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Some Studies on the 2011 off the Pacific coast of Tohoku Earthquake with a central focus on the strong motion

Earthquake Strong Motion, Alarm Issuing Situation, Strong Motion Observation and so on.

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1. Foreword

Ground motion of the 2011 Tohoku Earthquake on March 11, 2011, is quite difference from the past experienced one such as the earthquake motion increasing gradually, large motion repeatedly attacking after reaching its peak, or incredible long duration time.
Here, the timings of the various alarms issued for the earthquake (including tsunami warning), are shown on the graph indicating the temporal or special changes of the seismic intensity, and some topics are picked up for the discussion.

2. Earthquake Parameters

Table 1 shows the estimated earthquake parameters of this earthquake by the Japan Meteorological Agency, JMA, and the US Geological Survey USGS.
JMA says that the destruction started about 120 km east off of the Oshika peninsula with a depth of about 24km.

Table 1 Earthquake Parameters by JMA and USGS

Organization	Origin time	Magnitude	Epicenter		Depth
	2011/03/11		Latitude	Longitude	(km)
JMA	14:46:18.1(JST)	Mw9.0	38.103°N	142.860°E	24
JMA (preliminary)	14:46(apl.)	Mjma7.9	38.0°N	142.9°E	10
USGS	05:46:23(UTC)	Mw9.0	38.322°N	142.369°E	32

3. Expression Situation of Seismic Intensity and so on

(1) Space-time distribution of realtime seismic intensity

Figure 1 shows the variation of the local realtime seismic intensity derived from the strong motion records of K-NET and other seismometers. The horizontal axis shows the difference of epicentral distance and the vertical axis shows the elapsed seconds from March 11, 2011

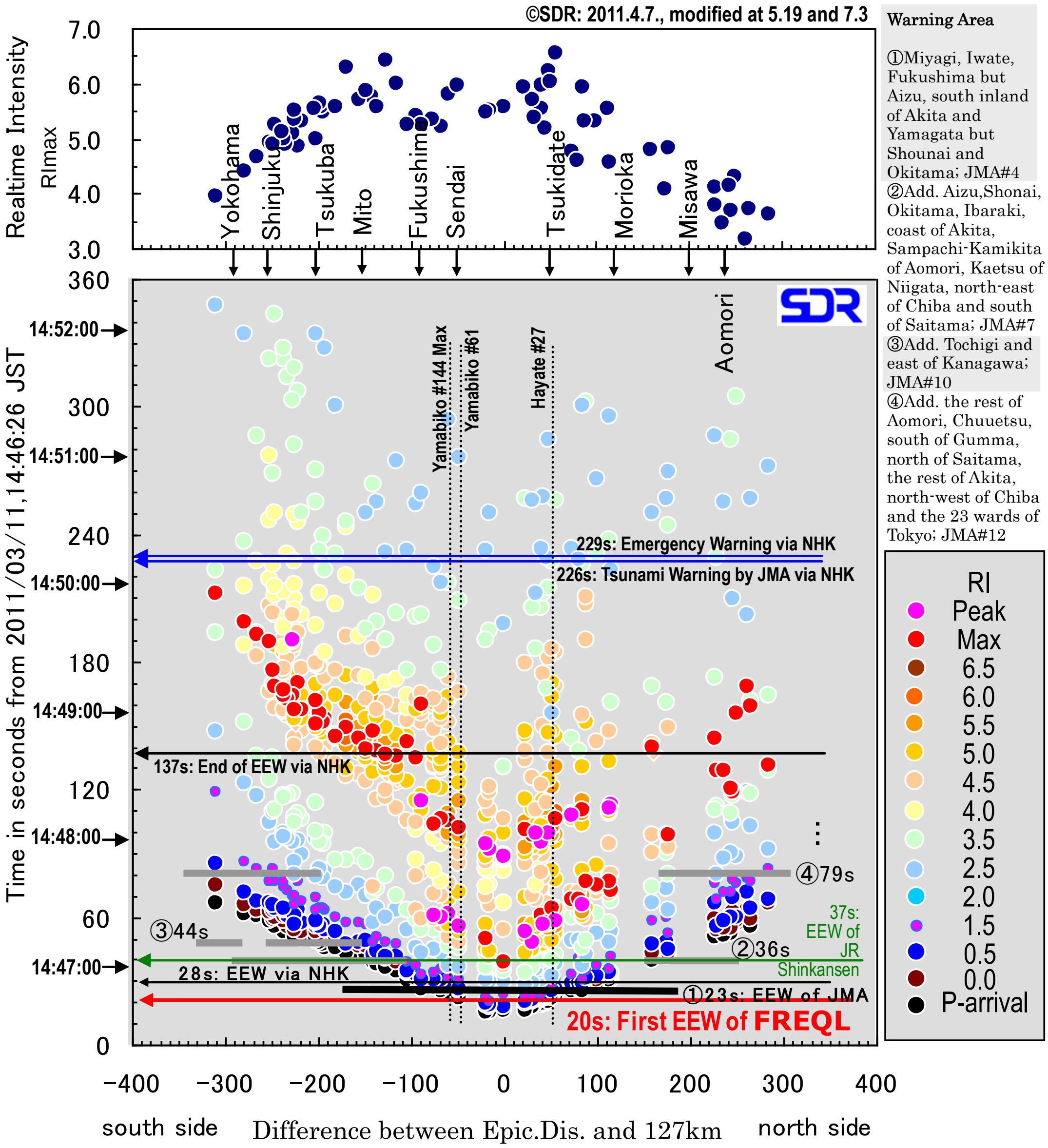


Figure 1 P-wave arrival time, Warning times, Realtime Seismic Intensity and etc. for the 2011 off the Pacific coast of Tohoku Earthquake

14:46:26 JST, start time of the first recorded waveform of Oshika K-NET station. The difference of epicentral distance was derived as a difference from the epicentral distance of each station based on the primary epicenter by JMA to the epicenter of 127km around K-NET Oshika station (MYG011) at Oshika peninsula. Plus and minus signs correspond to northern and southern side for Oshika peninsula, respectively. Colored circles correspond to the realtime seismic intensity or the expression time of peak or maximum value of it, as shown in the legend. The upper part of this figure shows the maximum value distribution of realtime seismic intensity. The circled number in this figure shows the time JMA issued the earthquake early warning, EEW. The mark ① is the issued time of EEW by JMA for the public, 14:46:49 <23>. Here the number in < > shows the elapsed seconds from 2011/03/11 14:46:26. In addition, with each extension of the area where the seismic intensity is estimated over 3 or 4 based on the EEW by JMA for advanced users during 60 seconds after ①, this figure shows this area with issued time of EEW. EEW by JMA for public was the fourth report and corresponds to ①, and the EEW by JMA for public is issued once for one event in principle. Thereafter, ②, ③ and ④ correspond to the 7th, 10th and 12nd report of the EEW by JMA, respectively. In addition, this figure shows the time displaying the EEW on the analog TV screen over the NHK program at 14:46:54 <28> and disappearing at 14:48:43 <137>. Also this figure shows the time of issuing Major Tsunami Warning at 14:50:12 <226> and the time receiving the emergency warning with sound signal at 14:50:15 <229>. Furthermore, this figure indicates the time issuing the early warning for the Shinkansen trains at 14:47:03 <37> based on the newspapers. For comparison with this situation, the results of the simulation issuing alarm using FREQL, for example the fastest alarm time was 14:46:46 <20> using the strong motion record at K-NET Kitakami station, MYG008, are shown. The actual P wave alarm was issued at 14:46:52 <26> from FREQL installed on the quite hard ground around the base of Oshika peninsula. It is confirmed that this result agrees with that of simulation with recorded waveform.

Figure 1 is modified from Figure 7 of SDR Report No. 3, only in Japanese, with correcting misunderstandings of the target area issued the EEW by JMA and adding the informed time of issuing EEW and Major Tsunami Warning on NHK TV program, announced time of emergency warning and issued time of early warning for Tohoku Shinkansen train.
On the following sections, some items are discussed based on this figure.

(2) On the realtime intensity

The real-time seismic intensity RI is a unique index of SDR (Patent No. 3,764,943) redefined and named in 2003 after considering the new earthquake motion index DI proposed in 1998. RI is internationally recognized as referred at international conferences. This index is defined as common logarithm of power, inner product of the acceleration vector and velocity vector, of ground motion acting per unit mass adding constant. It can be calculated in realtime with physical meaning in contrast to seismic intensity of JMA proceeded artificially from recorded waveform of 60 seconds (JMA Notification No. 4), and its maximum value fits to the instrumental seismic intensity of JMA.

