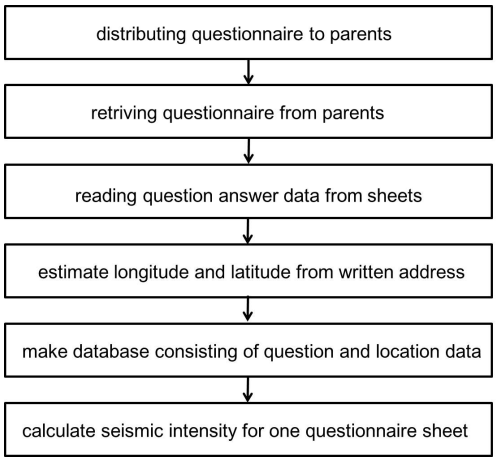

Figure 3. A flowchart for questionnaire survey and analysis

3. RESULTS ON QUESTIONNAIRE SURVEY

Table 1 shows a statistics of the questionnaire survey for the Iwate-Miyagi Nairiku Earthquake in 2008. Ns indicates a number of the surveyed elementary school in the city. Nd indicates a number of distributed questionnaire sheets. Nr indicates a number of retrieved questionnaire sheets. Rr indicates a ratio of the number of retrieved questionnaire sheets to the number of distributed questionnaire sheets. Na indicates a number of effective answer questionnaire sheets. Ra indicates a ratio of the number of effective answer questionnaire sheets to the number of distributed questionnaire sheets. The number of distributed questionnaire sheets was determined from the number of students of elementary schools. However, it is thought that the number of family unit is less than the number of students, thus, it is concluded that this study is high dense survey.

Table 1. A statistics of the questionnaire survey for the Iwate-Miyagi Nairiku Earthquake in 2008. Ns indicates a number of an elementary school in the city. Nd indicates a number of distributed questionnaire sheets. Nr indicates a number of retrieved questionnaire sheets. Rr indicates a ratio of the number of retrieved questionnaire sheets to the number of distributed questionnaire sheets. Na indicates a number of effective answer questionnaire sheets. Ra indicates a ratio of the number of effective answer questionnaire sheets to the number of distributed questionnaire sheets.

City Name	Ns	Nd	Nr	Rr	Na	Ra
Kitakami	18	5859	3604	61.5%	2390	40.8%
Oshu	28	6412	3736	58.3%	2409	37.6%
Ichinoseki	7	2742	1573	57.4%	1097	40.0%
total	53	15013	8913	59.4%	5896	39.3%

From one questionnaire sheet, one value of seismic intensity was felt by an answerer. Figure 4 shows the histogram of seismic intensities calculated from one questionnaire sheet retrieved in each City. The maximum of seismic intensity was 7.0 and the minimum is 1.0. In Kitakami City, many answerers felt at a seismic intensity of 4. We can see that a frequency in large seismic intensities is relatively low, but a frequency in small seismic intensities is relatively high. However, in Oshu City and Ichinoseki City, most answerers felt at a seismic intensity of 5 weak. A few answerers felt at a seismic intensity of 7. We can see that a frequency in large seismic intensities is relatively high, but a frequency in small seismic intensities is relatively low. The dispersion of seismic intensities depends on not only site effects based on the subsurface response but also individual differences, namely, personal errors. At next step, in order to cause a reduction of personal errors on individual differences, estimated seismic intensities are averaged within a field, for example, a 1km in NS by 1km in EW size mesh. In

the case of 1km mesh size analysis, a length of a mesh in EW direction is 45 seconds in longitude in sexagesimal scale and that in NS direction is 30 seconds in latitude. In the case of 500m mesh analysis, a length is half size in longitude and in latitude.

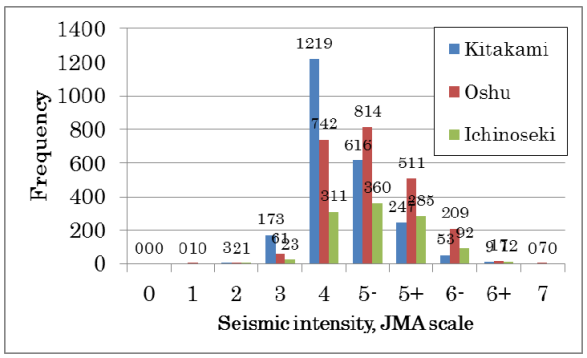

Figure 4. Histogram of seismic intensities calculated from one questionnaire sheet retrieved in each City. In Kitakami City, we can see that a frequency in large seismic intensities is relatively low, but a frequency in small seismic intensities is relatively high. However, in Oshu City and Ichinoseki City, we can see that a frequency in large seismic intensities is relatively high, but a frequency in small seismic intensities is relatively low.

