The 2011 off the Pacific coast of Tohoku Earthquake: Outline and some topics

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Abstract

The 2011 off the Pacific coast of Tohoku Earthquake emerged various phenomena. This paper describes the distribution and the propagation of the real-time seismic intensity. Although Earthquake Early Warnings (EEW) by Japan Meteorological Agency (JMA) was issued for public at 14:46:49 on March 11, 2011 (JST), the area issued the alarm was restricted and a lot of damaged areas were not included. EEW for Shinkansen-line consisting of JMA type instrument, also failed to issue the P-wave alarm, and only a conventional alarm system worked by exceeding the trigger level of 120 Gal (=cm/sec^2).

One FREQL, a single-station-system, nearby base of Oshika peninsula succeeded to detect the earthquake, to issue P wave alarm and to determine the earthquake parameters reasonably but magnitude. However even the site was on hard ground, it needed 15 seconds to issue P wave alarm. Proposed technique estimates the origin time and location from the P-wave detection time of at least 5 sites. In case of the 2011 off the Pacific coast of Tohoku Earthquake. The location estimated 3.7 seconds after the first P-wave detection. Growing up the magnitude, P-wave alarm can be issued around 6 seconds after P-wave detection.

Also this earthquake caused severe damage in a wide sphere. Even in Tokyo metropolitan area liquefaction was observed. From a viewpoint of earthquake disaster prevention, it is important to grasp the vulnerability from the inventory survey before the expected event. This paper explains the vulnerability index *Kg* value and compares the liquefaction caused by this earthquake with the results of the microtremor measurement in 1990. For example, at Maihama area we had 4 measurement points. In this area, *Kg* value was 9.8 to 34.9 (micro strain/Gal) and this agrees with the field investigation.

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1. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake (hereafter the 3.11 earthquake) emerged various phenomena. This paper describes the distribution and the propagation of the real-time seismic intensity RI and the situation of issuing various earthquake alarms. And what is necessary for earthquake disaster prevention learning from the experiences of the 3.11 earthquake is discussed and the author proposes for national organization like JMA, Japan Meteorological Agency.

On the other hand, the 3.11 earthquake caused severe damage in wide sphere focusing mainly around eastern Japan area. And even in Tokyo metropolitan area, more than 200 to 300 km far from the focal region, liquefaction was occurred in many places. By the way, the ultimate and proper countermeasure against earthquake disaster is to make all the structure earthquake resistance. For this, it is important to grasp the vulnerability from the inventory survey before the expected event.

This paper explains the vulnerability index *Kg* value derived from the result of microtremor measurement and adopts *Kg* value for the microtremor measurement in 1990 to estimate the possibility of liquefaction. Then *Kg* value compares the liquefaction situation caused by the 3.11 earthquake.

2. Outline of the 3.11 earthquake

2.1. Realtime Intensity RI

From a viewpoint of the vulnerability of various structures, a damage index *DI* was proposed, that is an earthquake motion index relating to the earthquake early warning [1]. Then, in consideration of the closely relationship between *DI* value and the instrumental seismic intensity of JMA, *Ijma*, *DI* is redefined as real-time intensity RI [2]. DI and *RI* are defined from the power per unit mass of the earthquake motion as Equations. (2.1) and (2.2), so it is characterized to be possible to grasp a physical value momentarily, unlike *Ijma* calculated as artificial value with 60 second-length earthquake motion after the event.

$$DI = \log(\,|\mathbf{a} \bullet \mathbf{v}|\,) \tag{2.1}$$

$$RI = DI + 6.4 \tag{2.2}$$

Here **a** is an acceleration vector (m/sec/sec), **v** is a velocity vector (m/sec), and then the product of these vectors is known as a power density in unit of W/kg. An operator "•" of Equation (2.1) indicates an inner product. And the frequency range is limited to 0.5 to 5 Hz.

Because *RI* can be calculated sequentially in realtime and can detect P wave, it is possible to utilize not only for the early warning for big earthquake but also assist proper countermeasures after an event by offering the power of seismic strong motion accurately.

By the way, the power density of a mankind is roughly 1.0 W/kg, and this amount of power density corresponds to 6.4 of the seismic intensity in Japan. The relationship between *RI* and *MMI*, Modified Mercalli Intensity, is shown as follows.

$$MMI = (11/7) \times RI + 0.5 \tag{2.3}$$

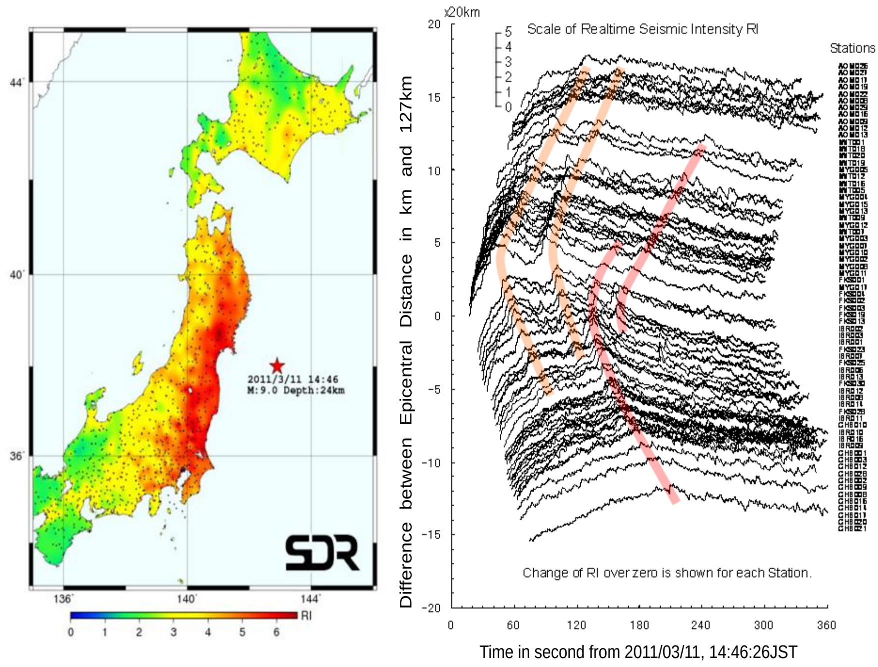
2.2. Earthquake motion viewed from RI

Figure 2.1 shows the change of *RI* more than zero of K-NET stations at Aomori, Miyagi, Fukushima, Ibaraki and Chiba prefectures corresponding to the difference of the epicentral distance between the epicentral distance of each station and the shortest epicentral distance (127 km), separated to the north and south part for the rupture point of the 3.11 earthquake. This figure shows the situation properly of the earthquake motion propagation from some sources with time difference. In southern side, *RI* grew gradually and reached its maximum value more than intensity 5 taking a lot time, while *RI* in case of northern side reached its maximum value relatively early.

