# Comparison of the P-wave Earthquake Alarm by Multi-Station and Single Station Detection System

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**SUMMARY:**
The earthquake motion of the 2011 off the Pacific coast of Tohoku Earthquake grew gradually larger and continued unusually long with high amplitude more than JMA intensity 4 in wide area. The single-station detection system FREQL succeeded to issue the P-wave alarm and estimated the earthquake parameters, although it took 15 seconds after detection. 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 3.67 seconds after the first P-wave detection at MYG011 Oshika station. The magnitude grew up, P-wave alarm can be issued around 6 seconds after P-wave detection. Although P-wave alarm with single-station observation could be issued 14 seconds after P-wave detection, multi-station observation method can be expected to shorten the alarm time for 8 seconds.

*Keywords: Single-Station Detection System, Multi-Station Observation System, FREQL, P-wave Alarm, Earthquake Parameter Estimation*

## 1. INTRODUCTION

The earthquake motion of the 2011 off the Pacific coast of Tohoku Earthquake (hereafter "the 3.11 earthquake") grew gradually larger and continued unusually long with high amplitude more than JMA intensity *Ijma* 4 (corresponding to *MMI* 7) in wide area. Although final seismic intensity *Ijma* reached 6+ (corresponding to *MMI* 10-11), there was relative little damage caused by the earthquake motion. In such situation, some early warning system had worked to issue alarm before large motion, but many of them could not perform up to expectation. Especially a single-station-detection early warning system developed by JMA, Japan Meteorological Agency, could not recognize the 3.11 earthquake danger and could not issue the warning. And also the alarm system for Shinkansen, bullet train, is the alarm system based on the JMA system replace after the 2004 Niigata-ken Chuetsu earthquake, and it issued the alarm lately. Fortunately, no high speed train run into a damaged area, but the train was under a risky condition. At the time of the 2004 Niigata-ken Chuetsu earthquake, Compact UrEDAS, the other early warning system for JMA system, worked as expected and kept safety for the passengers and crews, totally 154 persons, however the system for Shinkansen train had been replaced. A single-detection early warning system FREQL is a successor of UrEDAS and Compact UrEDAS. 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 (Nakamura, 2007). 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 without magnitude. But it needed 15 seconds to issue P wave alarm.
So this paper compares the early P wave alarm between ordinal FREQL single estimation and the

other multi-detection method using FREQL technique, and then considers a possibility of earlier earthquake warning.

## 2. ESTIMATION OF EARTHQUAKE PARAMETERS USING MULTI STATION INFORMATION

### 2.1. Estimation of Origin Time and Location of a Source

Origin time and location of a source (Latitude, Longitude and Depth) are estimated from times of P wave detection of more than five stations using least squares method, assuming a P wave propagation velocity 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 send 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 are in predefined range (5 km in this paper), the result will be 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 2004 Niigata-ken Chuetsu earthquake and 2010 Taiwan Kaohsiung earthquake, the source locations are determined in 1.04 second and 1.69 seconds after P wave detection, respectively. In contrast, the JMA method with multi observation required 5.4 seconds in average and another 5.4 seconds for issuing the first information for the 3.11 earthquake.

### 2.2. Estimation of Magnitude

Magnitude is estimated by a formula below (Takayama et al, 1981), based on the amplitude of P wave and its frequency by Gutenberg-Richter.

$$M=1.59(\log Vp + \log R)+1.53 \tag{2.1}$$

Here, *Vp* is P wave amplitude of vertical motion in mkine (= 0.001 cm/sec) and *R* is epicentral distance in km. Although equation 2.1 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 2.1 based on the estimate formula for seismic intensity (Saita et al, 2005), and equation 2.1 is modified as follows.

$$M=1.59(\log Vp+\log R)+1.53-1.59\log A \tag{2.2}$$

**Table 2.1** 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 Fig.(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 |