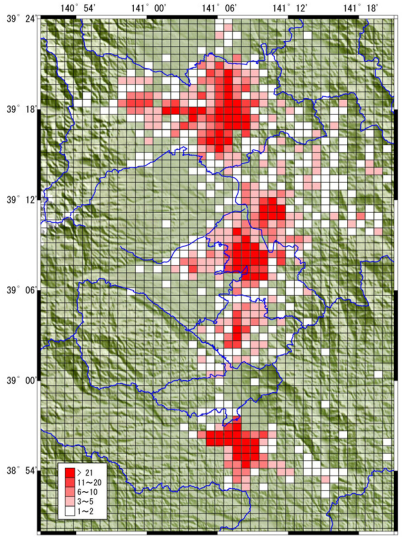

Figure 5. Distribution of the frequency of effective answer questionnaire sheets estimated with a 1km mesh. We can see that the frequency in the central area of the city is high, however, the frequency in the surrounding area of the city is low.

4. MAPPING SEISMIC INTENSITIES

Figure 5 shows the distribution of the frequency of effective answer questionnaire sheets estimated with a 1km mesh. We can see that the frequency in the central area of the city is high, however, the frequency in the surrounding area of the city is low. It is thought that the seismic intensity estimated from a few answerers at a 1km mesh is not reliable. The seismic intensity estimated from more than three answerers at a mesh is used for mapping, meanwhile, one estimated from one or two answerers at a mesh are rejected. The operation gives a reliable mapping to cause a reduction of personal errors. Figure 6 shows the histogram of seismic intensities averaged with a 1km mesh. The number of a mesh used is 308. The number of all meshes is 663, so the number is decreasing by the operation. The maximum seismic intensity of a mesh is 5.6, namely, 6 weak, the minimum is 2.0. The frequency of seismic intensity of 5 weak is high. Large seismic intensity, e.g. 6 strong or 7, is not found, so the dispersion of seismic intensities was decreased.