Taking advantage of the features of *RI* to be able to shows the intensity of the earthquake motion in real-time, it is possible to draw a propagation of the earthquake motion with distribution of *RI* of each station instantly. The motion picture is opened on our website (http://www.sdr.co.jp). The motion picture shows the situation that the earthquake motion reached wide area and spread at once, and then *RI* grew gradually. Because an area with large intensity spread increasingly toward to south side, the intensity slowly grew larger and reached its maximum value quite later than the epicentral area.

2.3. Discussion

The 3.11 earthquake is abnormal earthquake with extremely long duration even for Japanese people used to feel earthquake motion commonly. Most of Japanese people noticed the earthquake motion by themselves before reaching enlarged motion without any warnings. Although this abnormal motion started some tens seconds before the large motion, there was only a few people started activity for evacuation immediately. Especially staffs of local government did not start



(1) Distribution of Maximum Realtime Intensity RI (2) Change of RI on Time Domain at Various Sites

Figure 2.1. *Distribution of Maximum Realtime Intensity and Change of Realtime Intensity on Time Domain at Various Sites*

any activities immediately and waited tsunami warning from JMA, although it was only a few minutes. This inactive approach seems to enlarge tsunami damage of this earthquake. It is necessary to review in detail of the matter of this situation, but there are no signs to start review by third party. People may not judge to escape by themselves because of independency on the tsunami warning of JMA limited by low or on the huge coastal levee higher than estimated tsunami height by JMA. Moreover frequent excessive tsunami warning by over-estimation might cause crying wolf effect.

Although the activity for evacuation must reflect local conditions, the activity is triggered by the warning from JMA of central bureaucracy. This situation seems to be abnormal. After the Kobe earthquake disaster, sixteen years ago, why does JMA amend a law to restrict issuing tsunami warning by judgment of local government? Deprivation the judgment from local government causes dependency for central bureaucracy and lack of decision on activity for disaster prevention

Not only tsunami warning but also EEW, early earthquake warning, is also under same situation. Although EEW by JMA could not be issued before a large motion even in case of M7-class earthquake in damage area (within 30 to 50 km), public information continues saying the EEW by JMA is useful. The 3.11 earthquake was a rare chance that EEW by JMA can be useful, but no specific example that EEW of JMA was useful was reported. Therefore it is clear that the system failed to issue the proper warning. As a result, EEW by JMA is protected by low but can not protect local people. The author thinks that JMA with nation wide observation network must focus to inform immediately exact earthquake parameters of main shock and aftershocks by parallel way and it must be possible for various organizations to issue earthquake warnings. This will make enable to determine the severe damaged area quickly and help the rescue activity. As mentioned before, both earthquake and tsunami warning must be realized by local organizations in their domain and the warning issued by central bureaucracy is meaningless. If the offshore observatory of sea-wave height were distributed for coastal municipalities in realtime, the losses by tsunami will decrease drastically.

3. Earthquake Early Warnings

3.1. Working condition of various warning systems

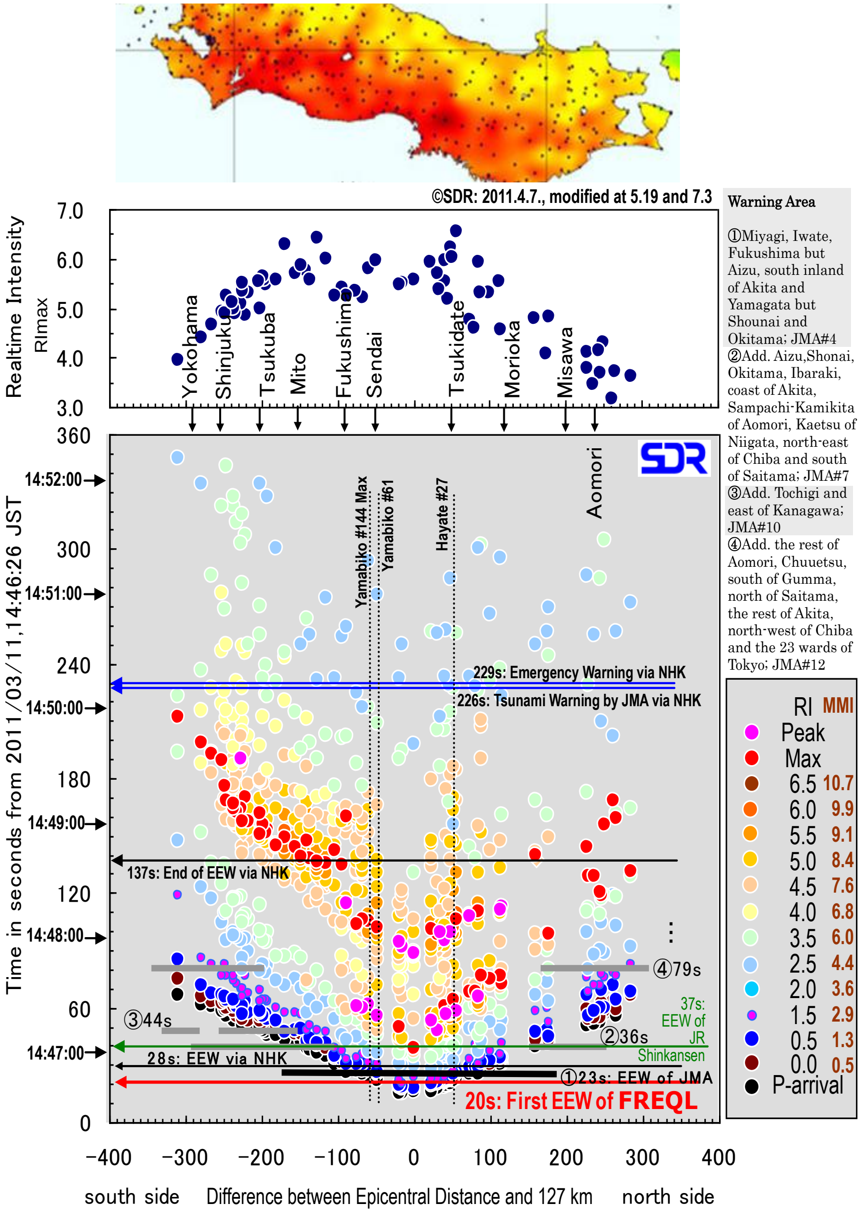


Figure 3.1. *Variation of Realtime Intensity around the Eastern Japan using Strong Motion Records of K-NET and other Organization with Alarm Situation*