4. Earthquake Motion

(1) Spatial distribution and time-series behavior of realtime intensity

According to the maximum value distribution of realtime seismic intensity on upper **Figure 1**, there are two peaks at around 150km of the epicentral distance difference of the south side and at around 50km of the epicentral distance difference of north side. The distribution slightly biased on the south side as a whole and seismic intensity of the Kanto region in south side is greater than that of the northern Tohoku region.

Based on the temporal distribution, the expression time of the each seismic intensity level roughly became late in proportion to the epicenter distance difference and that of the maximum earthquake motion showed in same manner in northern Tohoku region. In contrast to this, that in Kanto region assumes a slightly different aspect. Although the P-wave has been reached early, after reaching the seismic intensity 2, the expression time of the each seismic intensity level became later and the maximum seismic intensity appeared much later. In addition, a clear discontinuity is observed at the time of maximum seismic intensity expression in the area of the south side of the epicentral distance difference 100km. The peak of the seismic intensity corresponding to the first epicenter is not clear and hard to recognize in Kanto region. It seems to be the reason that the expression of the maximum seismic intensity became quite late. Overall the duration time has become strangely long. The duration time over seismic intensity 4 is around 1.5 minutes to over 2 minutes in the northern area with more than 100km of the epicentral distance difference, over 2.5 minutes in the area with a central focus on Sendai within 100km of the epicentral distance difference and reaching 3 to 3.5 minutes in the southern area in this figure. Since seismic intensity that can sense a human body is generally one or more, it takes even long time to decrease below weak unfelt vibration.

There are two clear peaks on the change of the realtime intensity in the area with a central focus on Sendai, largely from Fukushima to Morioka. The time interval of the two peaks is about 50 seconds in the Oshika Peninsula in the area of the center, about 45 seconds in the south, and about 35 seconds in the north. Additionally, although the second peak mainly becomes the maximum value, the first peaks sometimes gives the maximum value. This situation seems to reflect the location or size relation of the first and next epicenter. It is not clear but the secondary destruction seems to locate in northern side of the first destruction starting point.

According the video (http://www.sdr.co.jp/110311tohoku-eq/20110311tohoku.html) to visualize the wave propagation situation using realtime intensity, there are at least three main destructions. The first one progressed toward to a little bit to the north from the starting point, the epicenter, the second one started at slightly southern off of Sendai 50 seconds after the first one, and then the last destruction started seemed to progress from beneath the seabed at off Fukushima prefecture towards to Chiba prefecture, southern side, more 50 seconds later. As a result, it is estimated that northern region is less affected by the third destruction and because Kanto region is more affected by the latter destruction, the earthquake motion was gradually increased and the large motion continued more than three minutes.

To make clear more that above mentioned, a paste-up view of realtime intensity of almost collinear K-NET station was drawn as **Figure 2**. This figure has same meanings of **Figure 6** on

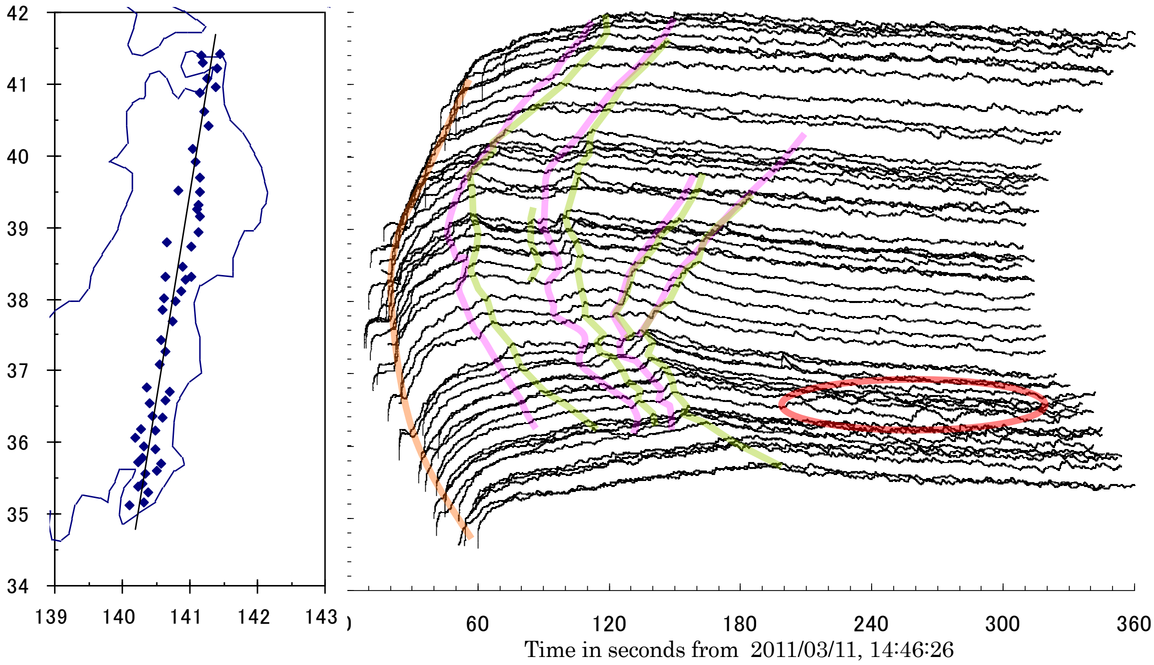


Figure 2 Past-up of Changing of Realtime Seismic Intensities at sites along NS line shown in the left figure for the 311 Earthquake

SDR Report No. 3, only in Japanese, and can be an improved version because of representing the latitude corresponding to the peak of the travel-time curve more clearly. The vertical axis indicates the value that the latitude of each station adding the real-time seismic intensity × 0.15. Changes of realtime intensity are expressed as a relief. Arrivals of the wave are shown as an edge of the relief in red and some phases can be confirmed as continuous mountains in yellow-green or valleys in pink. According to this figure, there are four sets of lines that can be recognized as a travel-time curve and the actual latitude around the peak of the yellow-green hyperbolic curve is the value about 0.8 (= 5 × 0.15) subtracting from the value of the vertical axis because the yellow-green line corresponds to the line about seismic intensity 5. That is, the latitude of the first epicenter is off Ofunato around 39°N, the second one after 45 seconds is off Sendai around 38.2°N, the third one more after 24 seconds is off Iwaki around 37°N and the last one more after 15 seconds is off Takahagi around 36.7°N. It is able to grasp roughly where the main destructions occurred from this figure.

(2) Problem of the strong motion records

Figure 3 shows a recorded waveform of K-NET MYG004 Tsukidate station at the time of the 2011 off the Pacific coast of Tohoku Earthquake with JMA seismic intensity 7 (realtime intensity 6.6). The waveform in this figure shows unusual behavior that the acceleration locus on the NS-UD plane draws a figure-of-eight in the frequency of 4-6 Hz. Especially, the section of one second around the maximum acceleration shows abnormal behavior that the basement block of the strong motion seismometer buried in the ground is estimated hitting surrounding ground and moving like dancing, from the displacement locus obtained by double integration in **Figure 4** with the predominant frequency of around 4 Hz. This means that the response of the basement block was recorded instead of that of the ground motion. Therefore, seismic waveforms of Tsukidate station with the highest seismic intensity of the 3.11 Earthquake cannot be compared with the damage situation around the station. The record of K-NET or KiK-net sometimes seems to reflect strongly the influence of the damage for the observation environment as the station or the basement, pointed with a “realistic model to reproduce the extreme acceleration waveform recorded at KiK-net IWTH25 station during the 2008 Iwate-Miyagi Nairiku earthquake” (Omachi et al.: Estimated cause of extreme acceleration records at the KiK-net IWTH25 station during the 2008 Iwate-Miyagi Nairiku earthquake, Japan, Journal of JAEE, Vol. 11, No. 1, 2011.). It seems that this kind of problem has become pronounced especially after obtaining large earthquake motion. It may get to the time for grasping the dynamic characteristics of the strong motion observation environment including the station. Proper improvement is expected with grasping the problems of the current strong motion observation environment using the large shaking table of NIED collaborating with JMA, universities or other organizations. It is also expected to indicate clearly the dynamic

