P 03

Improvement of Earthquake Early Warning
–Intensity Estimation from Initial Part of P-wave–

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1.Intoroduction

Earthquake early warning (EEW) is to enable advanced countermeasures to strong motion disaster by providing the expected seismic intensity and arrival time of the strong motions, as well as the estimated hypocenter parameters, before the S wave arrival. In the EEW, the hypocenter parameters (location, origin time and magnitude) are at first estimated using the first two seconds' P waves of acceleration by a single station method, although they are not accurate enough but very quickly estimated. At the next steps the location and origin time are estimated more accurately using plural stations' data and the magnitude is calculated using the P waves' amplitude of displacement doubly-integrated from acceleration records. They are more accurate but take more time. The seismic intensity are estimated using several empirical equations such as attenuation-relationship of PGV, VS30 for site-amplification, PGV-seismic intensity relation and so on. The provision of the information about the seismic intensity in the EEW takes about 5 seconds on the average.

On the other hands, the method of real-time seismic intensity by Kunugi et.al. (2008) can estimate the seismic intensity more accurately and earlier than the EEW (Fig.1), because the seismic intensity is directly calculated using the strong motion data. During 2008 Iwate-Miyagi Nairiku earthquake, the EEW was not able to provide with the seismic intensity before the S wave arrival at sites of near the hypocenter. However, the real-time intensity estimation method might provide the real-time information about seismic intensity in time even near the source area.

Hoshiba (2009) studied the appearance times of the maximum amplitudes such as acceleration, velocity, displacement, and real-time seismic intensity. He found the maximum amplitudes of acceleration in vertical component appear earliest among them (Fig2). The acceleration reaches the maximum value just behind P wave. It means the effectiveness of the onsite warning using the acceleration records of vertical component. However, the onsite warning is available only for sites with seismographs.

In this study, we propose a new method to estimate the seismic intensity using the first motion of P waves of acceleration of P wave as quickly as possible and provide the information to sites without seismographs.

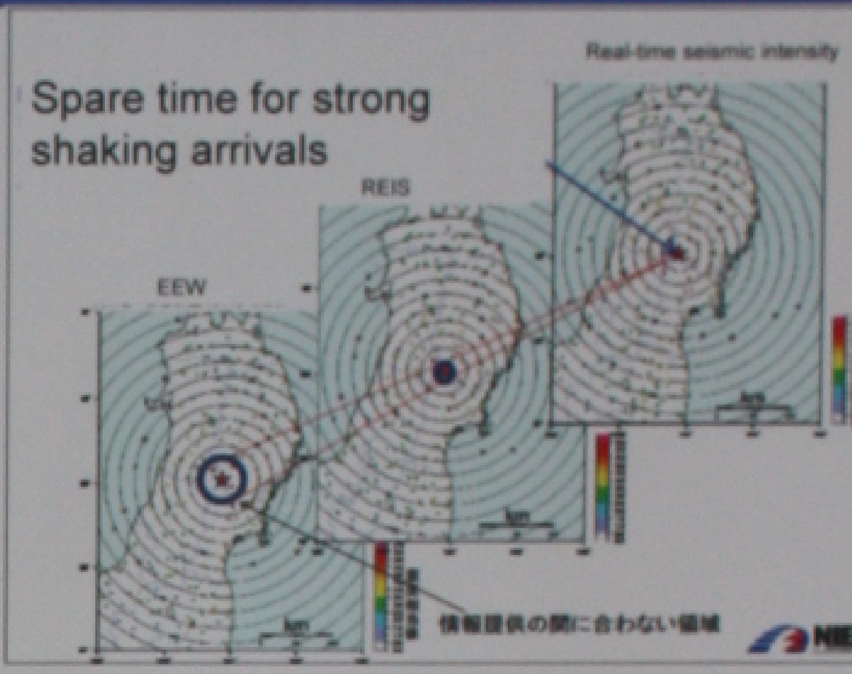

Fig1 Spare time for strong shaking arrivals (Nakamura,2008)