Figure 3.1 shows the variation of real-time intensity at eastern Japan using strong motion records of K-NET and other organization with alarm situation. Horizontal axis is a difference of the epicentral distance adding + or – corresponding to north and south to the epicenter and vertical axis is elapsed time from 14:46:26 on March 11, 2011 (JST), the start time of the waveform recording at MYG011 Oshika, the fastest detection station. Colored circles indicate the value of *RI*, peak and the time of maximum value as legend. Also circled number corresponds to the sequence number of the EEW by JMA based on the estimated intensity more than 3 or 4. An onset time of each intensity grade and maximum intensity delay roughly according to the difference of the epicentral distance in northern Tohoku area. On the other hand, although P wave arrived in advance in Kanto region, a time reaching each intensity grade increasingly slow and a time reaching maximum intensity is quite late. While the earthquake early information by JMA was issued for public at 14:46:49 (23 seconds from start) on Figure 3.1, the issued area was restricted all part of Miyagi and Iwate prefecture, and restricted part of Fukushima, Akita and Yamagata prefecture. And it was not issued for the other damaged area with maximum intensity more than 5, so it must be said that the alarm was issued unreasonable. Meanwhile, because hypocentral distance is more than 120 km even in limited area to epicentral region, a duration time of the initial motion is estimated more than 15 seconds. So people in the area had enough time margins before suffering large earth quake motion after noticing the earthquake occurrence. However it seems to be possible for the earthquake early information by JMA to be valuable for earthquake disaster prevention, there is no report to help something specifically. Earthquake alarm system for JR Shinkansen-line, the bullet train, failed to issue the P-wave alarm, and a conventional alarm system just worked by exceeding the trigger level, 120 Gal (=cm/s^2) in 14:47:03. This time is later at least five seconds than initial system installed in 1985 with trigger level of 40 Gal. And if there were same system which issued P wave alarm successively at the time of the 2004 Niigataken-Chuetsu earthquake, the additional leading time is estimated 15 seconds or more. The current earthquake early alarm system that failed to issue the alarm in this time is similar system to that of JMA.

Figure 3.1 also shows the result of simulation of FREQL which is assumed to be installed at K-NET or KiK-net sites. Here, FREQL is an earthquake early warning system essentially differs from that of JMA. FREQL is unique system characterized by its functions to distinguish P wave from ground motion, to determine the earthquake parameters independently at installed site. Also FREQL can issue P wave alarm based on the dangerousness of the detected earthquake motion with realtime data processing. FREQL has been operated as practical system for a disaster prevention system of railway companies or other organization. Please see the detail of FREQL in the paper [3]. FREQL detected the event at 14:46:40 and issued the P-wave alarm at 14:46:46 as a simulation result with waveform of MYG008 Kitakami.

An actual working FREQL at a base of Oshika peninsula issued P-wave alarm at 14:46:54 and estimated exact earthquake parameters, location and depth, exception of magnitude. The simulation results for this case agree with the actual situation. FREQL took some to issue P wave alarm after earthquake detection, because the site is extremely hard rock site and the earthquake motion grew very slow to large motion, FREQL required rather long time to judge the earthquake motion danger. The P wave alarm was issued exceeding 2.1 of *PI, RI* value during initial motion, and the earthquake motion reached finally 5.5 of *RI* at that site. This earthquake motion seems not to cause serious damage around the site. It shows the validity of the FREQL simulation.

3.2. Proposal of the new estimation technique of earthquake parameters from multi station information

One FREQL station nearby base of Oshika peninsula succeeded to detect the 3.11 earthquake, to issue P wave alarm and to determine the earthquake parameters reasonably exception of magnitude. However even the site was on hard ground, it needed 15 seconds to issue P wave alarm. So this paper compares the early P wave alarm between ordinal FREQL single-site-estimation and the other multi-detection method using FREQL technique, and then considers a possibility of earlier earthquake warning.

(1) Estimation of origin time and location of a source

Origin time and location of a source (latitude, longitude and depth) are estimated from P wave detection time information of more than five stations using least squares method, assuming a P wave propagation velocity as 6 km/sec. Consideration below uses strong motion records of K-NET and KiK-net and assumes that the station has an instrument corresponds to FREQL and sends a time of P wave detection in real time, and monitors a detection, an alarm, growth of magnitude and so on. That is, initial estimation is done with P wave detection information from first five stations, and the estimation is updated as often as receiving the information from the other station and the result is compared with the result before. If the scatter of the results is in predefined range (5 km in this paper), the result is fixed. If a density of strong motion observatories is less than 20 km, it will be expected that the location is fixed within 4 seconds after first P wave detection. In case of simulation for the 2004 Niigata-ken Chuetsu earthquake and 2010 Taiwan Kaohsiung earthquake, the source locations can be determined in 1.04 seconds and 1.69 seconds after first P wave detection, respectively. In contrast, the JMA method with multi observation required about 5 seconds in average and 5.4 seconds the 3.11 earthquake.

(2) Estimation of magnitude

Magnitude is estimated by a formula below [4], based on the amplitude of P wave and its frequency by Gutenberg-Richter.

$$M = 1.59(\log Vp + \log R) + 1.53 \qquad (3.1)$$

Here, Vp is P wave amplitude of vertical motion in mkine (= 0.001 cm/sec) and R is epicentral distance in km.

