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TSUNAMI-GENERATION WARNING SYSTEM USING EARTHQUAKE EARLY WARNING

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ABSTRACT : We propose early-warning system for reducing tsunami refuge using the data of the magnitude and the depth informed by the Earthquake Early Warning (EEW) by Japan Metrological Agency (JMA). The EEW provides advance announcement of the estimated seismic intensity and expectSed arrival time at the just points and regions before arriving strong motion. The hypocenter and magnitude of the earthquake are estimated by using wave form data observed by seismographs near the epicenter. Inukai et al. (2009) proposed the method to determine whether generate tsunami using scaling relation between magnitude and depth of hypocenter. The probability of tsunami generating is calculated by using the EEW information (magnitude and depth) and the Inukai's scaling relations. In this method, the information of probability of tsunami generating is issued in a few seconds after EEW. We incorporated this method into our system and verified validity of our system.

Keywords: Earthquake Early Warning, Tsunami Warning,

1. INTRODUCTION

On 11 March 2011, an Mw 9.0 earthquake occurred off the Pacific coast of Tohoku (after call the Tohoku earthquake), Japan. This was one of the largest earthquakes in terms of magnitude and consequences in the history of Japan. The huge tsunami generated by this earthquake struck the east coast along Tohoku, causing the deaths or disappearances of 19,000 people (Fire and Disaster Management Agency) [1]. It is mentioned as one of the cause of tsunami damage that the tsunami warning by which height was upgraded was not transmit by power failure, and people did not escape because they did not believe that tsunami struck at their place. In the present, Japan Meteorological Agency (JMA) issues the tsunami warnings/advisories based on hypocentral parameters such as location, depth and magnitude, and the tsunami-simulation database system which stores more than one hundred thousand cases of previously-conducted tsunami-propagation simulation results. This system enables tsunami warnings/advisories to be issued within about three minutes after events. In the case of the Tohoku earthquake, the tsunami warning of initial warning was issued about three minutes after the occurrence of the earthquake. The prediction of JMA Magnitude is 7.9. However, moment magnitude finally decided was 9.0, as a result, the tsunami warning was underestimated.

If we can know that about tsunami information (ex, information on the possibility of tsunami generating), we can take the action which protects ourselves. Particular, it is the necessity of teaching information early more to those who require time for refuge, such as elderly people and a physically handicapped person, and people who live near the sea.

In Japan, system which provides predicted S-wave arrival time and seismic intensity from occurred an earthquake was built by JMA. This system is called Earthquake Early Warning (EEW), started nationwide in Japan and became fully operational in October 2007. The seismic intensity and arrival time of the S waves was calculated by EEW from the magnitude of an earthquake and hypocentral distance between hypocenter and target site and site effect at target site. The hypocenter and magnitude of an earthquake are determined as quickly as possible using only early parts of the P waves at a few stations close to the hypocenter. If we can use this source information by EEW, we may be able to calculate probability of tsunami generating.

The Disaster Prevention Research Center (DPREC), Aichi Institute of Technology (AIT), Japan, has organized a consortium which composed of enterprises in this area in order to mitigate seismic disaster. One of main research topics of DPREC is to re-distributing the EEW system, which is developed by JMA.

We built the system in which the information on the possibility of tsunami generating is show from the magnitude and depth the occurrence of the earthquake by EEW.

2. EARTHQUAKE EARLY WARNING (EEW) SYSTEM BY AIT

The JMA has started to serve EEW which includes an origin time, a hypocenter and a magnitude estimated by using P-wave information observed at nationwide seismometer network installed by JMA and National Research Institute for Earth science and Disaster Prevention. JMA informs EEW to users including second supplier within five seconds (average) after detecting P-waves. DPREC receives EEW and informs offices and factories in Mikawa Area, Japan, of EEW from several and dozens of seconds before arriving strong motions. Fig.1 shows the conception diagram of EEW system. Fig.2 shows the distribution system. JMA informs EEW to the Japan Meteorological Business Support Center (JMBSC) by dedicated lines. DPREC receives EEW from JMBSC by IP/VPN and distributes it EEW to about fifty sites (offices and fabrics) by internet dedicated lines (ADSL, ISDN or optical fiber line) within one second.

The DPREC also has installed a seismometer network in the area aiming at getting observed seismic intensity and compare it with estimated one. Besides, the PC monitor installed at a central office can display information, such as epicenter, magnitude, seismic intensity and arriving time which is estimated by EEW. It also can animate P and S-wave propagating front and display it. The DPREC get observed seismic intensities from observing sites through the web system and send back the map of seismic intensities to monitor at other sites at once. The re-distribute EEW system developed by DPREC, now, has been installed at about thirty factories and works for seismic disaster prevention successfully.