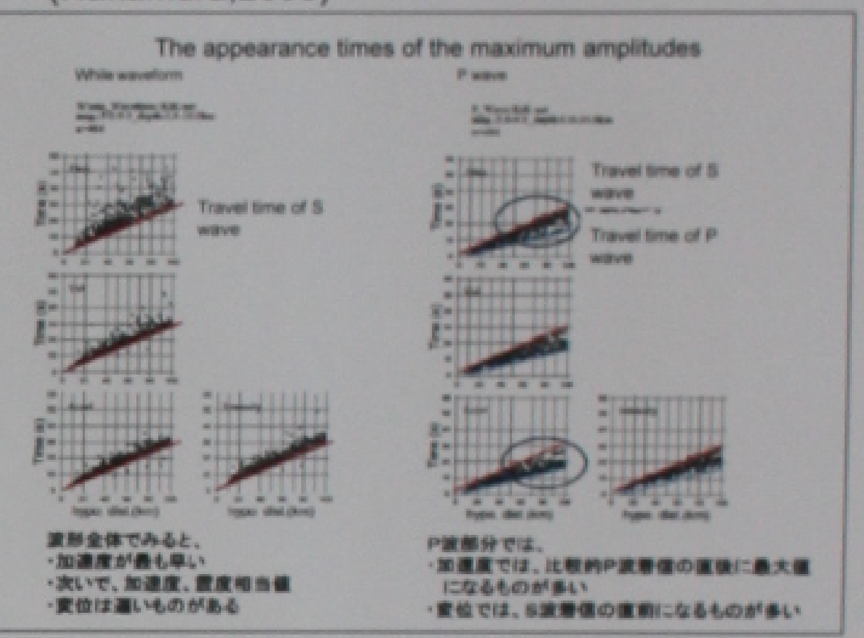

Fig2 Appearance time of the maximum values in whole waveforms and P waves' waveforms. (Hoshiba,2009)

2. Methodology

In this paper, we propose a conception of P-wave's Magnitude (Mp). Mp is defined as a function of the maximum acceleration Pmax in initial parts of the P-waves and the source distance r.

$$\log P_{\max} = a \cdot M_P - \log r - b \cdot r + c \qquad (1)$$

P_{max} : Max acceleraion of P wave (UD) (cm/s²)
M_P : P wave magnitude
r : distance of hypocenter (km)
a, b, c : regression coefficient

Here, the constant b is a coefficient of internal attenuation and c is the site effect. On the other hand, seismic intensity I is estimated by using the following equation.

$$I = m \log P_{\max} + n \qquad (2)$$

I : seismic intensity
m,n : regression coefficient

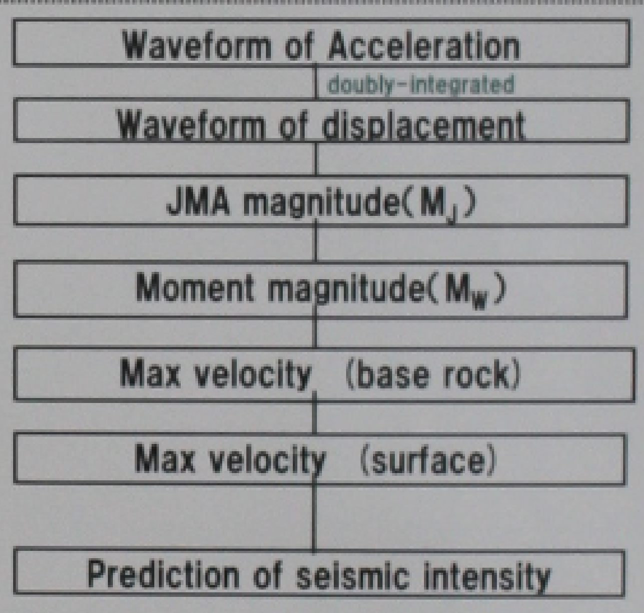

Fig3 Procedure of prediction of the seismic intensity by EEW

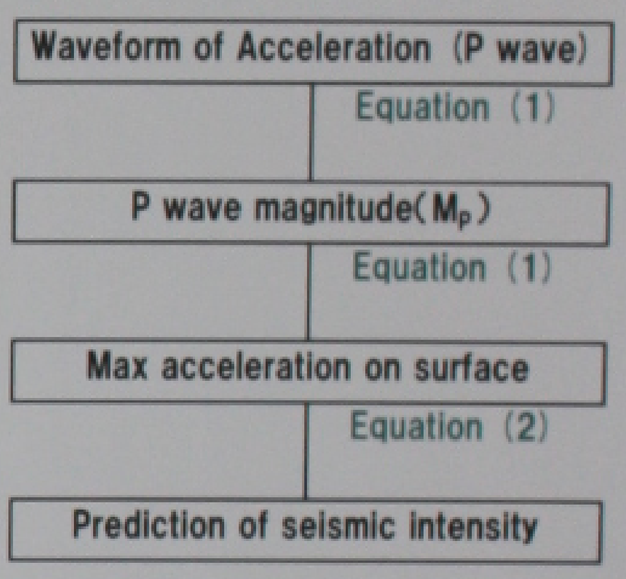

Fig4 Procedure of prediction of the seismic intensity by this study.