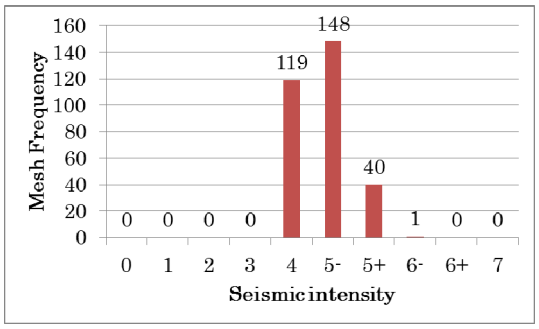

Figure 6. Histogram of seismic intensities averaged with a 1km mesh

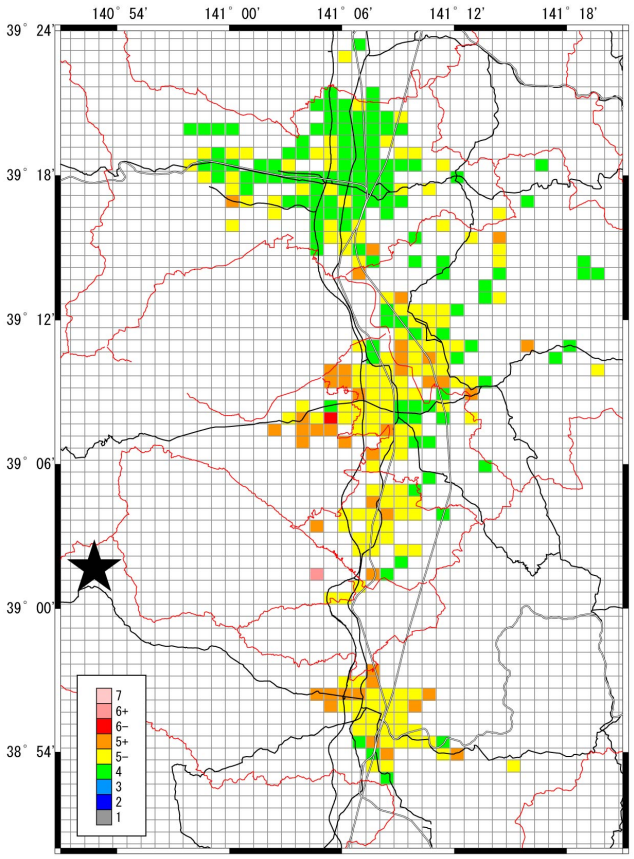

Figure 7. Seismic intensity distribution in Kitakami City, Oshu City and Ichinoseki City for the Iwate-Miyagi Nairiku Earthquake in 2008 averaged with a 1km by 1km mesh size. A number of a legend indicates seismic intensity based on JMA scale. A symbol of '+' indicates 'strong' ,and a symbol of '-' indicates 'weak'. The mapping is made using only reliable meshes where effective answered sheets are more than three, with a spatial moving averaging technique. A star indicates the location of the epicenter.

Figure 7 shows the seismic intensity distribution in Kitakami City, Oshu City and Ichinoseki City for the Iwate-Miyagi Nairiku Earthquake in 2008 averaged with a 1km mesh. The mapping is made using only reliable meshes where effective answered sheets are more than three, with a spatial moving averaging technique. The maximum mesh seismic intensity of 5.6 at the mesh in Isawa District of western area of Oshu City is same as the instrumental seismic intensity at Isawa observation station of Oshu City reported by JMA. In Ichinoseki City of southern area of the figure, seismic intensities of 5 strong are seen at western area. In Oshu City of central area of the figure, seismic intensities of 5 strong to 6 weak are seen at western area, but those of 4 to 5 weak are seen at central and eastern area.

In Kitakami City of northern area of the figure, seismic intensities of 4 are seen at almost area. In the south-western area near the epicenter large seismic intensities are observed, and in the northern area far off the epicenter, small seismic intensities are observed except a part of eastern area of Oshu City. Figure 8 shows a relation between questionnaire seismic intensities averaged with a 1km mesh in the case of more than three questionnaire sheets and the observed instrumental seismic intensities at the site of the strong motion observation station. Estimated seismic intensities are in good agreement with instrumental seismic intensities by JMA.

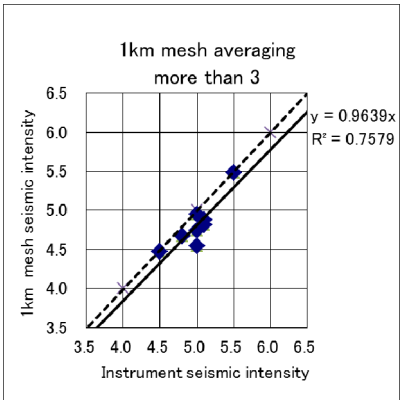

Figure 8. Relation between questionnaire seismic intensities averaged with a 1km mesh in the case of more than three questionnaire sheets and the observed instrumental seismic intensities at the site of the strong motion observation station.

5. PRECISE SEISMIC INTENSITIES DISTRIBUTION USING 250M MESH AND SITE AMPLIFICATION FACTORS

Throughout Japan, subsurface geological and microtopography maps with a scale of 1 to 50,000 are published. And site amplification factors based on the microtopography maps with a scale of 1 to 50,00 are published by Japan Seismic Hazard Information Station(J-SHIS) on the website. We try to discuss on a relation between seismic intensities and site amplification factors. Figure 9 shows precise distribution of seismic intensities at the area of Ichinoseki map area and site amplification factors by J-SHIS. The area of Ichinoseki Map consists of the central Ichinoseki City. The mapping is made using only reliable meshes where effective answered sheets are more than three, with a spatial moving averaging technique. Figure 10 shows precise distribution of seismic intensities at the area of Mizusawa map area and site amplification factors by J-SHIS. The area of Mizusawa map consists of the central Oshu City. Similarly, Fig. 11 shows precise distribution of seismic intensities at the area of Kitakami map area and the site amplification factors. The area of Kitakami map consists of the central Kitakami City and a part of the northern Oshu City. Seismic intensities of Figs. 9 to 11 are displayed by a color bar with a fine resolution of 0.25.
Figure 12 shows the relation between estimated seismic intensities and site amplification factors. Seismic intensities averaged at a 250m mesh using more than three answerers are used. We can see that the correlation between seismic intensities and site amplification factors is apparently low.
From Fig. 9, we can see that seismic intensities are large at western area of Ichinoseki City, and from Fig. 10, that those are large at southern and western areas of Oshu City. It is seen that seismic intensities effect on the attenuation on an epicentral distance but not on the subsurface site amplification. However, from Fig. 11, we can see that seismic intensities are large at the northern area of Oshu, Esashi District, where is far distant from the location of the epicenter. We can see that site amplification factors(ARV) are relatively large in this area from the right figure of Fig. 11. It is thought that seismic intensities in this area effect on the site amplification.