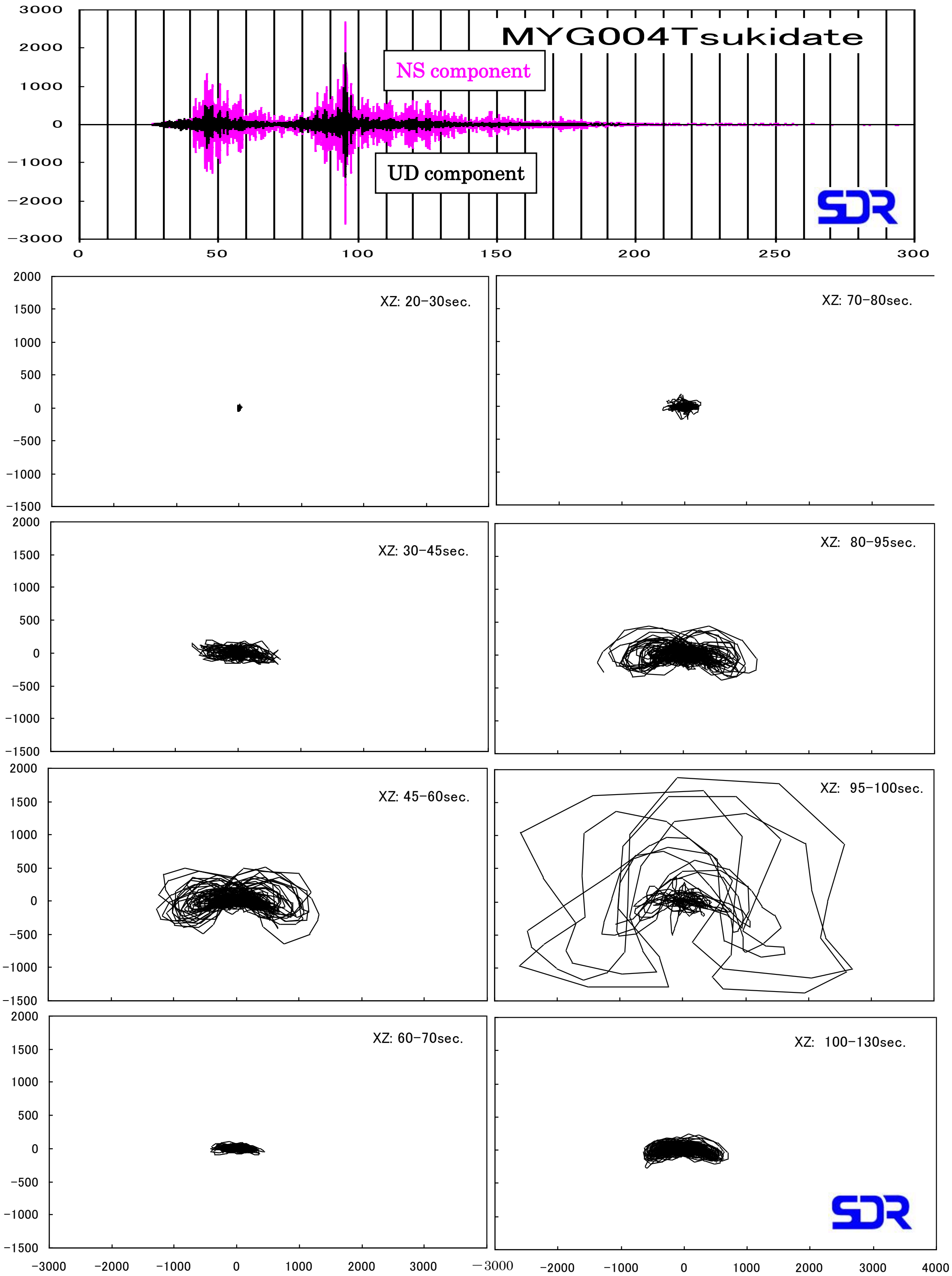


Figure 3 Acceleration Waveforms and Locus in Gal on the NS-UD plane at K-NET Tsukidate MYG004 for the 311 Earthquake

characteristics of the observation system changing with input, in order to properly correct the past recorded waveforms. This is confirmed that it is basically and important issue related to the reliability of the strong motion observation data.

Figure 5 is a waveform recorded at K-NET MYG013 Sendai station and the shape shows acceleration waveform characterized in case of a liquefaction of the foundation ground. Thus,

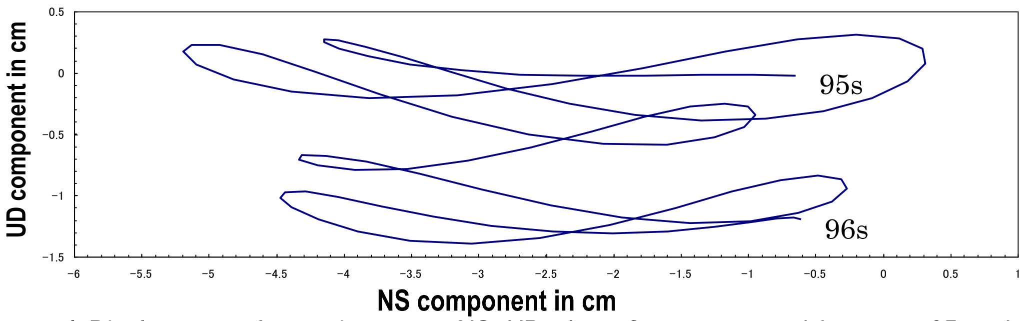


Figure 4 Displacement Locus in cm on NS-UD plane for one second between 95 and 96 seconds of the waveform recorded at K-NET MYG004 Tsukidate for the 311 Earthquake

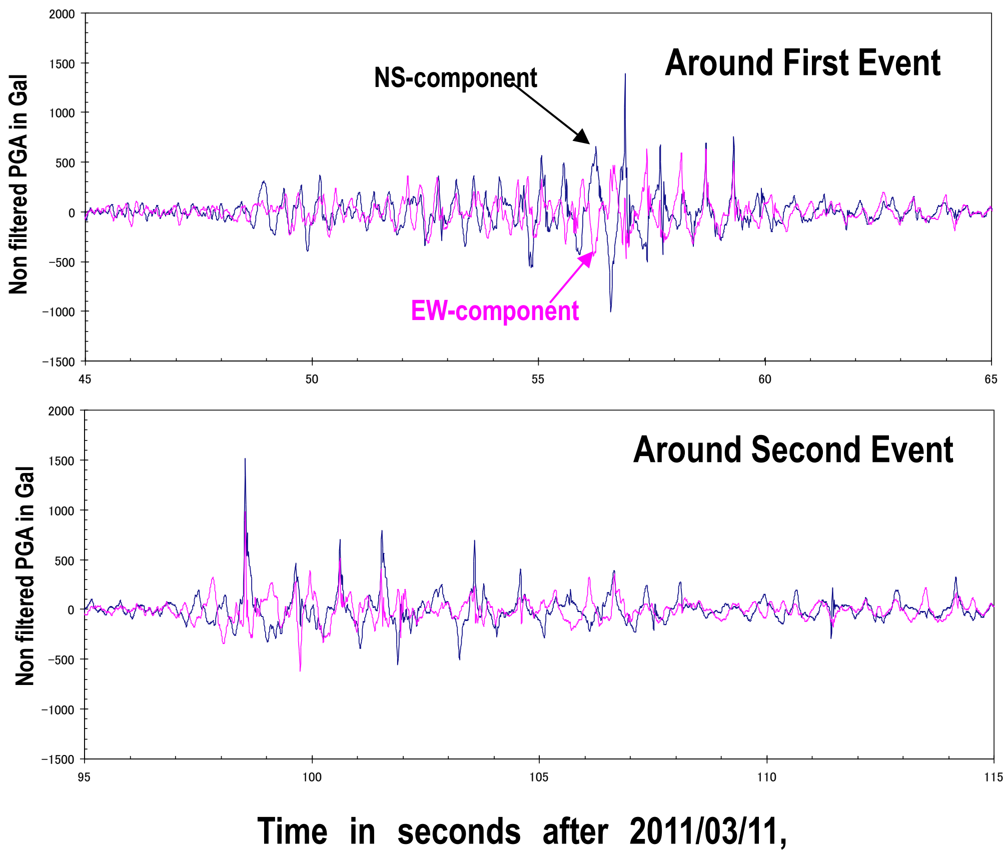


Figure 5 Acceleration waveform of K-NET MYG013 Sendai at the time of the 311 Earthquake: the amplitude near 57 seconds on the first event is diminished quickly and there are overlapped pulse noises on the peak and on the trough, and on the second event the waveform shows similar shape from its start

the strong motion records include not only the information of particular fault rupture process and amplification characteristics of the surface ground, but also occasionally influence of the distinctive vibration for individual observation system or the damage of the observation system. It is important for performing a detailed analysis of strong motion waveform to accurately understand the points to be remembered on the recorded situation.