3. Data and Regression Analysis

In this study, we used data from the 2004 Chuetsu earthquake and the 2008 Iwate Miyagi Nairiku earthquake. We selected data for regression analysis using the following criteria: (1) Mw is larger than 4.5; (2) data were recorded on the ground surface; (3) data of vertical components of P waves' motions were used for analysis. The number of data used in the regression analysis is 1570. The numbers of earthquake and station are 55 and 124, respectively. (Fig 5)

In our base model, we used only two parameters (P wave magnitude (Mp) and source distance). Average ground motion characteristics were determined by the two-step stratified regression analysis method of Fukushima and Tanaka(1990).

The PGAs of P-waves as well as those of S-waves from both earthquakes seem to be saturated within the distance of about 20 km from sites to the rupture area. Such phenomena are consistent with the attenuation relations of maximum acceleration of S-waves in the NGA reports in US (e.g. Abrahamson and Silver, 2008). Therefore, we excluded the observed records at near-source stations less than 20 km when making the regression analysis.

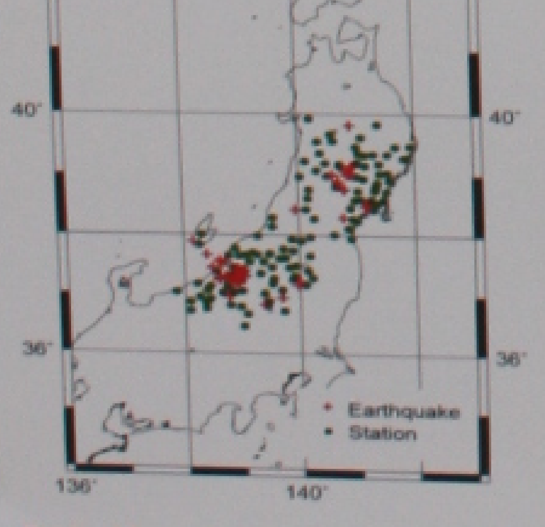

Fig5 Map of epicenters of earthquakes used in this analysis.

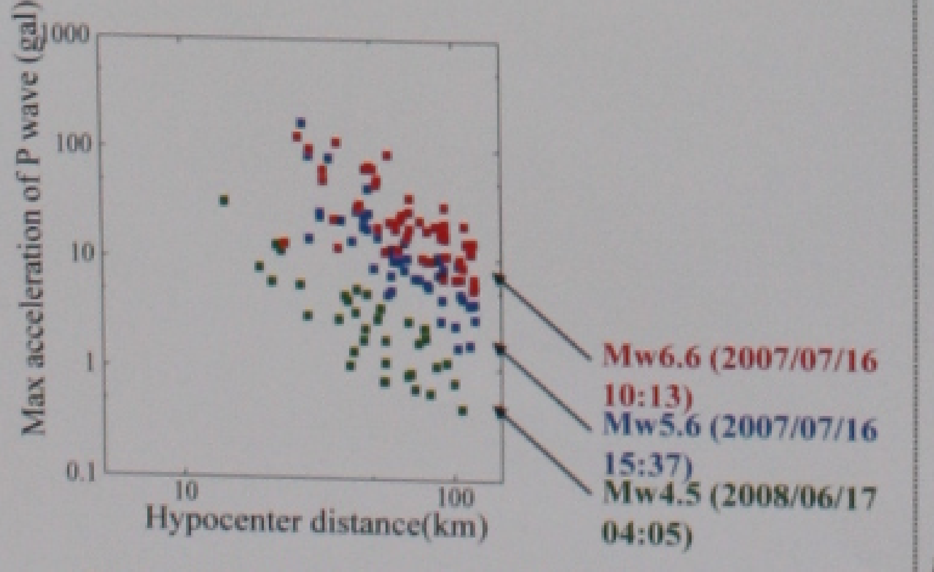

Fig6 Attenuation-distance relationships of PGA of P waves

Acknowledgment
We acknowkedge the National Research Institute for Earth Science and Disaster Prevention, Japan(NIED) for providing the KiK-net and K-net waveform data.