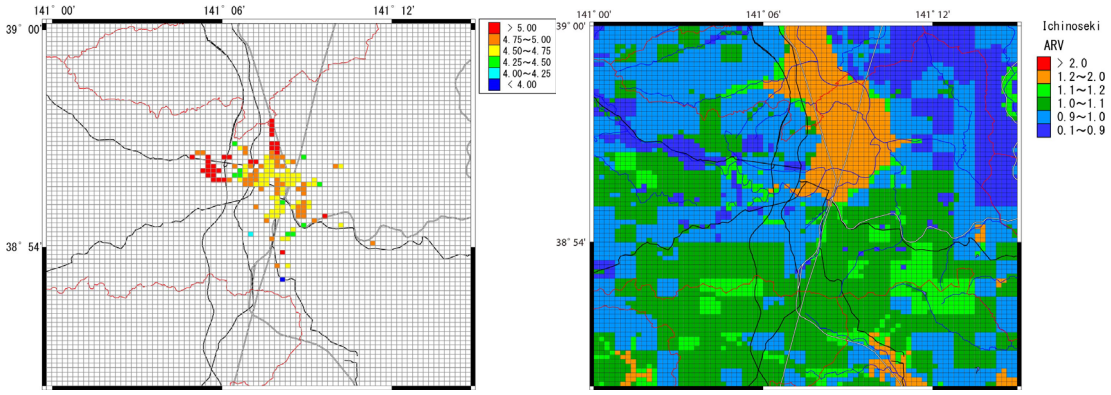

Figure 9. Precise distribution of seismic intensities(left) at the area of Ichinoseki map area and site amplification factors(right) by Japan Seismic Hazard Information Station(J-SHIS). The area of Ichinoseki Map consists of the central Ichinoseki City. The mapping is made using only reliable meshes where effective answered sheets are more than three, with a spatial moving averaging technique.

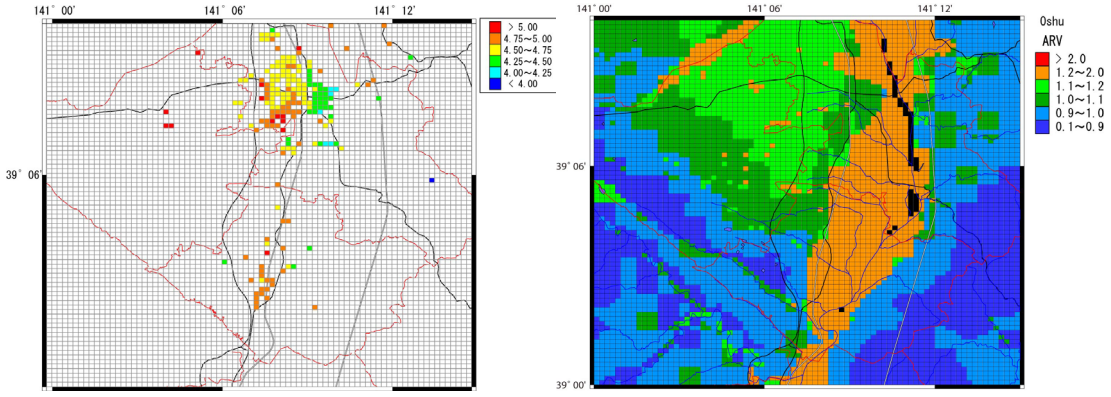

Figure 10. Precise distribution of seismic intensities(left) at the area of Mizusawa map area and site amplification factors(right) by Japan Seismic Hazard Information Station(J-SHIS). The area of Mizusawa map consists of the central Oshu City.