Although Equation (3.1) supposes that the value of Vp is observed on a hard ground, K-NET station is not always installed on a hard ground. So the earthquake motion amplification factor A for each station is estimated as Table 3.1 based on the estimate formula for seismic intensity [5], and Equation (3.1) is modified as follows.

$$M = 1.59(\log Vp + \log R) + 1.53 - 1.59 \log A \qquad (3.2)$$

Table 3.1 *the amplification characteristics at station of k-net and kik-net*

Site		Sum of data	Averaege of RI amplification	Dispersion of 2logA	Constant term of Eq.(3.2)
MYG011	Oshika	9	1.504	0.885	0.33
MYG008	Kitakami	11	0.749	0.602	0.93
MYG002	Utatsu	14	1.203	0.570	0.57
MYGH03	Karakuwa(kik)	13	0.375	0.589	1.23
MYGH12	Shizugawa(kik)	13	0.350	0.629	1.25
MYG010	Ishinomaki	12	1.683	0.864	0.19
IWTH25	Ichinoseki−W(kik)	10	0.854	0.740	0.85
IWTH26	Ichinoseki−E(kik)	11	1.203	0.858	0.57
IWT010	Ichinoseki	9	0.805	0.888	0.89
AKT023	Tsubakidai	8	0.500	0.706	1.13
IWTH24	Kanegasaki(kik)	10	1.133	0.771	0.63
MYGH02	Naruko(kik)	6	0.136	0.712	1.42
FKSH03	Takasato(kik)	12	1.128	0.319	0.63

Although epicentral distance is calculated based on a rupture start point estimated in first few seconds, epicentral distance will be changed by the progress of fault rupture. And also main shock will arrive after the initial motion. So Equation (3.2) can be adopted for a time window *R/4Cr* after P-wave detection. Here, *Cr* is rupture velocity of the fault. And a rupture time for 1/4 of the epicentral distance from the start point of the rupture. In this time, the scatter of the estimated magnitude will be less than ± 0.2 during the applying time.

After fixing the epicenter, magnitude is estimated from Equation (3.2) and then the P wave alarm can be issued based on the *M-Δ* relation if a station seems to be danger. Because this method can grasp the location of the earthquake relatively accurately, it is possible to determine an area needed alarm with tremendous precision. Finally averaged magnitude will be the magnitude of whole system.

3.3. Discussion

In case of the 2008 Iwate and Miyagi earthquake (M7.2), information from five stations is observed 3.46 seconds after first detection at IWTH25 Ichinoseki-Nishi station, and the location of the epicenter is determined latitude 39.008˚N, longitude 140.875˚E and depth of -4.6 km. Then after 0.55 seconds, information from MYGH02 Naruko station was added and the location of the epicenter moved to latitude 39.027˚N, longitude 140.867˚E and depth of -2.1 km. Because the difference was within 5 km, the estimation was fixed. The depth was minus value but less than 5 km so the depth fixed as 0 km. The epicenter by JMA was latitude 39.028˚N, longitude 140.880˚E and 8 km depth.

In case of the 3.11 earthquake, information from five stations is observed 2.54 seconds after first detection at MYG001 Oshika station, and the location of the epicenter is determined latitude 36.376˚N, longitude 146.094˚E and depth of 381.6 km. Then after 1.13 seconds, information from MYG010 Ishinomaki station was added and the loca-

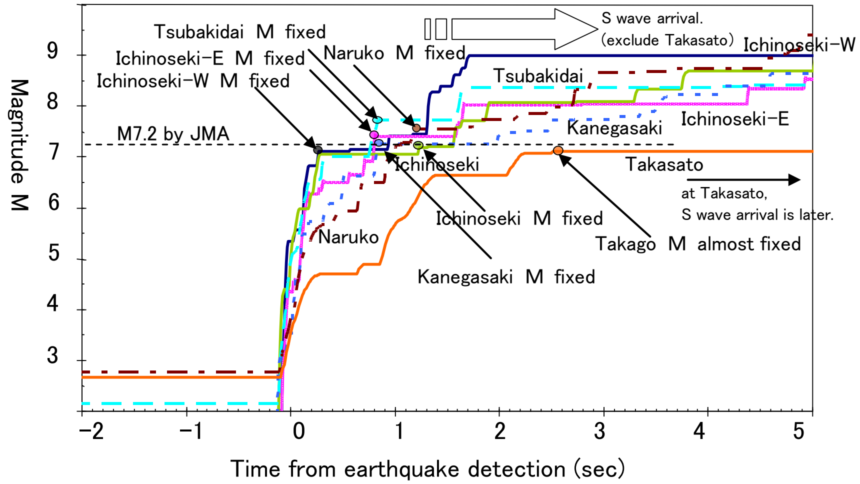


Figure 3.2 *The growth of magnitude of the 2008 Iwate and Miyagi Earthquake*

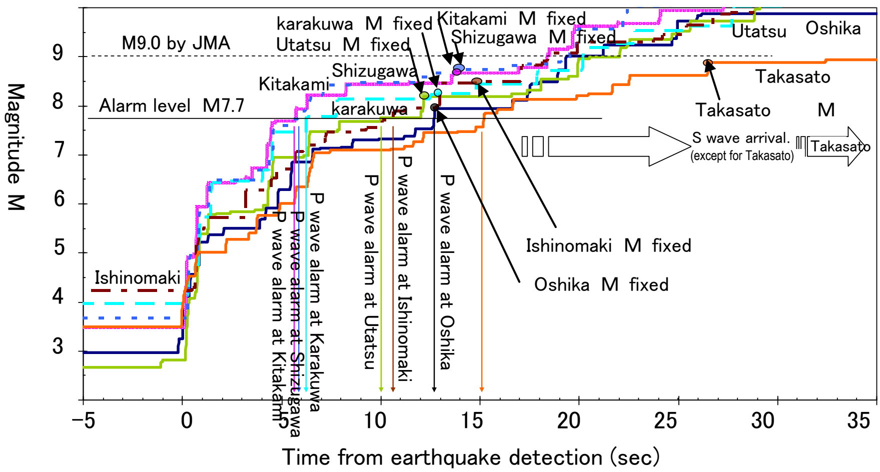


Figure 3.3 *The growth of magnitude of the 2011 off the Pacific coast of Tohoku Earthquake*

tion of the epicenter moved to latitude 38.023˚N, longitude 143.331˚E and depth of 10.8 km. The difference of estimation was quite large. After 0.89 seconds, information from MYG030 Towa station was additionally arrived and the location of the epicenter moved to latitude 38.003˚N, longitude 143.356˚E and depth of 81.1 km. Because the difference of the location is within 5 km but the depth was quite differ for each other but the reliability of the depth estimation at this region was low, the fixed estimation became the second one with 4.56 seconds. Also, the epicenter by JMA was latitude of 38.103˚N, longitude 142.860˚E and depth of 24 km.