5. FREQL Alarm Simulation and EEW by JMA or Early Waning System for Shinkansen Train

(1) Issuing and receiving EEW by JMA

Earthquake early warning by JMA for public issued only once in principle through the broadcast such as NHK and mobile phones, for the areas with estimated seismic intensity 4 or over in case of an earthquake expected maximum seismic intensity over 5-. **Figure 6** shows the situation during earthquake motion on the analog TV screen of NHK program with the result of the simulation of alarm indication of palmtop seismometer AcCo using K-NET waveform.

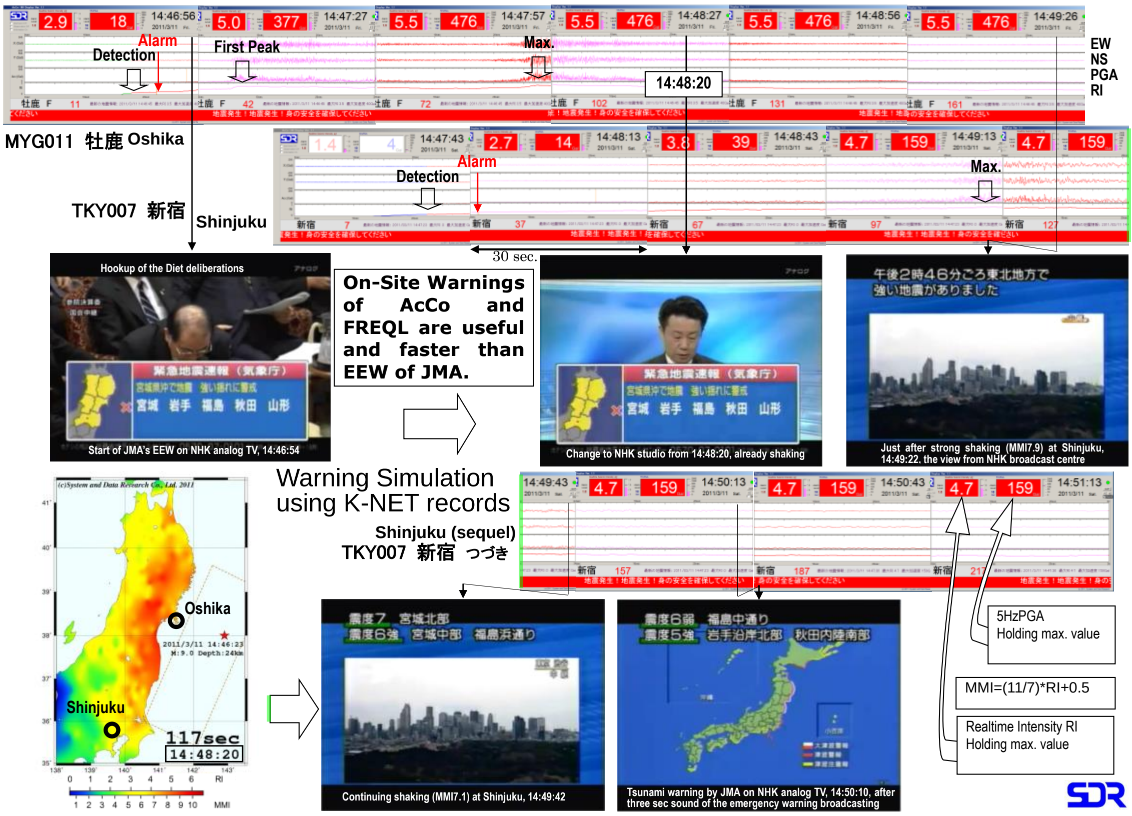


Figure 6 Timing of Alarms for the 311 Earthquake using K-NET Shinjuku and Oshika records, captured NHK TV program and etc.

The national broadcast of NHK TV program issues the EEW by JMA for nationwide independently of the target area with indicating the issued area. On the other hand, in case of mobile phones, EEW by JMA is issued to identify the target area, so called “Area Mail”. At the time of the 3.11 Earthquake, the target area of EEW by JMA was entire Miyagi and Iwate prefectures, Hamadori and Nakadori area of Fukushima prefecture, southern inland of Akita prefecture and Mogami and Murakami area of Yamagata prefecture, as shown as the alarm area ① of **Figure 1**.

Seismic intensity over 5- observed at Miyagi, Iwate and Fukushima prefectures in the area mentioned above. However, seismic intensity over 5- also observed at wider area in a part of Aomori prefecture, Ibaraki prefecture and bay area of Tokyo and Chiba prefecture. This means that the manner of alarm issuance was not appropriate. This is because the predicted seismic intensity was considerably underestimated, and it is impossible with such predicted intensity not only to transmit necessary alarm to necessary area but also to provide reasonable action promptly after the earthquake. On the other hand, even in the area close to the epicenter, epicentral distance is more than 120km and P-S time is more than 15 seconds. Furthermore, since this earthquake motion increased gradually, common people had much time margin before hit by large earthquake motion, after notification of earthquake occurrence. Probably because this, even in case of this huge the earthquake, there was no specific report that EEW by JMA was useful.

Time lag between issuance of EEW by JMA and reception cannot be ignored. In case of the analogue broadcasting of NHK program, it takes about five seconds between issuance of EEW by JMA and appearance on the screen as shown in **Figure 1** or **Figure 6**, and it is said that the digital broadcasting requires more. For notification to a mobile phone, the time lag from the warning issued to the reception is said to be at least several seconds. Actually in Sendai, it was about 5 seconds for au and 10 seconds for NTT DoCoMo. Other mobile phone careers may take similar time.

It has been already known that it is impossible to take a lead against large earthquake motion in the area 30 – 50 km from the epicenter even if it is possible to receive EEW by JMA at the moment of the earthquake occurrence, except in the case epicenter is quite deep. Taking into the consideration that it takes 5 – 10 seconds as transfer time, it is impossible to receive EEW by JMA before the large earthquake motion at the area of around 50 – 100 km from the epicenter, far away from 30km, the expected damaged area of M7 class earthquake. The only huge earthquake as the 3.11 Earthquake will suffer damage in wide area outside of this area.

In other words, it is possible for EEW by JMA to take a lead against large motion only for the area more than 100km from the epicenter only in case of the huge earthquake with over 100 km of the damaged area, and it may have meanings to broadcast in nationwide by NHK program. However from this distance, it is possible for the on-site alarm to take a lead more than 12 seconds against the large motion. On the other hand, EEW by JMA makes no sense at all for M7 class earthquake because it is too late for the large motion within 50 km from the epicenter. So Ministry of Internal Affairs and Communications forcing for local broadcasting stations to install the receiver of EEW by JMA becomes enforcing spending the meaningless cost from the viewpoint of disaster prevention. Additionally, the predicted seismic intensity of EEW by JMA has no accuracy available to utilize for emergency response after the earthquake. In the fact of the response after the earthquake, it is important to install a seismometer not only issuing the early warning but also inform the seismic information in realtime and to organize a framework to broadcast the information immediately.

If the predicted intensity exceeds the preset level, EEW by JMA for advanced users is informed and announced using broadcasting equipment and so on. Although JMA recommends setting the predicted intensity 4 or more, some organizations set 3 as describing later. Because EEW by JMA for advanced users a private line, the time lags between issuance and reception must be short. However even in this case, it is impossible to take a lead against large earthquake motion in the damage area of M7 class earthquake. Because such EEW by JMA often priors to the earthquake motion without damage at an area far from the epicenter, a lot of people have been misunderstood to receive the information before the large motion with damage. In this state, it is afraid that the disaster prevention countermeasures must be neglected because of exaggerated expectations and unexpected damage suffers without any discretion.

(2) Emergency stop of Shinkansen train by EEW by JMA and the mail of EEW by JMA for mobile phone

Although this is no concern of the 3.11 Earthquake, here I would like to introduce a case that EEW by JMA might stop Tokaido Shinkansen train. This kind of EEW by JMA is one of the misinformation increasing significantly after the 3.11 Earthquake.