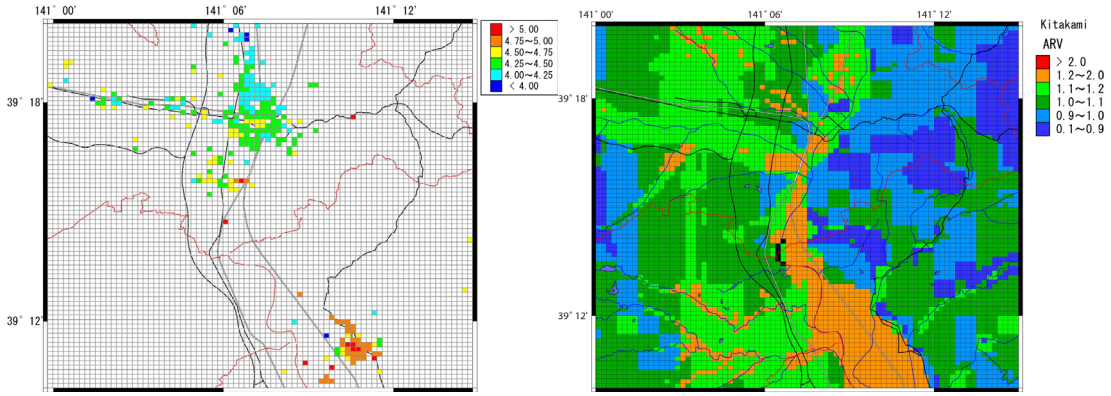

Figure 11. Precise distribution of seismic intensities(left) at the area of Kitakami map area and site amplification factors(right) by Japan Seismic Hazard Information Station(J-SHIS). The area of Kitakami map consists of the central Kitakami City and a part of the northern Oshu City.

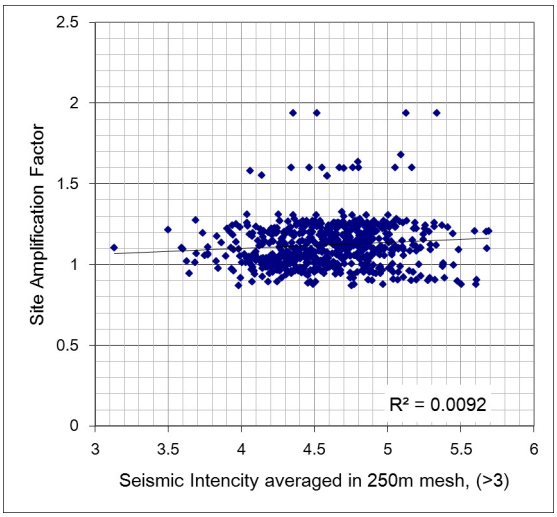

Figure 12. Relation between estimated seismic intensities and site amplification factors. Seismic intensities averaged at a 250m mesh using more than three answerers are used. A site amplification factor at a 250m mesh throughout Japan is published by Japan Seismic Hazard Information Satation (J-SHIS).

6. QUESTIONNAIRE SURVEY ON THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE AND THE AFTERSHOCK OCCURRED AT APRIL7, 2011

The 2011 off the Pacific Coast of Tohoku Earthquake occurred at March 11. The seismic intensity of 6 weak was observed by JMA in Ichinoseki City of a part of studied area. And, the large aftershock occurred at April 7, 2011. The seismic intensities of 6 weak were observed in Ichinoseki and Oshu Cities. Both earthquakes gave many dameges houses in Ichinoseki City. The aftershock gave damages in the central area of Maesawa District of Oshu City where the mainshock did not give damage, nevertheless. We tried to do more dense questionnaire survey on seismic intensities in the area of Ichinoseki City and Oshu City again for the mainshock and the aftershok in order to clarify a relation between earthquake damege and the strong morions in local area.
Table 2 shows A statistics of the questionnaire survey for the 2011 off the Pacific coast of Tohoku Earthquake (mainshock) and the aftershock occurred at April 7, 2011. To increase a precision of the questionnaire survey, 10,000 questionnaire sheets were distributed in the central area of Ichinoseki City with the city government's co-sponsorship. The number of distribution is corresponding to one-second number of all family unit. The sheets were distributed to the parents of elementary school and junior high school, and residents directly in the area of Maesawa District of Oshu City. The sheets were distributed to the parents of elementary schools in other area of Oshu City. From Table 1 and Table 2, we can see that effective answer ratios of the survey in 2011 are higher than those in 2008, so many comminity residents have impotant interest in strong motions that provide house dameges.