Figures 3.2 and 3.3 show the progress of the magnitude based on equation 3.3 with the information of first six stations for each earthquake. Information of FKSH03 Takasato station was added as an example of little far station as a reference for both figures.

In case of the 2008 earthquake, applicable time is only 1-2 seconds for the first six stations and the magnitude grew drastically and reached and was fixed 7.2 around one second after detection. In case of FKSH03 Takasato station about 170 km away, the magnitude grew relatively slow and stopped within about three seconds. Finally the magnitude was fixed about 7.

In case of the 3.11 earthquake, applicable time was about 13-15 seconds during the growth of the magnitude and the magnitude was fixed. In case of FKSH03 Takasato station about 300 km away, the magnitude grew yet slower and stopped after the applicable time. The magnitude reached or was estimated to reach further finally more than 8 for each station. Magnitude 7.7 seems to be the alarm level for each station based on the M-Δ relation and the alarm could be issued mainly about six seconds and 15 seconds at least after detection.

Thus it shows that it is possible to issue the alarm six seconds at the earliest after detection. This is almost same time for the earliest P-wave alarm of single detection method for over all sites. For example Karakuwa station detected P wave at 14:46:40 and issued 14:46:46. Because in case of the single-station detection system seen in Figure 3.4, the alarm seemed to be issued at 14:46:54, this multi-detection method can be expected to gain time 8 seconds. Figure 3.4 shows the alarm time of the multi-detection method on the time-line of real time intensity *RI* [2] with *RI* = 1.5 as P wave alarm level.

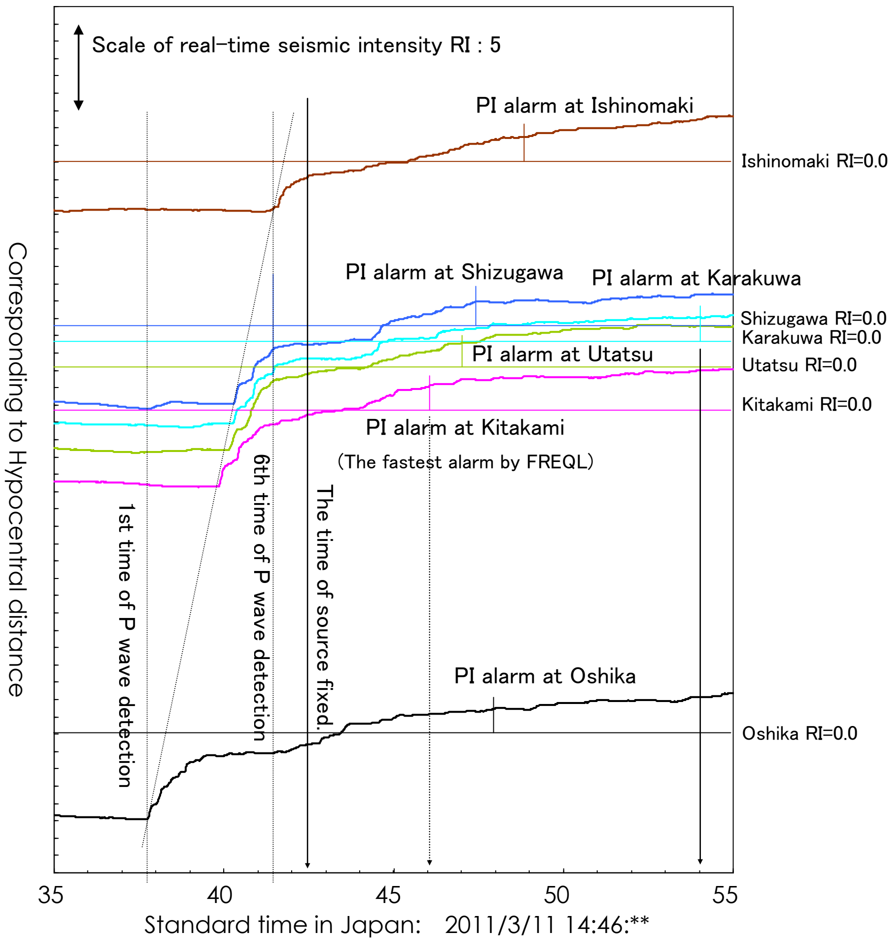


Figure 3.4 *P wave alarm time of first 6 sites of the 2011 off the Pacific coast of Tohoku Earthquake*

4. Liquefaction

4.1. Vulnerability index Kg value for ground

Vulnerability index K values is proposed as an index to estimate the strain of ground or the focused part of the structure against estimated earthquake motion, derived from the predominant frequency F and its amplification factor A of microtremor, and the dimensions of the structure. The common estimating equation of the strain γ or ε is as follows.

$$\gamma \text{ or } \varepsilon = K \times a \tag{4.1}$$

Here, K and a are K value and the acceleration value at the base ground, respectively.

In case of ground, Kg value, K value for ground, is defined as follows;

$$\begin{aligned} \gamma &= eAd / h \\ &= eAa / \omega^2 / h \\ &= eAa /(2\pi F)^2 (4F / Vs) \\ &= eAa /(2\pi F)^2 (4FA / Vb) \\ &= eA^2 / F /(\pi^2 Vb) \\ &= A^2 / Fe /(\pi^2 Vb) a \end{aligned} \tag{4.2}$$

Here, e is input efficiency and Vb and Vs are the velocity of the base ground and surface layer, respectively, in unit of m/s. Also d is displacement at base ground and h is depth of the surface ground.