EEW by JMA for public was issued for around Kanagawa prefecture at 6:19:40.9. March 12, 45.7 seconds after the earthquake detection at 6:18:55.2. This earthquake was practically small unfelt earthquake. If it was false recognition for M4.1 earthquake of Nagano prefecture at around 6:19, this earthquake was almost unfelt in Kanagawa prefecture and it is clear misinformation.

Although Tokaido Shinkansen train was stopped at that time, it seems to be caused by EEW by JMA because it is hard to concern that the earthquake warning system for Shinkansen train worked with such an earthquake. A video file is opened on YouTube. This video recorded the situation of emergency stop by this earthquake after leaving Shin-Yokohama station at the seat 8A of ninth car, super express Nozomi #1 for Hakata station. It is impressive to understand the situation of EEW by JMA transmitting with mobile phones and Shinkansen system.

Nozomi #1 had started smoothly and after the seat number 8A of ninth car passing the platform of the Shin-Yokohama station, the train was shaken. Room lights were turned off by power interruption just after it, and a mobile phone begin to ring a characteristics buzzer to inform EEW by JMA at the same time. Then four seconds after, other mobile phones started ringing simultaneously. The first shaking is estimated as a vibration passing a crossing and the location of the train can be specified. On the video, the location starting ringing the EEW by JMA was around 400m after departing the Shinkansen train, and then the train stopped after 24.5 second.

A sound informing EEW by JMA is common for each mobile phone carrier and it is impossible to grasp the gap between the carriers. However, because the first sound came from only one mobile phone and secondary sound came from several mobile phones, the carrier of the secondary mobile phones may be NTT DoCoMo having the top shear in Japan at that time.

Considering the situation at the time of the 3.11 Earthquake occurrence mentioned above together, it seems to take 5-10 seconds to inform EEW by JMA for each mobile phone. In this case, because the first report of EEW by JMA for public and that for profession might issue simultaneously, the transmission time of EEW by JMA for the power stations of Shinkansen train can be also estimated about five seconds, same as the first informed time for the mobile phones.

Because JMA reports that EEW by JMA requires 5.4 seconds in average from earthquake detection to warning issuance and adding 5-10 seconds as the transmission time, the time to receive EEW by JMA via mobile phone network is estimated about 10-15 seconds. Assuming 4 km/s as the propagation velocity of the main motion, the detected earthquake motion reaches 40-60 km. In case that the depth is 10-20 km, even if a seismometer of JMA can detect the earthquake just at the epicenter, it is impossible to inform the warning within the circle of the epicentral distance 50-60 km in advance for the large motion. At the time of the 3.11 Earthquake, JR East Company operating Shinkansen train in Tohoku area did not stop Shinkansen trains with EEW by JMA and modified to stop in this time.

(3) Experience at the facility of EEW by JMA for advanced users and preventing people from heading home during the 3.11 Earthquake

A meeting on the investigation of the 2011 New Zealand Earthquake was held in the day afternoon of the 3.11 Earthquake at Institute of Industrial Science, the University of Tokyo. When a lecturer started speaking, announcement in the campus informed EEW by JMA as "Earthquake early warning. Earthquake motion will arrive in 40 seconds. Predicted seismic intensity is 3.". It seems corresponding to the ④ of **Figure 1** and the time was added several seconds as transmission time to the time 14:47:45. The announcement has no sense of urgency at all and the lecturer waited the start shaking with many audiences to terminate the earthquake because of EEW by JMA. The earthquake motion was clearly started when the announce said "the earthquake motion will arrive in 20 seconds.". One parson stood up under too long shaking with a feeling of anxiety and abnormal little by little against slowly growing earthquake motion, and it was triggered for a lot of people to stand up simultaneously and come out from the hall. The earthquake motion continued for several minutes. I was thrown into confusion because I felt serious matter had happened due to my assumption that the earthquake remain shaking for one minutes at the longest in Japan.

Eventually, the seismic intensity was around 5-, differently from the forecast that the predicted intensity is 3 or it is 40 seconds to start shaking. The forecast is too much to make the people believe that the earthquake is nothing much and I remain strong impression that the forecast is a unnecessary information to the earthquake warning. I realized for the first time the risk of Normalcy bias.

In addition, I experienced the preventing people from heading home. Because my mobile phone became no longer available since it was marginally enable just after the occurrence, I stood in line to call with public phone and made necessary contact. At that time, I noticed that the public phones often could not accept coins near convenience stores, and then I have carried telephone cards. I walked around focusing the railway station without operation to find a way back to my office or home. It was impressive to see the situation changing or collapsing of a normal life as the situation of convenience stores disappearing items, the situation of road jamming with cars, the situation of sidewalk filled by peoples walking or waiting a bus, the situation of loaded buses impossible to enter and so on. Especially, the situation was rapidly worsened after 17 o'clock the closing of many offices. Because it became dark and cold and I could not do anything, I came back to Institute of Industrial Science around 19 o’clock. I was really touched by tender-heartedness of the staffs of the office and laboratories. Here, I would like to express my deep gratitude.

In the Tokyo metropolitan area, however the duration time of this earthquake was long, the earthquake motion was about seismic intensity 5+ and predicted to cause only little or be very limited damage for railway facilities. Nevertheless, this earthquake caused great confusion even for this area. The confusion was spurred by the fact that JR, Japan Railways Company, abandoned the operation at an early stage and kept out the passenger from the most of the stations. It is expected to ensure an accurate response to the problems to have to be improved or to run into with validation of this situation including the behaviors of JR staffs before and after the earthquake what and why this situation was caused. Other transportations without JR had muddled through misery as the first situation with efforts to recovery the operation. I would appreciate it if transportations have made an effort to identify and solve the problems to reduce as much as possible the confusion, amid fears of the occurrence of huge earthquakes in the future. It is most important for restarting the operation to confirm safe conditions and it is necessary to grasp promptly the situation after the earthquake occurrence. And it is also important to assess correctly and promptly the present condition with learning of relative weaknesses on a regular basis and visit accessible weaknesses with changing the correspondence flexibly. In the future, it is expected to establish more proper countermeasures after earthquake disaster not only to response promptly the earthquake without damage, but also to consider the case suffering damage for facilities.

(4) Earthquake alarm system for Tohoku Shinkansen and its working condition

1) Summary

Earthquake alarm system for Tohoku Shinkansen has been replaced to the similar system developed for EEW by JMA, after the derailment of the Shinkansen train caused by the Mid Niigata prefecture Earthquake in 2004. The new system started operation from the time of the Noto Hanto-Oki Earthquake in 2007. Although this new early warning system could not work and issued no alarm at the time of the 3.11 Earthquake, there is almost nothing to explain this situation properly. Therefore many people misunderstood that the new system worked as expected and then Shinkansen trains were stopped safety. In fact, the early warning system renewed after the Mid Niigata prefecture Earthquake in 2004 could not fulfill a function and the timing of alarm issuance was significantly delayed, even if compared with the previous system installed at the time of starting operation of Tohoku Shinkansen nearly 30 years ago. Here, the problems of the earthquake disaster countermeasures with renewed early warning system will be clarified.

2) Earthquake alarm system for Tohoku Shinkansen line

Concurrently with the inauguration of Tohoku Shinkansen line, the alarm system against the large earthquake motion started operation to detect it quickly the earthquake under the seabed away from the Pacific Ocean coastline, with installing the alarm seismometers 80-100 km apart along the coast line (see **Figure 7**). This system aimed to keep safety of the running trains with emergency brake before the large earthquake motion arriving. Specifically, in case of detecting the earthquake motion over 40 Gal, it designed to issue alarm for the specified area considering occurrence of the largest earthquake in the detected area. Then Compact UrEDAS had installed from 1997 and started function of P wave alarm in September 1998. Compact UrEDAS was set to issue alarm after one second for the system along Shinkansen line or after three seconds for that along the coast line. After stating operation of Compact UrEDAS, the ordinary acceleration alarm seismometer was saved as a backup system and the trigger level was set as 40 Gal or120 Gal (in 5Hz PGA) for the system along Shinkansen line or for that along the coast line, respectively. At the time of the 2004 Niigataken Chuetsu Earthquake, Joetsu Shinkansen line operated Compact UrEDAS which had been developed based on the experience during the Great Hanshin Awaji Disaster Earthquake and had the world's fastest earthquake alarm. And