4. Result

The Mp derived tentatively from the data is given as follows.

$$M_P = \frac{1}{0.600}(\log P_{\max} + \log r + 0.0055 \cdot r + 0.338) \qquad (3)$$

Fig.7 shows the relationship between the P waves' maximum-accelerations and the observed seismic intensities. It seems to have a clear linear relation, which is useful to estimate the seismic intensity. The relationship of Pmax and the seismic intensity I was obtained as follows.

$$I = 2.18 \log P_{\max} + 0.77 \qquad (4)$$

Fig. 8 shows the comparison of observed and the estimated seismic intensity by using the P wave magnitude Mp. The agreement between them is well. We conclude that the method presented in this paper is very successful and credible to improve the technique of EEW.

However, this method can not apply to estimate the seismic intensity during great earthquakes. The P waves' motions for great earthquakes seem to be saturated within the distance of about 20 km from sites to the rupture area. Then, we need propose another methodology for great earthquakes as further developments of this method. (Fig9) This result is presented by Irikura et.al (2009).

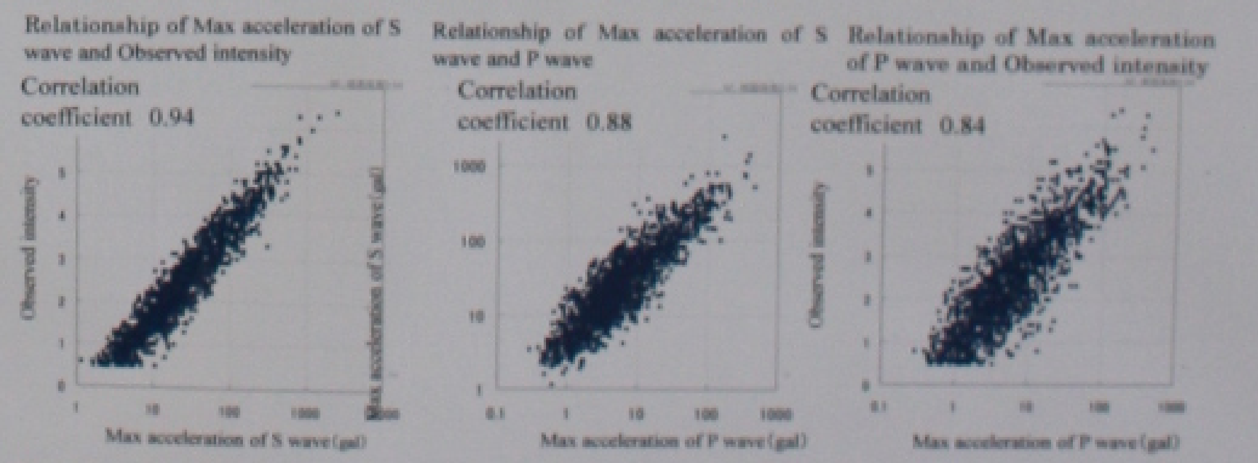

Fig7 Relationships of the maximum acceleration of S waves versus observed intensity, the maximum acceleration of P waves versus the maximum acceleration of S waves, and the maximum acceleration of P waves versus observed intensity.

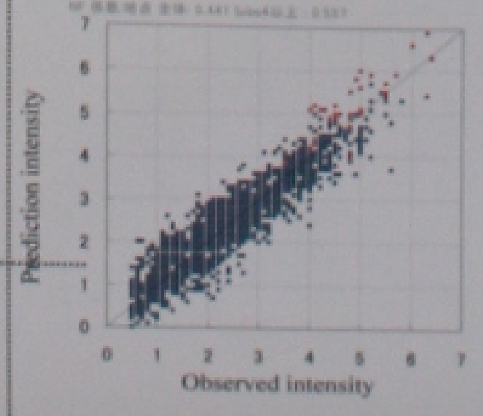

Fig8 Relationship of predicted intensity and observed intensity. The predicted intensity is calculated using Mp defined in this study. Red solid circles are intensity for two mainshocks. Black circles are intensity for aftershocks.

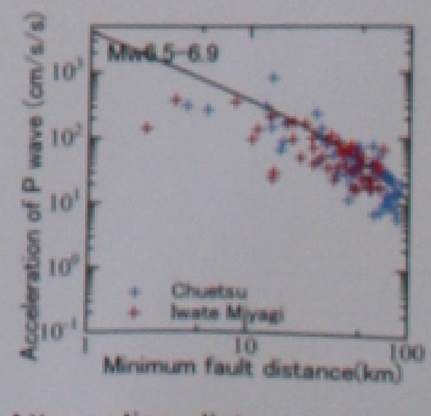

Fig9 Attenuation-distance relationships of PGA of P waves.