Hence,

$$\gamma_e = \beta \times Kg \times a \tag{4.3}$$

Here, $Kg = A^2 / F$ and $\beta = e /(\pi^2 Vb)$. In a discussion below, a dimension of Kg sets in μ/Gal to make clear the relationship that the product of Kg and a indicates strain. Vb can be assumed 600m/s in Japan.

It seems that the input efficiency e may be fluctuated by the waveform of input earthquake motion. In case of the single pulse wave, large acceleration is required to cause large strain so the input efficiency e must be small. However in case of common event causing liquefaction including the 3.11 earthquake has enough long duration, so input efficiency *e* can be set 0.6 and then β becomes 1.0. Thus,

$$\gamma_e = Kg \times a \tag{4.4}$$

The trial on the determination of liquefaction occurrence using *Kg* value will be described below.

4.2. Result of microtremor measurement and liquefaction occurrence

This paper uses the result of microtremor measurement conducted in 1990 [6]. The instrument for this measurement was PIC, Portable Intelligent Collector, a microtremor measuring tool with a three-component sensor and data logger units. The microtremor was repeatedly recorded for 40.96 seconds (4,096 data in 100 Hz sampling) at every measurement site, and a 10.24 seconds length data was chose from a viewpoint of less artificial noise. Then the selected data was Fourier transformed. After that, the horizontal to vertical spectrum ratio was calculated for each component of every measurement and finally H/V spectrum ratio was derived as an averaged spectrum ratio [7]. Predominant frequency *F* and its amplification factor *A* are read from the H/V spectral ratio. Procedures above had been done in 1990.

This paper calculates *Kg* value from this result in 1990 to eliminate any artificial processing and estimates the strain in the surface ground layer with the acceleration value at the time of the 3.11 earthquake observed nearby sites. Then the proposed index and method are verified their validity with comparing the estimated strain with the actual liquefaction situation.

(1) Maihama area

Maihama is a reclaimed area filled in 1970s and locates at eastern side of Tokyo metropolitan area. Tokyo Disney Land built on it. In 1990, microtremor measurement was conducted at four corners of a reclaimed land as MH01 to MH04 shown in Figure 4.1. *Kg* value ranges 9.8 to 34.9 μ/Gal (=micro strain/(cm/sec^2)) for MH01 to MH04 as shown in Figure 4.2. A nearby strong motion station, K-NET

Urayasu, recorded 164 Gal (= cm/sec^2) as maximum acceleration. Here this maximum acceleration value is 5HzPGA, 5Hz low passed peak ground acceleration, to restrict the acceleration value to explain-

Figure 4.1 Measurement Point and Liquefaction Situation at Maihama Area

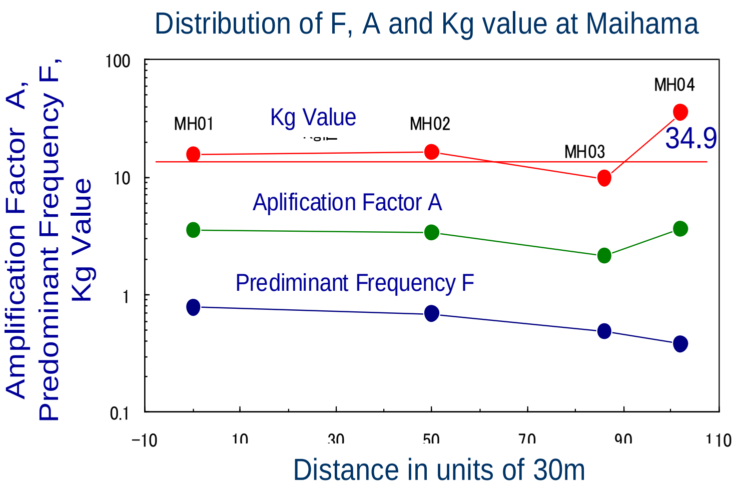


Figure 4.2 Distribution of Kg value, Predominant Frequency F and Amplification Factor A at Maihama Area

ing the damage situation properly. And because the amplification factor is assumed about 4 for the ground in this area, maximum acceleration at base ground can be assumed 41 Gal.

From the boring investigation in Urayasu, close to this reclaimed area, *Vb* can be estimated about 300m/sec, so the β in equation (4.3) becomes 2.0. In this case estimated strain will be double. So the strain in the surface ground is estimated roughly 1240, 1290, 820 and 2710 μ for MH01 to MH04, respectively. If strain more than 1000 μ causes liquefaction as it is often expressed, it seems that liquefaction occurs at MH01 and MH02, does not occur at MH03 and severely occurs at MH04. Figure 4.1 also shows the result of the field survey of the liquefaction situation after Yasuda [8]. We can see that the *Kg* value distribution agrees with the liquefaction situation.

(2) Omori and Oi area

Omori and Oi area in northwest part of Tokyo bay and the main part of Oi had been filled up in before 1940s. Measurement points were set along EW line between a park west side of JR Omori train station and Oi container wharf, and along NS line in the center of Oi pier (see Figure 4.3). Figure 4.4 shows the *Kg* value distribution. This

Figure 4.3. *Distribution of Measurement Point and Reported Damage at Omori an d Oi Area (★: Reported Damage)*

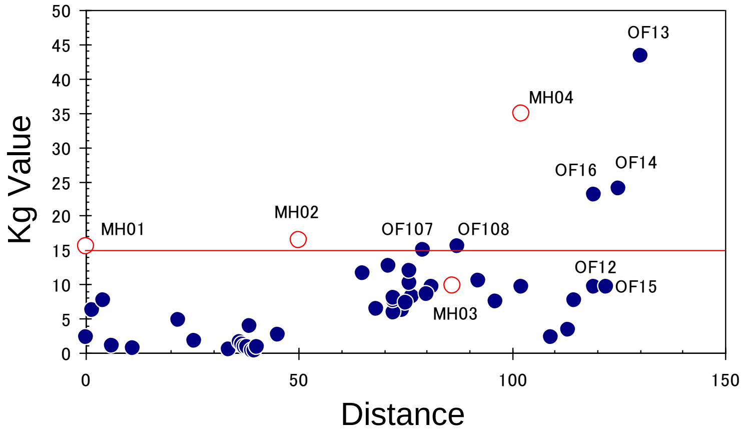


Figure 4.4. *Distribution of Kg Value at Omori and Oi Area*

figure shows that *Kg* value exceeds 15 around the wharf and a park in the west side of the reclaimed land. Liquefaction occurs around the pier [9], and also a park in the center of reclaimed land temporary closed a baseball ground because of liquefaction and informed damage as crack at artificial shore. There is no more information of damage for this area. In any case the liquefaction situation is less severe than that of Urayasu or other area.