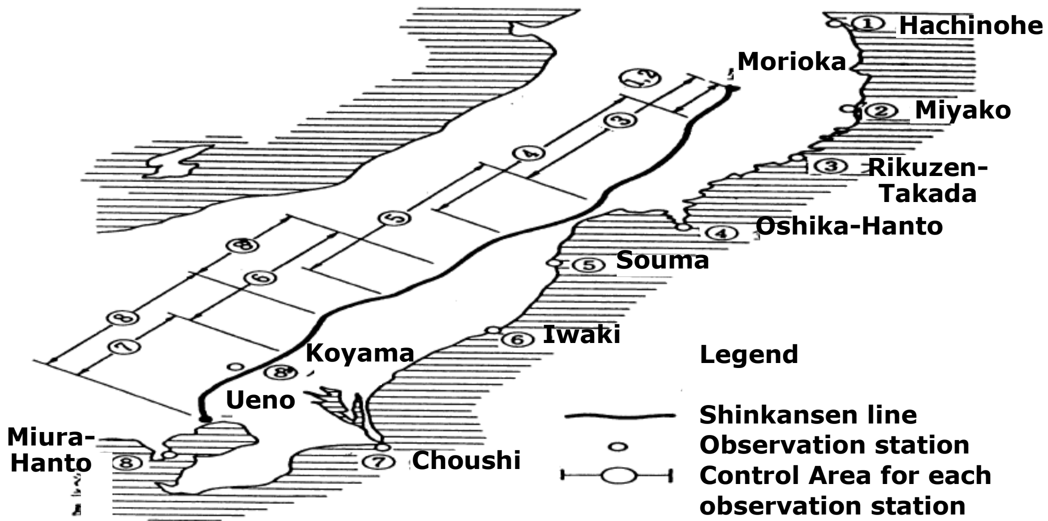


Figure 7 Front Detection/Alarm System for Tohoku Shinkansen: Eight Detection Sites and Control Area for earthquake (1985)

this system issued the alarm one second after the P wave detection as expected and interrupted the substation against the earthquake occurred just below the Joetsu Shinkansen line. As a result the power supply to the Shinkansen trains was stopped and the running train applied the emergency brake automatically. It was only about three seconds before the large motion. But totally 154 passengers and crew of the train were kept safely without any injuries due to the rapid brake actuation although the train was finally derailed. In other word, Compact UrEDAS succeeded to keep the safety of the train with issuing the alarm, as expected, just before the large motion characterized as the near-field earthquake (see the papers on the web, http://www.sdr.co.jp/paper.html). This Compact UrEDAS is still the fastest earthquake alarm system in the world, without the other products of System and Data Research.

3) Early warning system by JMA and its operation result for JR

In those days, completion of the early warning system by JMA was bruited and JR group decided totally adopt the system. Because JMA system required an alarm processing time for two seconds in the shortest or 5.4 seconds in average, the alarm was expected to be later more than one second for the system along Shinkansen line or 4-5 seconds in average for that along the coast line than Compact UrEDAS. Therefore, JR planed to shorten the earthquake detection time with changing the distance of each seismometer 10 km instead of 20 km in past. However that effect was only one second in maximum, the whole time had to be absolutely later than usual. Because the alarm processing time of the usual Compact UrEDAS for the coast line was set three seconds, if the system was replaced to the JMA system that requires two seconds in minimum or 5.4 seconds in average for alarm processing time, whole alarm issuing time would be one second in the shortest on the performance but be later 2.4 seconds in advance average. Although I have pointed out to the press about the misunderstanding of reports that the replacement aims to shorten the alarm processing time, no press covered the fact pointed out.

The early warning system with JMA method has started operation for Shinkansen line from around the time of the 2007 Noto Hanto-Oki earthquake, and then when the system works, SDR has reported the working condition of the system based on the news reports and so on (see the reports on the web, http://www.sdr.co.jp/paper.html). The validation shows that the timing of issuing alarm becomes later as expected.

And at least as of July 2011, I have fretted about issuing proper alarm for the appropriate area eliminating the excessive alarm as possible. However after replacement, a little before the 2007 Noto Hanto-Oki earthquake, the alarm range has always extend to entire Shinkansen line. I was surprised that the policy of issuing alarm has been changed to an easy way that may cause unnecessary confusion. This earthquake occurred under these circumstances. The working situation provided below is modified and organized with my own knowledge based on the press release or the information that has been published before now.

4) Status of Tohoku Shinkansen trains at the time of the 3.11 Earthquake

First, JR East Company says that 27 trains of Tohoku Shinkansen line were in commercial service and 8 trains of them were stopped at a station. These stopping trains may include trains decreasing the speed toward to a station or leaving a station. **Figure 8** shows the distribution of the stopping trains based on the time table and the location of the running trains with the speed estimated by news and JR reports. In addition to these commercial, a 10-car train on a test run inspection finished in Sendai rolling stock depot run toward to the Sendai station at low speed and the first car of this train stopped 900m away from Sendai station with derailing two axels of the front truck of the fourth car see picture 1). Railway accident investigation report of Japan Transport Safety Board says "The driver of the train, entering to the premises of Sendai Station at about 72 km/h, felt the strong shake and, at the same time, noticed that the stop signal of the cab signal device turned on," and it means the alarm arrived at the same time for receiving the large motion. The other trains including high-speed running trains around between Sendai to Fukushima stopped safely without derailment because of the emergency brake before the large earthquake motion.

5) Operating status of the early earthquake warning system for Tohoku Shinkansen

Figure 9 shows the distribution of the seismic observation stations of JMA and JR including the station which detected the earthquake first. This figure indicates the area centered on the Sendai and the observation value of the major stations. See **Figure 1** for the situation of the earthquake motion expression.

According to news reports, the operation status of the alarm system is organized as follows.

One of the coast line station, Kinkazan observation station installed in Oshika Peninsula detected strong acceleration over 120Gal (5HzPGA) and issued the earthquake alarm at 14:47:03. This alarm was transmitted to the substations such as Furukawa substation with transmission time of two seconds and stopped power supply for Shinkansen trains. The emergency break of Shinkansen trains was activated automatically one second after this power interruption detection.

According to the strong motion data of K-NET, the Shinkansen train Yamabiko #61 was high-speed running in a tunnel at 265km/h around 15km north of Sendai station and started activating the emergency break almost at the same time when the seismograph of K-NET Furukawa observatory MYG006 detected 40 Gal (5HzPGA).

Figure 8 Stopping Locations of 27 Operating Trains relating Tohoku Shinkansen at the time of the 311 Earthquake

Figure 9 Situation of around Sendai at the time of the 311 Earthquake: Arrows indicates the direction and the location of stopping trains, orange circles are K-NET and KiK-net sites, green circles are detection sites for Shinkansen, and blue one is JMA observation site.

Figure 1 shows the time 14:47:03 <37> when Kinkazan station issued the alarm with exceeding 120Gal (5HzPGA). It was a moment when the first peak of the earthquake arrived at Oshika peninsula and was quite late as a time to issue the alarm. It was only 3-4 seconds after issuing alarm at Kinkazan station to exceed 40 Gal (5HzPGA) at the K-NET station close to the Shinkansen line, K-NET Sendai station MYG013 and K-NET Furukawa station MYG006 at 14:47:06 <40> and 14:47:07 <41>, respectively. On the other hand, if K-NET Oshika station MYG011 instead of Kinkazan JR observatory issued alarm over 40 Gal as same as at the time of the start operation of Tohoku Shinkansen line, the alarm would be issued at 14:46:59 <33> and precede the current alarm by about four seconds. And assuming that Compact UrEDAS works as same as at the time of the Niigata-ken Chuetsu Earthquake, the P wave alarm may be issued at 14:46:48 <22>, advanced about 15 seconds for the current alarm. However even the late alarm fortunately caused no serious damage as derailment of the train in service at the time of the 3.11 Earthquake, the difference about 15 seconds has unimaginable meanings under the extreme situation such as at the time of the Niigata-ken Chuetsu Earthquake.

It is major problem that the earthquake early warning system with JMA method did not function at all. JMA method originally cannot gain the time margin for the damaged area caused by the M7 class earthquake concerned a frequent occurrence in near future. If EEW by JMA cannot function against over M8 class earthquake it has no value. It means that the current Shinkansen lines depend on only the initial 40 Gal alarm against the damage earthquake occurring neat the lines.