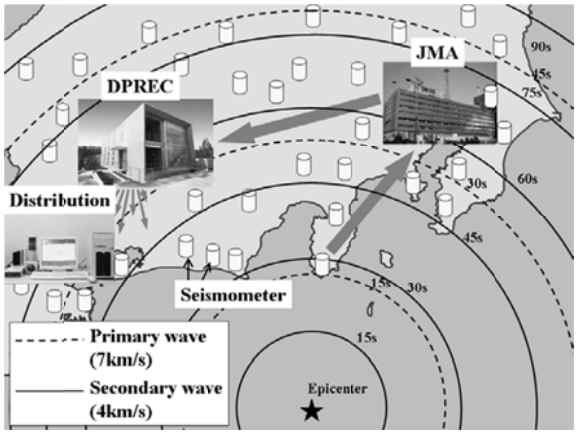

Fig. 1 Conception diagram of EEW system

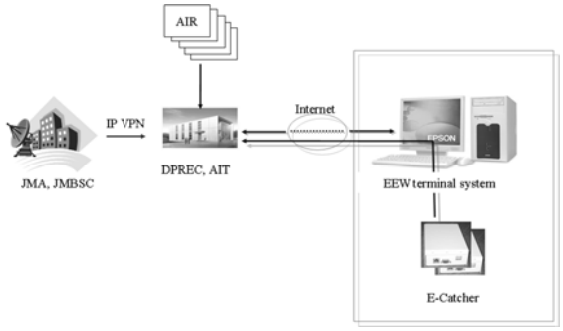

Fig. 2 EEW system of AIT system

3. RELATIONSHIP LAW MAGNITUDE AND DEPTH OF HYPOCENTER

Tsunami is generated in case of a large earthquake at sea area because the cause is crustal deformation in sea area. The depth of hypocenter is also related to generation of tsunami. Inukai et al. proposed the method to determine whether generate tsunami using scaling relation between magnitude and depth of hypocenter [2]. This relationship data were analyzed by 146 earthquakes in which tsunami occurred. The equation of this relationship is showed by

$$M=0.005\ D + 6.21 \quad ,$$

Whrer M is the magnitude, and D is the depth of hypocenter.

Fig. 3 shows graph about this relationship. This relationship means that tsunami is generated if earthquake occur beyond about magnitude 6.3 in case of a shallow earthquake.

Fig. 3 was added line of relationship magnitude and depth of hypocenter by Iida [3]. Inukai's scaling law is more accurate than Iida.

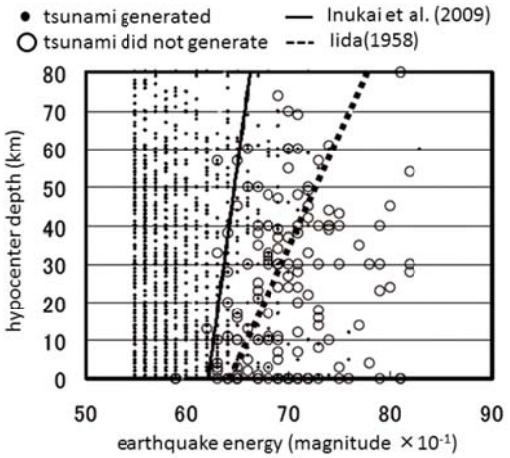

Fig. 3 relationship magnitude and depth of hypocenter. Dot and circle are indicated not generated earthquake and generated earthquake, respectively. Thin line and dot line are showed Inukai law and Iida law, respectively.

3.1 Algorithm of calculation method of probability of tsunami generating

The EEW was provided source information (ex. origin time, location and depth of hypocenter). In addition, we can also obtain other information (ex. region of sea area or continental area and accuracy of prevention). We constructed method to provide probability of tsunami generating using this information by EEW.

Fig. 4 shows flowcharts of the algorithm of calculation method of probability of tsunami generating.