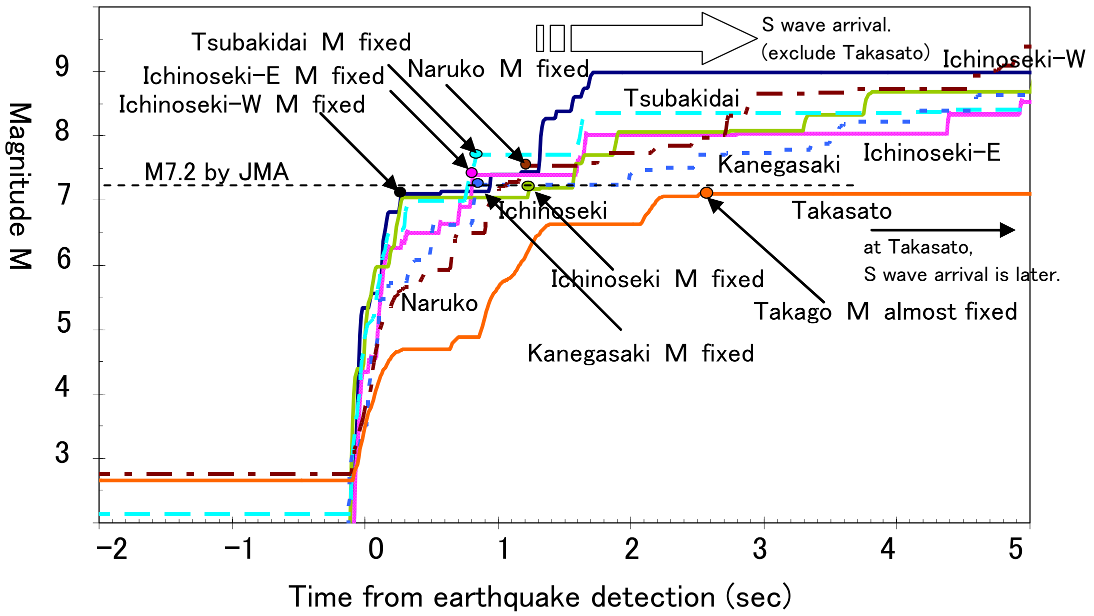


**Figure 2.1** The growth of magnitude of the 2008 Iwate and Miyagi Earthquake

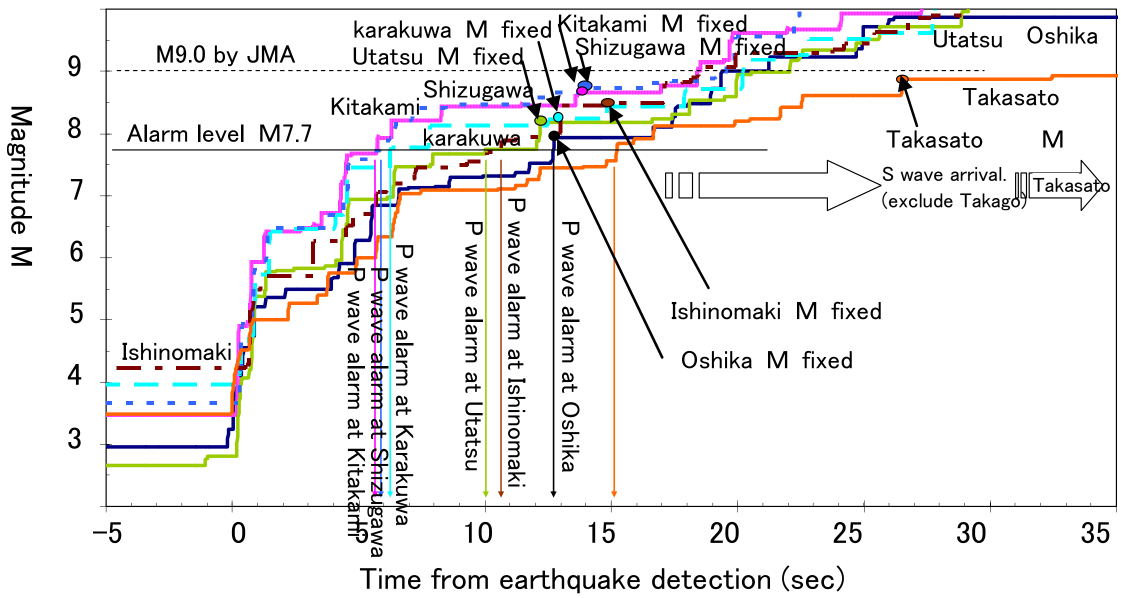


**Figure 2.2** The growth of magnitude of the 20112011 off the Pacific coast of Tohoku Earthquake

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 2.2 can be adopted for a time window *R/4Cr* after P-wave detection, 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 is less than +/- 0.2 during the applying time.

After fixing the epicentre, magnitude is estimated from equation 2.2 and then the P wave alarm is 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. This paper concerns the change history of the estimated magnitude for the 3.11 earthquake and the 2008 Iwate and Miyagi earthquake.