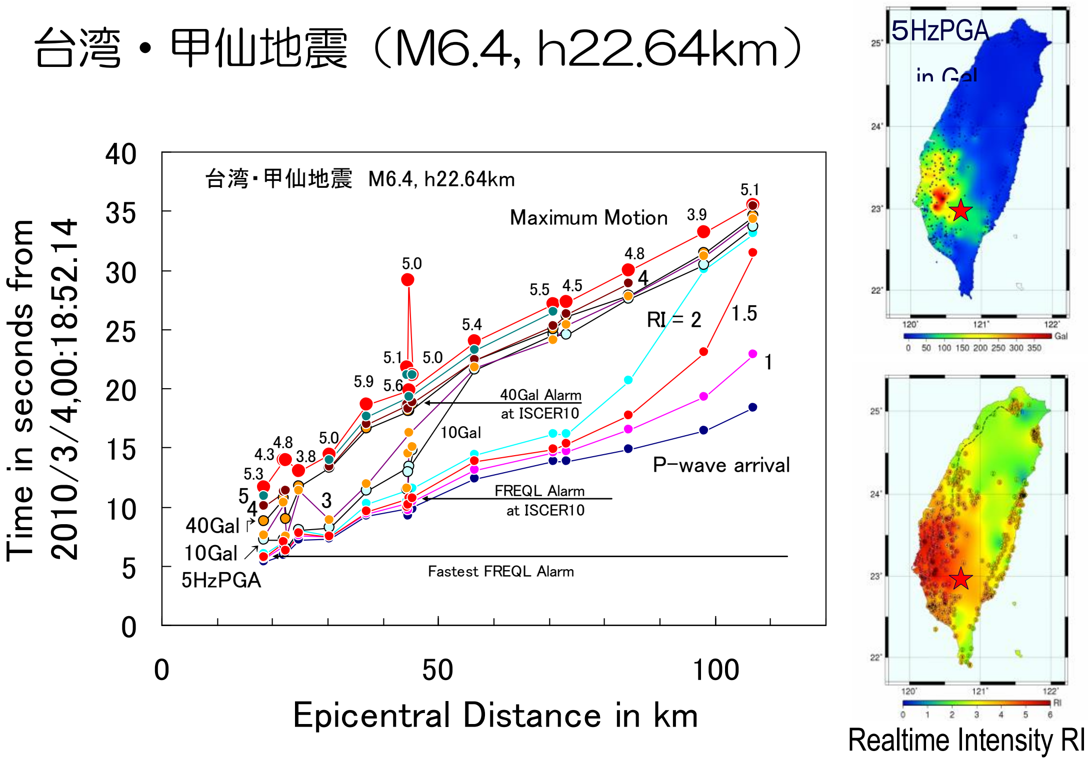


Figure 10 FREQL Simulations for the 2010 Kaohsiung Earthquake M6.4 on 2010/03/04 in Taiwan

6) 40Gal alarm system for Taiwan Shinkansen

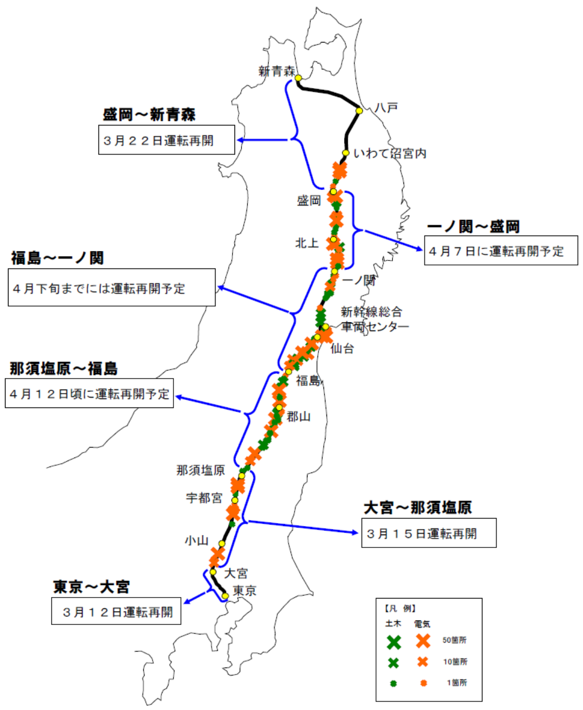
Although Taiwan Shinkansen operate modified 700 series Shinkansen train developed by JR Central company with a maximum speed of 300 km/h, it has equipped only 40 Gal triggering system as the earthquake alarm system. Under this situation, M6.4 earthquake occurred 50km away from the Shinkansen line on March 4, 2010 and this earthquake caused the derailment of one axle of the first car running in high-speed. Although a wayside alarm seismometer was issued a 40Gal alarm for this earthquake, it is estimated that there was very little time margin before the derailment. **Figure 10** shows the time from issuing the alarm to starting the large motion based on the simulation using the strong motion record provided Taiwan weather bureau. If FREQL was installed as a wayside on-site P wave alarm system, it could earn more seven seconds for time margin than the current system and avoid the derailment. Furthermore, if the front detection P-wave alarm system to capture the earthquake closer to the source region, it could earn additionally about eight seconds for time margin and it is expected to improve substantially the safety of the running trains. Additionally, the wave propagation situation using the realtime intensity at the time of this earthquake can be seen in the video file (http://www.sdr.co.jp/activities.html#311tohoku). It seems that the large intensity observed concentrating around the place of the derailment.

7) Earthquake damage for the Tohoku Shinkansen line

Structures of the Tohoku Shinkansen line locates more than 200km apart from the beginning of the destruction starting point of the 3.11 Earthquake. They are also over 100km from the boundary of the source region of about 500km × 200km lying along the Pacific Ocean coast. At an area away from the fault, it is estimated that the earthquake motion lost the sharpness and destructive power. The recorded strong motion shows clearly different behavior from that of the near source earthquake with large shape motion. Nevertheless, structures of Tohoku Shinkansen line suffered severe damage as shown in **Figure11** from the JR East report. The damage extent for the Shinkansen facilities are relative larger than that for the neighborhood facilities and it is necessary to take a proper counter measurements with clarifying the cause. Tilt and breakage of the wire pole hanging the overhead wire are big problems for the safety of the Shinkansen train running high-speed. **Figure 12** shows the tilt and breakage of the wire pole between Sendai and

東北新幹線の地上設備の主な被害と復旧状況（４月４日現在）

2011年4月5日
東日本旅客鉄道株式会社



■ 主な被害と復旧状況

主な被害	箇 所 数	進 捗 率(注)
電化柱の折損・傾斜・ひび割れ	約540箇所	約70%
架線の断線	約470箇所	約70%
高架橋柱等の損傷	約100箇所	100%
軌道の変位・損傷	約20箇所	100%
変電設備の故障	約10箇所	約85%
防音壁の落下・傾斜・剥離	約10箇所	100%
天井材等の破損・落下	5駅	約80%
橋桁のずれ	2箇所	100%
橋桁の支点部損傷	約30箇所	100%
トンネル内の軌道損傷	2箇所	100%
合　　計	約1200箇所	約75%

※高架橋、橋りょう、駅舎、トンネルの崩落はありません。

■ 区間毎の復旧状況

区　　間	箇 所 数	進 捗 率(注)
大宮～那須塩原	約120箇所	3/15運転再開
那須塩原～福島	約270箇所	約95%
福島～新幹線総合車両センター（仙台付近）	約390箇所	約55%
新幹線総合車両センター（仙台付近）～一ノ関	約150箇所	約25%
一ノ関～盛岡	約230箇所	約98%
盛岡～新青森	約40箇所	3/22運転再開
合　　計	約1200箇所	約75%

（注）運転再開をするための復旧工事の進捗率であります。運転再開後に更に補強工事等を行うことがあります。

Figure 11 Damage of Tohoku Shinkansen facilities against the 311 Earthquake

(source: website of JR East)

Figure 12 An example of Damage of wire poles for Shinkansen at the time of the 311Earthquake

Iwakiri as an example. The 1993 Hokkaido Nansei-Oki Earthquake on July caused the tilt or breakage of the wire poles of the Tsugaru Kaikyo line as same as this time. The viaducts of Tsugaru Kaikyo line was built with a specification for Shinkansen line and the wire poles were also set in the same way as the Tohoku Shinkansen structures. I am wondering the validity of the building way since the beginning because of its particularity. I proposed to improve the earthquake resistance with increasing the rigidity by connecting the top of the wire pole opposing inbound and outbound lines a wire pole with because exceptionally high predominant frequency of around 3 Hz was not affected in case of Tsugaru Kaikyo line (Nakamura et al., 1993). There were some wire poles with connection the top at damaged area and each of them did not affected. Severe tilt or breakage of the wire poles were occurred at 5km to 7.5km northeast from Sendai station, between Sendai station and Sendai rolling stock depot. Not only a

10-car train on a test run but also trains in commercial service as Yamabiko #61 and Hayate #27 passed this section just before the 3.11 Earthquake, and it could be catastrophic if the earthquake had occurred just a few minutes before. The tilt or breakage of the wire pole is a problem to be solved only by hardware response of the facility.