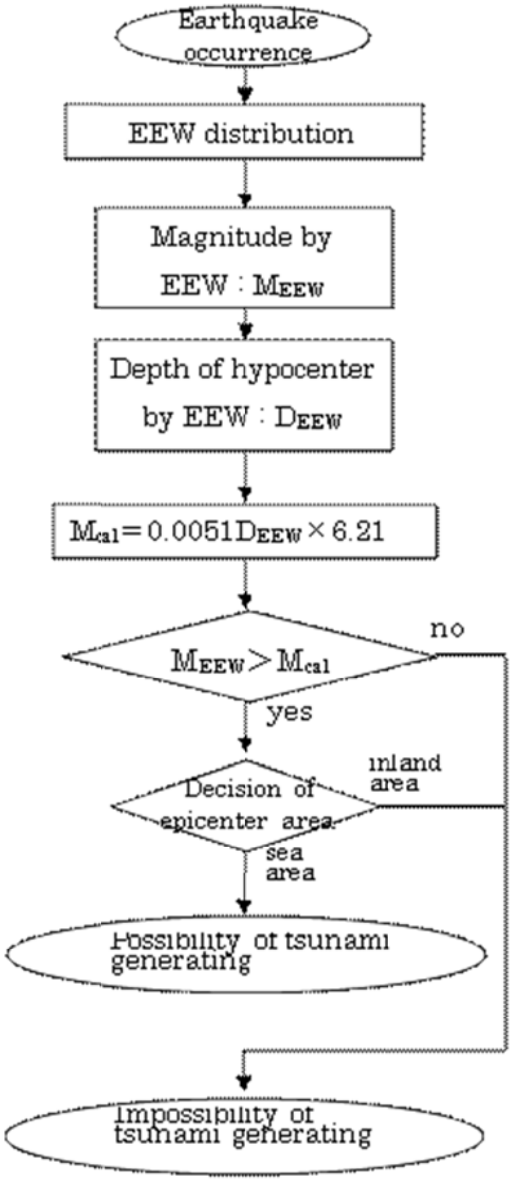

Fig. 4 flowchart of procedure of calculate of probability of tsunami generating.

3.2 Installed the EEW system by AIT

We installed this algorithm into the EEW system by AIT. The information of probability of tsunami generating is shown in the PC monitor screen. Fig. 5 shows the monitor screen which can display the information as follows.

(1) An epicenter and dynamic state of propagating P-wave (yellow) and S-wave (red) front from an epicenter to predicting site (upper central). Estimated seismic intensity and a margin time before arriving strong motions at a factory (center).

(2) The seismic intensity and arrival time by EEW at target site. The biggest sign is main site and the small sing are other sites. The color of sign shows seismic intensity. Red is lower 5, yellow is 3 and 4, blue is 1 and 2, and gray is zero.

(3) The information of EEW (ex. origin time, EEW receive time, hypocenter, information number, magnitude and depth of hypocenter) (bottom left)

(4) On-time data of seismic intensity observing by AIR type seismometers installed at five sites (bottom center).

(5) Communication situation between receive and transmission server at DPREC and analyzed server at target site (bottom left).

(6) the sign of probability of tsunami generating.

3.3 Verification of this system by the 2011 Tohoku earthquake

We verified this system by the 2011 Tohoku earthquake.

The EEW is provided some information from one event if source information is changed. In case of the 2011 Tohoku earthquake, the EEW information was provided fifteen. Table 1 shows this information list. We calculated provability of tsunami generation by this system. As result, this information was provided third information of EEW, namely, after two seconds from first information of EEW.

On the other hands, JMA's tsunami warnings/ advisories was provided within about three minutes after the earthquake. The initial warning issued at 14:49 on March 11 was based on the promptly-estimated JMA Magnitude of 7.9, and "Major Tsunami" warnings were issued to the areas of Iwate prefecture, Miyagi prefecture and Fukushima prefecture. At the same time, "Tsunami" warnings and Tsunami advisories were issued for many other areas (Ozaki) [4].

This system cannot be provided the sea height, however, can be showed probability of tsunami generation so quickly.