Kg values corresponding to this damage information are small value around 10 except more than 23 at the pier and more than 15 around the park. Considering that the strain of 1000 μ is required for liquefaction, it shows that liquefaction must be caused more than 100, 43 and 67 Gal of the acceleration at the base ground, respectively. Because here is old reclaimed land, *Vb* must be less than 600 m/sec, but greater than 300 m/sec at Urayasu area. It seems that the acceleration between 50 and 100 Gal were required for causing liquefaction in the non-damaged area, although between 22 (=43/2) and 67 Gal were required for damaged area. So *Kg* value distribution gives proper result for the possibility investigation of liquefaction.

(3) JR Keiyo-line

JR Keiyo-Line is running along northeast coastal line of Tokyo bay.

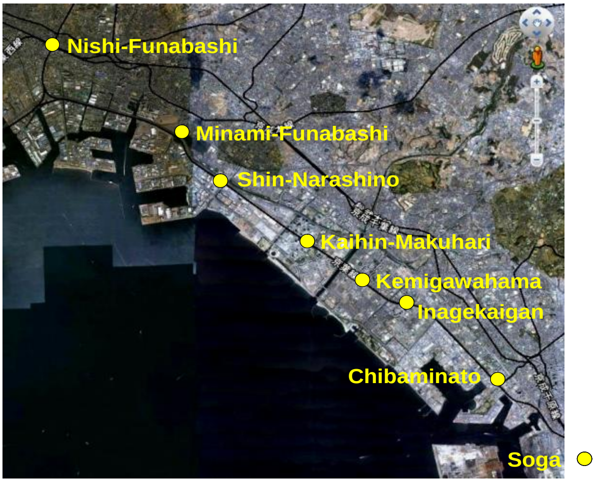


Figure 4.5. *Distribution of Measurement Points for JR Keiyo-line*

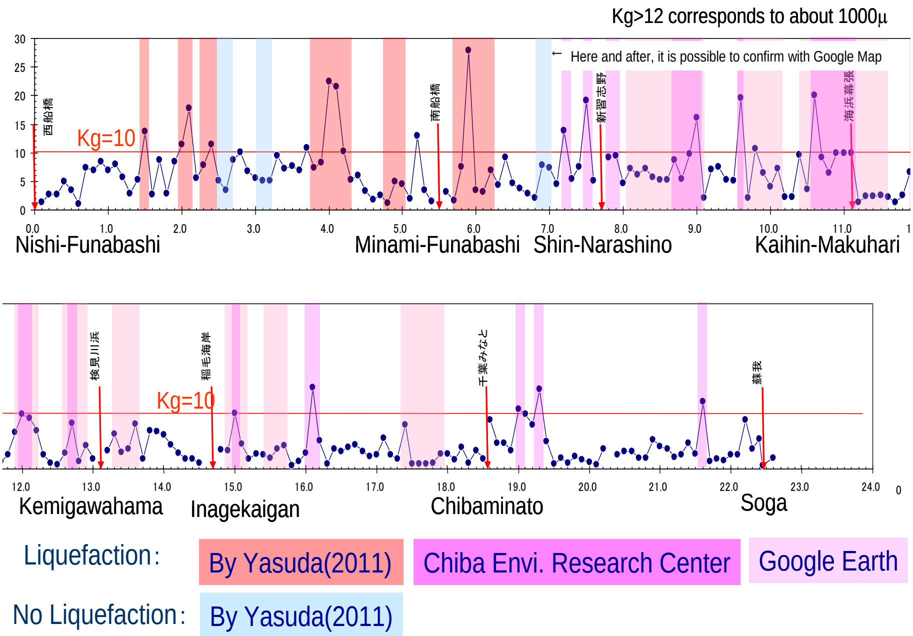


Figure 4.6. *Distribution of Possible Damage and Kg Value for JR Keiyo-line*

Microtremor measurement in 1990 was conducted every 100m for 22.5km between Nishi-Funabashi train station and Soga train station (see Figure 4.5). Figure 4.6 shows distribution of *Kg* value for the distance from Nishi-Funabashi station, the western end of the measured area. An area marked dark pink and light blue indicates a portion of liquefaction and not liquefaction, respectively, after Yasuda [8]. Also light pink indicates liquefaction after Chiba Prefectural Environmental Research Center [10]. After 7 km, purple part indicates a possible area with liquefaction from comparing Google Earth photos before and after the earthquake.

It seems that distribution of *Kg* value in Figure 4.6 agrees with the result of reconnaissance survey. And at the area of liquefaction occurrence, *Kg* value is mostly more than 10. Maximum acceleration around this area can be estimated about 50 Gal because observed acceleration was around 200 Gal and amplification factor is assumed 4. With considering the low *Vb* as 300 m/sec, the strain is estimated about 1000 μ when *Kg*>10. It is able to be thought that the liquefaction judgment is almost proper.

(4) JR Kashima-line

JR Kashima-Line is running through marsh land in northern greater Tokyo area. Microtremor measurement in 1990 was conducted every 100m from south to north between JR Katori station and JR Kashima Soccer Stadium station. In this area, we have no public information of liquefaction occurrence. So we have compared aerial photos opened by Google Earth to find out differences between before and after the earthquake. Figure 4.7 shows distribution of *Kg* value for the distance from Katori station, the southern end of the measured area. An area marked pink and brown indicates a possible area with liquefaction and damage for embankment, respectively. Although this is not a result of reconnaissance survey, it seems that the damage relates to the change of *Kg* value and threshold level for damage occurrence is little more than 10 of *Kg*. Because this area is rather close to the epicentral area, observed earthquake motion was larger than that of Tokyo bay area.