6. Tsunami Warning

(1) Tsunami hazards

I was shocked into silence from the extremely huge damage by tsunami caused by the 3.11 Earthquake. The image of tsunami hazard in Japan in my mind considering the earthquake disaster mitigation is quite outstripping from the reality. I think that the problem is not available to image properly the tsunami hazard, caused the hazard for the nuclear plant, beforehand, because it seemed to be possible to take some counter measures if many relations for disaster mitigation could image properly the possible hazard. I feel in need to establish effective countermeasures against the tsunami hazards with not only recognizing and investigating the hazards in detail but also constructing the proper image of the tsunami hazards, in order to reconstruction from the tsunami hazard in practice or to make provision to evacuate or survive from the tsunami hazard.

(2) My surprise and question

There was a number of surprising matters for me on the scene of tsunami attacking.

* Why did houses sweep away easily? And a video shows a few independent wooden houses still remaining among the houses swept. What is the reason? Are there hints to keep remaining?
* Although I remember there had been many ships escaping from the port in past, TV programs on NHK and other stations reported the situation after tsunami warning for the 3.11 Earthquake and there was a few ships to escape. What is the difference?
* At the time of the 1983 Nihon-kai-Chubu Earthquake, tsunami killed more than 100 people in the coast. It was said that such an accident never happens in the Pacific Ocean side because the people have a custom to evacuate to higher place when large earthquake occurred under the sea spontaneously. Did the custom diminish drastically today only 28 years after that?
* I heard after the 3.11 Earthquake that there is a legend that tsunami attacks twice people in Sanriku area during their life. Is this legend well-known among that area still now, especially for

young generations?

Matsushima is a famous s picturesque place with many small islands in the bay. It is said that there was relative small tsunami damage in this area because these islands diminished the energy of tsunami. And an inland sea Mangoku-ura area located east of Ishinomaki seemed to be suffered less tsunami damage.

These facts suggest that an idea diminishing the energy effectively could be one view. The idea is to withstand the tsunami even if the tsunami is higher than estimated and is not an idea to equip the huge rigid seawall keeping out the tsunami perfectly. The destruction of the seawall may cause unexpected hazard if the seawall only resist immoderately against the power of the tsunami as same as the earthquake. I think that it is required an idea that the facility must be destroyed during under control.

I am painfully aware of the idea from the earthquake damage situation of the 1995 Hyogoken-Nambu Earthquake, and I also have a strong desire as same from the tsunami hazard. How can we control against the tsunami hazard? I think that the mega-float may be a hint for the new idea against the tsunami hazard.

Was there no lesson except the evacuation to higher place from Meiji or Showa Sanriku tsunami hazard? Although the importance of the evacuation to higher places is obvious, the fact that the other countermeasure for the person who failed to escape is only the evacuation tower seems poor idea. It is better to keep various countermeasures for people under various situations. It may be required a simple plan corresponding to various situation as emergency without enough time or as for old people or handicapped people, for example.

(3) Problems of tsunami warning by JMA and the necessity of JMA reformation

The accuracy of estimated height or the manner of issuing the tsunami alarm by JMA at the time of this tsunami hazard became a problem and an expert committee to solve the problems was set up. However, is this problem setting appropriate? Tsunami warning by JMA was issued very quickly at 14:49 for the 3.11 Earthquake and it had more than 30 minutes before attacked by the large tsunami. Although the tsunami prediction as more than 3m or 6m depending on the location was underestimation in retrospect, it might make recognize to be attacked by abnormally large tsunami than usual. Therefore, the problem of this tsunami warning is not the accuracy or the manner to issue warning information. Problem of the tsunami warning by JMA lies in the system itself shifted as top-down warning without proper debate after the Great Hanshin-Awaji Earthquake. Of course the tsunami warning is not without a problem on its accuracy or the manner to issue. Because the expression of the warning was easy to bring into the normalcy bias, it can not deny the possibility to provide various excuses not to evacuate immediately, such as that the seawalls is higher than the height of the predicted tsunami or it is safe to go up to the roof in case of failure of evacuation. Additionally, it can be pointed as a problem on the news reports that the impression of repeated information of the first tsunami height was 50cm at the predicted time had stayed and it made a similar situation for the other low tsunami warning for the earthquake few days before.

However, a bigger problem is that the wisdom carried on the tradition of suffering the tsunami hazard in the area may be lost in these 20-30 years for any reason. During this time, the tsunami disaster has come to be treated as a natural disaster to be addressed by the nation absolutely. While the government says that the basic of the response against the natural hazards is self-help efforts, the central government constructs huge seawalls or makes dependency on the central government with unifying the tsunami warning for JMA. This kind of the measure by the central government makes the local government lost the tension for the natural hazard. This trend has gradually lost the basic stance of local society to handle the problem by itself, such as the extinction of a local tradition, wisdom or customs for various aspects against the tsunami hazard. This period overlaps with the period that the tsunami warning is no longer stated only to be issued by JMA with the amendments of the law.

Like Dr. Katada, Professor of Gunma University, there are examples to save not only schoolchildren but also many local residents with a practical teaching of the strategy against the tsunami. This is a typical case of the self-help efforts. There are academic research institutions, local government agencies, industries and livelihoods with the characteristics of each region. May local residents lose sight of the importance of devisal against various natural hazards with cooperation to develop the local industry for the region?

Of course there are facts to be addressed in national scale. The basic part of the accurate earthquake observation requires a nation scale construction. Even in such a case, it is possible to transfer the information to each region in realtime and local organizations can utilize this information for the local disaster prevention with processing using of the regional properties. It is expected that each regions create good countermeasure competing against each other.

I feel that local residents or organizations slowly lose their mettle to deal by themselves against the earthquake or the tsunami as a target of the alarm, if they relinquish the rights to issue alarm for the institution of authorization as JMA, in case of the society having a tendency to blindly submit to superiors as Japan. For this reason, it seems that the custom and knowledge to be handed down to future generations in the area becomes a dead letter gradually. It resulted in a marked technological stagnation of JMA like a king of the hill, and there is always a risk getting in a situation such as one lap behind, far from the cutting-edge technology. Now is the time to require JMA to provide the promptness and accuracy of the earthquake observation, and to change the framework that the provided information can be preceded mainly by the region itself and added the characteristics or necessity by each regional organization.

It is necessary for realization of this consideration to change drastically the Meteorological Service Act. Moreover, the organization as JMA or NIED, National Research Institute for Earth Science and Disaster, assuming a important role for the disaster prevention with engineering sense has a few staffs educated as engineer. This current situation must need to be corrected as soon as possible. It seems to become a time to discuss completely the future of the government for meteorological and terrestrial phenomena and reform the framework itself. This reformation must aim to establish the policies for the disaster prevention free from the past back ground or constraints. It is necessary to establish the framework for the next generation assigning the really needed manpower for the required department, without keeping or saving the old human resource allocation for the human-intensive observation.

Earthquake or tsunami hazard causes drastic damage for a particular area. Disaster relief and restoration support for such serious damaged area is exactly the work for the country. It is necessary to identify the location of the witheringly damaged area and to send the restoration support team with needed materials or staffs in national scale. Administrative agencies providing the information to enforce the support promptly and effectively are the national organizations as JMA, NIED, Public Works Research Institute, Building Research Institute or Port and Airport Research Institute. Of these, JMA seems to be a backward organization and needed significant revision. For example, JMA restricts to provide the precise earthquake parameters for the other organizations. In case of the earthquake occurring in the inland areas, even not large earthquake sometimes causes a catastrophic damage in the epicentral area. Although the precise earthquake parameters are the critical data to identify exactly the damaged area, the system to provide the precise earthquake parameters form JMA is not established and does not put any efforts into establish. There are many problems but currently the accuracy of the preliminary information from JMA is only about 10km.

7. Afterword

Here I mentioned about the interest matters from the viewpoint of the earthquake disaster prevention with a focus on the 3.11 Earthquake. It will be a real pleasure for me that this report touches up various discussions.

Note: This report is an English version of SDR Report No.5 issued on 2011/07/11 with correction and adding new data.