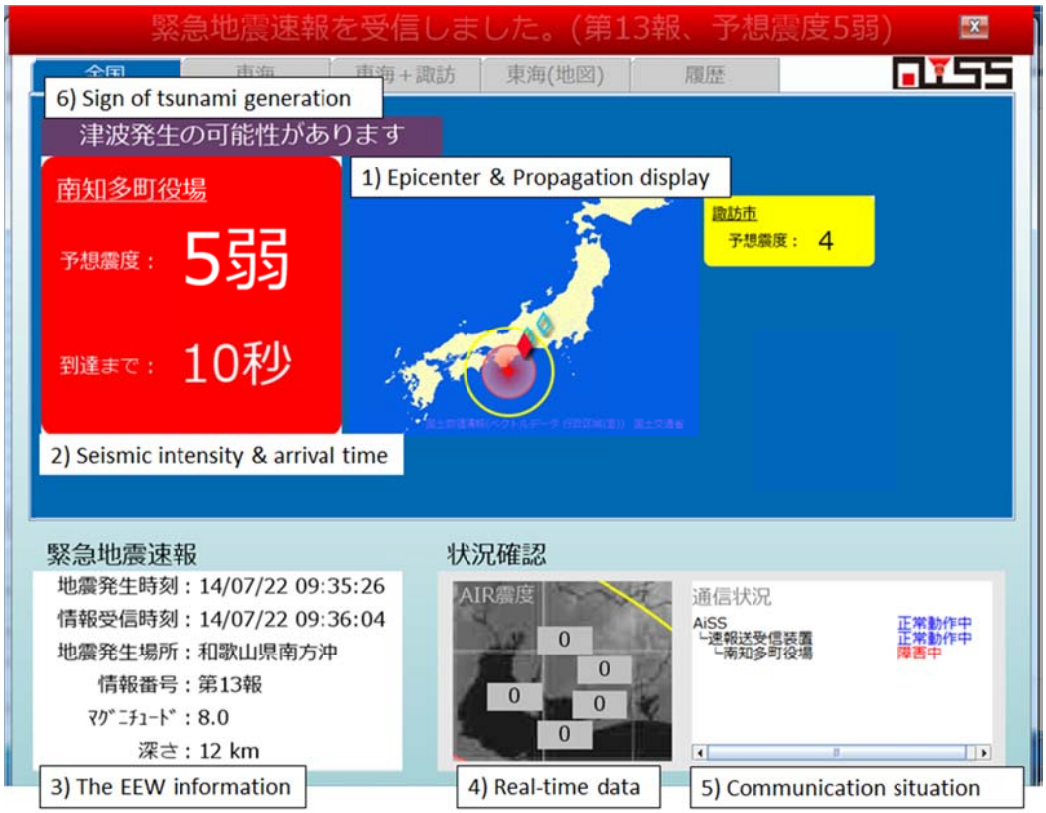

Fig. 5 the monitor screen which can display the information.

Table 1 The EEW information of the 2011 Tohoku earthquake.

Information number	Delay timefrom no.1 information	Origin time	latitude of hypocenter	longitude of hypocenter	magnitude	depth of hypocenter	maximum seisminc intencity
1	0:00:00	14:46:19	38.2	142.6	4.3	10	1
2	0:00:01	14:46:19	38.2	142.6	5.9	10	3
3	0:00:02	14:46:19	38.2	142.6	6.8	10	4
4	0:00:04	14:46:19	38.2	142.6	7.1	10	5弱
5	0:00:05	14:46:19	38.2	142.6	6.3	10	4
6	0:00:06	14:46:19	38.2	142.6	6.5	10	4
7	0:00:06	14:46:19	38.2	142.6	6.5	10	4
8	0:00:11	14:46:17	38	142.8	7.1	10	4
9	0:00:17	14:46:16	38	142.8	7.5	10	5弱
10	0:00:25	14:46:16	38	142.8	7.6	10	5弱
11	0:00:40	14:46:16	38	142.8	7.6	10	5弱
12	0:01:00	14:46:17	38	142.8	7.9	10	5強
13	0:01:20	14:46:17	38	142.8	8	10	5強
14	0:01:40	14:46:17	38	142.8	8.1	10	6弱
final	0:01:52	14:46:17	38	142.8	8.1	10	6弱

Fig. 6 shows time line of 2011 Tohoku earthquake.

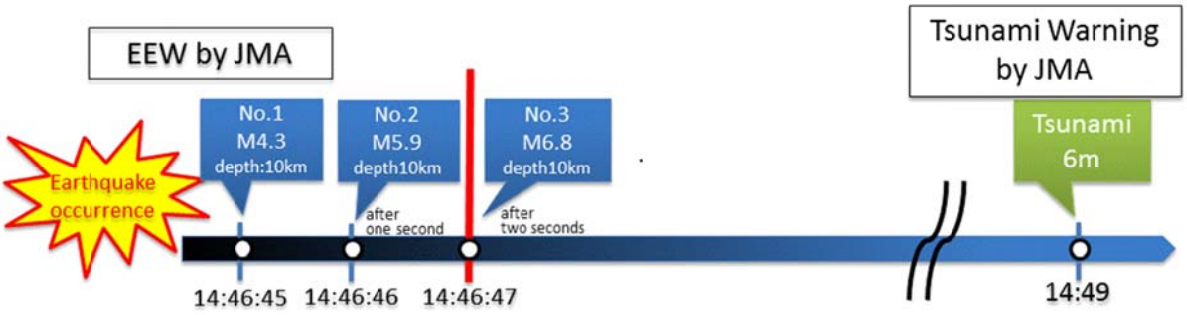

Fig. 6 Time line of 2011 Tohoku earthquake of EEW information and tsunami warning.

4. CONCLUSION

We proposed method which offers probability of tsunami generation using relationship law magnitude and depth of hypocenter from Inukai by EEW information. We also installed this procedure to EEW system by AIT. The probability of tsunami generation information is showed by display.

As a result of verification of this system by 2011 Tohoku earthquake, information of probability of tsunami generation is provided after two seconds from first information by EEW. This time is fast about three minute by JMA tsunami warning.

The JMA tsunami warning is more accuracy our system. However, more quickly data can be use first move information, especially, it is information very effective in those who cannot move early.

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