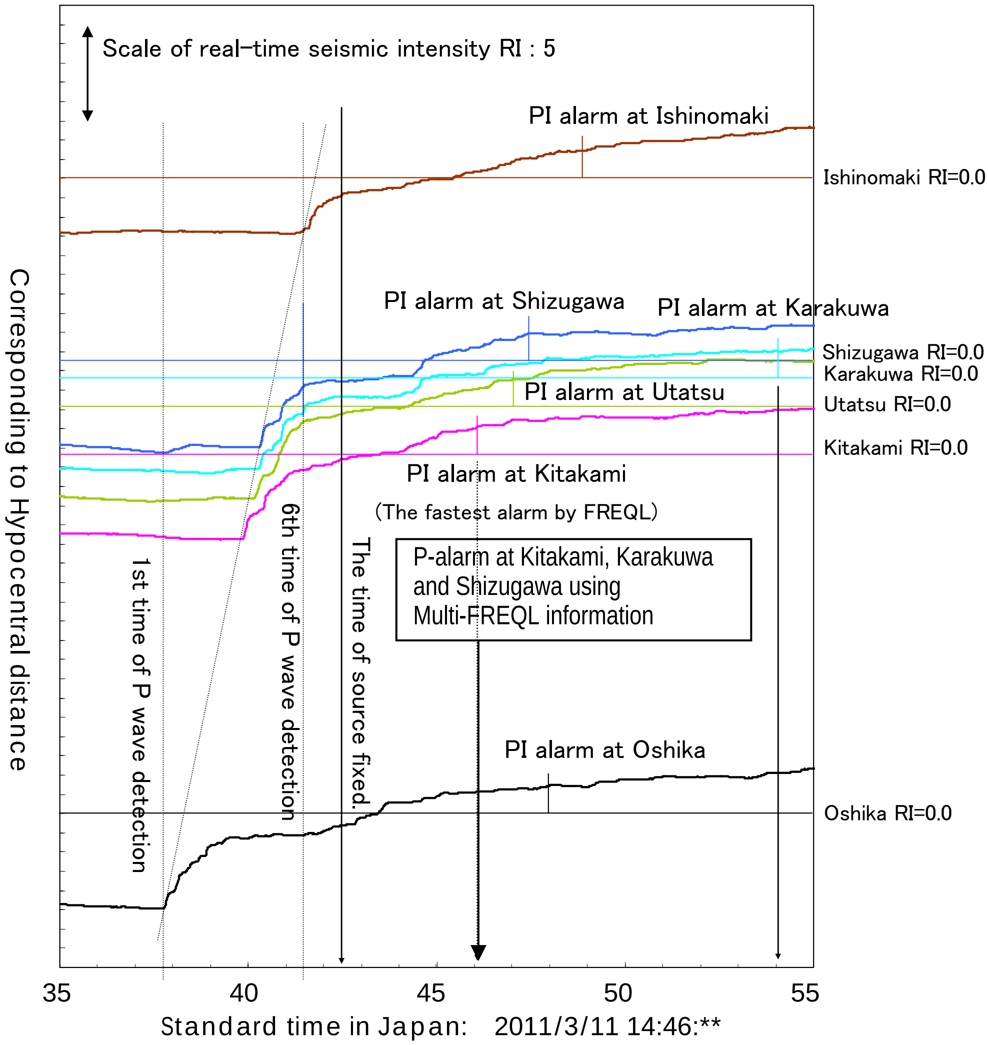


**Figure 2.3** P wave alarm time of first 6 sites of the 20112011 off the Pacific coast of Tohoku Earthquake

## 3. RESULT AND DISCUSSION

In case of the 2008 Iwate and Miyagi earthquake, 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. Also, the epicenter by JMA was latitude 39.028˚N, longitude 140.880˚E and depth of 8 km.
In case of the 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 location 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 at this station 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 2.1 and 2.2 show the progress of the magnitude based on equation 2.2 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 $M$-$\Delta$ 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 simple 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 2.3, the alarm seemed to be issued at 14:46:54, this multi-detection method can be expected to gain time 8 seconds. Figure 2.3 shows the alarm time of the multi-detection method on the time-line of real time intensity *RI* (Nakamura, 2003) with *RI* = 1.5 as P wave alarm level.

## 4. CONCLUSIONS

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. Because the exact earthquake parameters are fundamentals for proper countermeasure soon after the event, we would like to construct a system to grasp the source information in a certain level of accuracy for disaster prevention under isolation of the information.

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