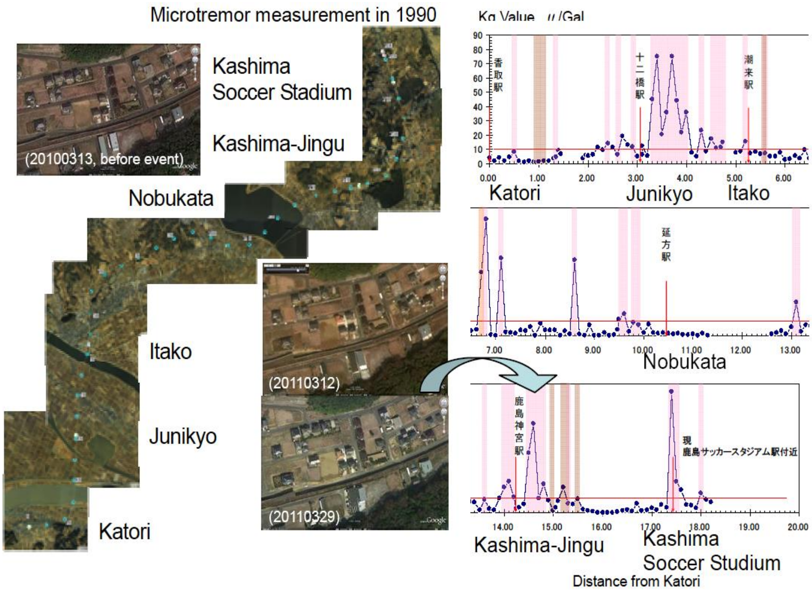


Figure 4.7. *Distribution of Measurement Point, Possible Damage and Kg Value for JR Kashima-line*

5. Conclusion

This paper shows that real-time intensity *RI* can comprehensibly express the distribution of the seismic intensity and the propagation of the earthquake motion of the 3.11 earthquake.

And this paper compares between the early P wave alarm using multi-detection method with FREQL P wave detection and that of single-station detection. As a result, a tendency is seemed that the slower magnitude grew, the farther the station locates. Although P wave alarm is relative earlier for the distant earthquake, it is confirmed that some station can issue earlier alarm with the multi-detection method and more exact magnitude and location of the epicenter can be determined promptly. A single site detection system is commonly early detection system for earthquake alarm system, however it sometimes requires rather long process time for P wave alarm in case of an earthquake growing the motion gradually. On the other hand, because a multi-detection system uses only information of P wave detection time, the system provides exact earthquake parameters as source location and magnitude promptly, and could be possible to advance issuing the P wave alarm. Currently, JMA issues the earthquake early warning as an activity required by law. However national institutions with nation wide observation network must concentrate into prompt announcement of the accurate source location and magnitude from their network. This is the primary role of the national institutions and will contribute to the action immediately and accurately after earthquake.

On the other hand, from a viewpoint of earthquake disaster prevention especially against liquefaction, this paper adopted the proposed index *Kg* value for liquefaction occurrence based on the result of microtremor measurement conducted in 1990, and then compared between the result of determination of the liquefaction possibility and the actual liquefaction situation at the time of 3.11 earthquake. As a result, it confirmed that liquefaction occurred at the site with *Kg* value more than 12. And also the possible damaged area only from the change of the aerial photographs before and after the earthquake on Google Earth agrees with the result of the microtremor measurement along the railway in 1990. The validated technique here is a simple technique to measure microtremor and it can realize an inventory survey. So it will be possible to take a proper countermeasure based on the ordinary investigation technique in detail for an area fell out by this proposed technique. And also it is possible to confirm an effect the countermeasure work with a change of microtremor characteristics before and after the work.

EEW by JMA can gain only comparable or a little long time margin comparing with on-site FREQL or ordinary alarm seismometer, so the merit cannot be recognized. It has been also cleared that EEW by JMA is not applicable for the near-field earthquakes. Earthquake early warning by JMA is not a kind of a system operated under a low because it is feared adverse result from excessive expectation. It seems to be necessary to amend Meteorological Service Act as abolish the unnecessary restrict on earthquake early warning or tsunami warning, base on a view that such a kind of restrict causes the serious damage of the 3.11 earthquake. Finely-tuned responses are required for a disaster like epicentral earthquake or tsunami because of the strong reflection of the local conditions as geography, local culture, or regional industry. It is desirable to change the centralized way of JMA and handle in close coordination and cooperation with local authorities specified familiar with local circumstances. A system to directly link the necessary information to the area must be established and the author expects JMA to support the system.

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References

[1] Nakamura, Y. (1998): A New Concept for the Earthquake Vulnerability Estimation and its Application to the Early Warning System, Early Warning Conference '98.

[2] Nakamura, Y. (2003): Examination of a Rational Strong Motion Index – Relationship between the DI value and the other strong motion indices –, the 27th JSCE Earthquake Engineering Symposium, 54.

[3] Nakamura, Y. (2007): FREQL and AcCo for a Quick Response to Earthquakes, Earthquake Early Warning Systems, Springer-Verlag, 2007/08, pp.307-324.

[4] Takayama, A., Emoto, Y,. Abe, H., and Nakamura, Y. (1981): A study of earthquake early warning system, JSCE Magazine, Vol.66, No.5, 51-56.

[5] Saita, J. and Nakamura, Y. (2005): The development of a formula for seismic intensity estimation added the characteristics on strong motion observation, Proceedings of the 4th Annual Meeting of Japan Association for Earthquake Engineering, 308-309.

[6] Nakamura, Y. and Takizawa, T. (1990): Ground Motion Characteristics around the Ooi Reclaimed Land in the Tokyo Bay Area Estimated by Microtremor Measurements, Proceedings of the Eighth Japan Earthquake Engineering Symposium, 679-684.

[7] Nakamura, Y. (1989): A Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface, Quarterly Report of RTRI, Vol.30, No.1, 25-33.

[8] Yasuda Laboratory Web Site on Tokyo Denki University (2011), http://yasuda.g.dendai.ac.jp/

[9] Tokimatsu, K. et al (2011): Damage for Ground caused by the 2011 off the Pacific coast of Tohoku Earthquake, Research Reporton Earthquake Engineering, No. 118, 21-47. (in Japanese)

[10] Chiba Prefectural Environmental Research Center website (2011), http://www.wit.pref.chiba.jp/ (in Japanese)