Table 2. A statistics of the questionnaire survey for the 2011 off the Pacific coast of Tohoku Earthquake (mainshock) and the aftershock occurred at April 7, 2011.

Earthquake	City Name	Nd	Nr	Rr	Na	Ra	remarks
mainshock	Ichinoseki	10000	5309	53.1%	-	-	
aftershock	Ichinoseki	10000	5439	54.4%	4465	44.7%	
mainshock	Oshu	7284	5501	75.5%	-	-	31schools
aftershok	Oshu	7284	5488	75.3%	4412	60.6%	31schools

At the present time of paper submitting, the seismic intensity analysis for the aftershock was finished but that for the mainshock was not because of a large amount of questionnaire sheets to be processed. Thus, only the aftershock results are shown in this paper.
Figure 12 shows seismic intensity distribution in Ichinoseki City averaged with 1km and 500m meshes for the aftershock occurred at April 7, 2011. We can see that two areas of distributions of seismic intensities are obtained at central Ichinoseki area and at Hanaizumi Town area in Ichinoseki City, respectively. Seismic intensities in Hanaizumi Town area are smaller than those in central Ichinoseki area. The mesh area with a large seismic intensity are found at western area of central Ichinoseki. In the case of 500m mesh analysis the mesh that a meshe with a seismic intensity of 7 or some meshes with that of 6 strong are found in the western area. We conclude that seismic intensities at western area are larger than those at eastern area in central Ichinoseki. This strong motion are affected by site amplification effects because the aftershock occurred in coast area.

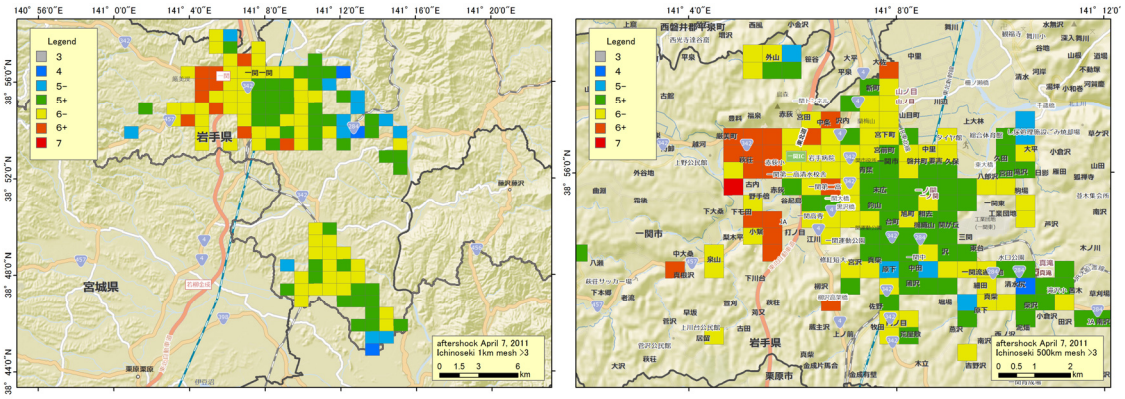

Figure 12. Seismic intensity distribution in Ichinoseki City averaged with 1km(left) and 500m(right) meshes for the aftershock occurred at April 7, 2011. A number of a legend indicates seismic intensity based on JMA scale. A symbol of '+' indicates 'strong' ,and a symbol of '-' indicates 'weak'. In the case of 500m mesh analysis the mesh that an estimated seismic intensity is 7 is found in the west area.

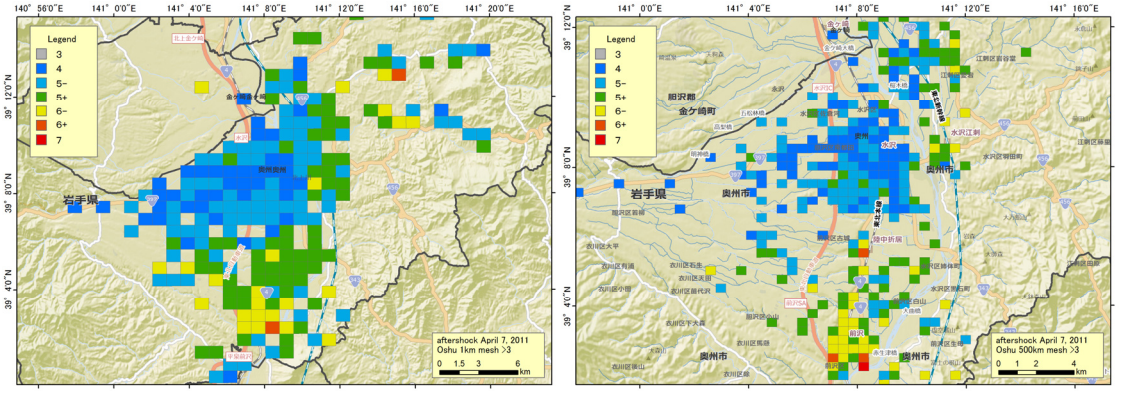

Figure 13. Seismic intensity distribution in Oshu City averaged with 1km(left) and 500m(right) meshes for the aftershock occurred at April 7, 2011. In the case of 500m mesh analysis the mesh that an estimated seismic intensity is 7 is found in the south area.

Figure 13 shows seismic intensity distribution in Oshu City averaged with 1km and 500m meshes for the aftershock occurred at April 7, 2011. We can see that the dispersion of seismic intensities ranging from 4 to 6 strong for the 1km mesh map or ranging from 4 to 7 for the 500m mesh map in Oshu city. Seismic intensities are largest in the southern area of Oshu City where many houses had been dameded. Those are larger in eastern area where some houses had been dameged. Those are smaller in central and western areas. In the case of 500m mesh analysis the mesh where an estimated seismic intensity is 7 is found in the southern area. The map of Fig.13 and the site amplification map of Fig.10 imply a correlation between strong motions in regional area and the subsurface site amplification. However, it is necessary to discuss on much further analyses, for example, such as the results of seismic intensities of the mainshock to verify the relation.

7. CONCLUSIONS

The seismic intensity map by a questionnaire survey was made up in Ichinoseki City, Oshu City and Kitamaki City of southern area of Iwate Prefecture for the Iwate-Miyagi Nairiku Earthquake in 2008. In addition, the seismic intensity map with a high precision and a good resolution by more densely questionnaire survey was made up in Ichinoseki City and Oshu City for the aftershock occurred at April 7, 2011. Two maps imply the relationship of strong motion distribution in regional area to the subsurface site amplification factors. In the future, we will make up seismic intensity mapping in two cities for the 2011 off the Pacific coast of Tohoku Earthquake, and will discuss on strong motion effects on the subsurface site amplification by using all results.

AKCNOWLEDGEMENT

We use the data of site amplification factors of Japan Seismic Hazard Information Satation (J-SHIS) by National Research Institute for Earth Science and Disaster Prevention. Education committees in Ichinoseki City, Oshu City and Kitakami City gave supports to distribute and retrieve questionnaire sheets for the Iwate-Miyagi Nairiku Earthquake in 2008. The members of the governments of Oshu City and Ichinoseki City gave supports to distribute and retrieve questionnaire sheets for the 2011 off the Pacific coast of Tohoku Earthquake and the maximum aftershock occurred at April 7, 2011. It is grateful to their supports.

REFERENCES

Ichinoseki City Webs, http://www.city.ichinoseki.iwate.jp/

Japan Meteorological Agency, http://www.jma.go.jp/jma/indexe.html

Japan Meteorological Agency (1996), Learning Seismic Intensity - Fundamental Knowledge and Its Application-, Gyousei (in Japanese).

National Research Institute for Earth Science and Disaster Prevention, Japan Seismic Hazard Information Satation (J-SHIS), http://www.j-shis.bosai.go.jp/

Ohta, Y., N. Goto and H. Ohashi (1979), A Questionnaire Survey for Estimating Seismic Intensities, Bulletin of the Faculty of Engineering Hokkaido University, **92**, 117-128. (In Japanuse)

Ohta, Y., M. Koyama and K. Nakagawa (1998), Revision of Algorithm for Seismic Intensity Determination by Questionnaire Survey -In High Intensity Range-, Journal of Japan Society for Natural Disaster Science, **16:4**, 307-323. (In Japanese)

Oshu City Web, http://www.city.oshu.iwate.jp/