Development of Emergent Alarm System using the Earthquake Early Warning by Japan Meteorological Agency

K. Masaki
Department of Urban Environment, Aichi Institute of Technology, Japan

S. Kurahashi
Disaster Prevention Research Center, Aichi Institute of Technology, Japan

T. Ochiai
Falcon Co.Ltd, Japan

SUMMARY:
The Disaster Prevention Research Center (DPREC), the Aichi Institute of Technology receives the Earthquake Early Warning (EEW) information from the Japan Meteorology Agency (JMA) through the dedicated IP-VPN line and deliver it to the enterprises in the Toaki region, central Japan, through internet by using the system developed by DPREC. The terminal server installed in the offices, factories and plants of the enterprises estimates the seismic intensity and S-wave arriving time several and dozens of seconds before arriving of strong motions. In the case that estimated intensity exceeds the thrshhold intensity, the server informs the emergent alarm to start PC monitor, buzzer, broadcast, optical signal, and watch vibrations for the evacuation of workers. The system is also avairable to stop elevators, machines, production lines and suuply of dangerous materials. DPREC has been delivering EEW through the emergent alarm system to a hundred offices, plants, schools etc since 2005. The system is working well and expected to be useful method ro mitigate earthquake damage.

Keywords: Earthquake Early Warning, Emergent alarm, Alarm information, Alarm measure

1. INTRODUCTION

In the Tokai region (Aichi, Mie, Gifu and Shizuoka prefecture), located in the central area of Japan, **t**he large automobile complexes such as Toyota, Honda, Suzuki and their industrial cluster factories have a number of production bases, and are expanding their production activities in this sarea. On the other hands, in these several hundreds of years the Tokai region was attacked several times by large earthquakes of magnitude 7-8 occurred along the Nankai trough subduction zone. In these days, the following occurrence of the next large earthquakes has been concerned. The Tokai-Tohnankai-Nanaki earthquake of magnitude 8 to 8.4 has been considered as one of the next earthquake, whose possibility is evaluated to be 60-70% in next 30 years. After the 2011 off the Pacific coast of Tohoku Earthquake, the possibility of an larger earthquake of magunitude of 9 is strongly feared. The Tokai region will be damaged seriously due to strong motion, liquefaction and tsunami caused by these earthquake. The facilities of the enterprises in the Tokai region should suffer catastrophic damages, which caused the economic impact not only in the Tokai region but also in Japan and in the world.

Disaster Prevention Research Center（DPREC）, Aichi Institute of Technology, Japan, has organized the consortium with the enterprises in the Tokai region to develop technologies to improve the enterprise's disaster management force. Main research objective of DPREC is to deliver the Earthquake Early Warning (EEW) by Japan Meteorological Agency to the server installed in the plants, the factories and the offices of the enterprises in the Tokai region, by using internet system. The server estimates seismic intensity and arriving time (or postponement time) by using EEW information. The PC servers alarm the occurrence of a large earthquake several and dozens seconds before the arriving of strong motions. The alarm system performs workers-evacuation, stopping machines and system-down of lines before arriving of strong shaking.

Animated P- and S-wave propagating front from the epicenter toward a target site is displayed on the monitor of the EEW server. Estimated seismic intensity and margin time before arriving of strong motions are also displayed on the monitor. The seismometers network has been installed in the Tokai region by DPREC. The seismic intensities observed by the network are sent to the server at DPREC on time by internet system. DPREC informs observed intensity data on time to the enterprises.

The Emergent Alarm System developed by DPREC has been installed at about 100 facilities of the enterprises not only in the Tokai region but in the other region in Japan now.

2. EARTHQUAKE EARLY WARNING (EEW)

2.1. EEW System

Japan Meteorological Agency（JMA）releases the Earthquake Early Warning(EEW) which provides advance announcement of the earthquake information (origin time, hypocenter and magnitude). These data are estimated based on prompt analysis of P-wave information observed at nationwide strong motion network managed by JMA and National Research Institute for Earth Science and Disaster Prevention.

Delivery by the Japan Meteorological Agency has started since 2004. DPREC also has started the project to deliver the EEW for 30 facilities of the enterprises in the Tokai region since 2005.

EEW is aimed at mitigation of earthquake damage by allowing countermeasure such as stopping train, quick evacuation of peoples, so on, before arriving of strong motions. EEW seems to be useful for disaster mitigation. In the case of the 2011 Tohoku Earthquake, EEW was released 12 seconds before arriving of strong motions at Sendai City.

DPREC received EEW and delivered it to the facilities in the Tokai region. However, until today the estimated seismic intensities in all facilities in all earthquakes were less than IV in JMA scale. The facilities did not need to start emergent countermeasure, although they received EEW.

2.2. Estimation of seismic intensity and arriving time

EEW gives information of the estimated origin time, hypocenter and magnitude of an earthquake. Seismic intensity at a site is estimated by following procedure.

(1) Mj (Japan Meteorological scale magnitude) is transformed to Mw (moment magnitude)

$$Mw=Mj-0.171 \text{ (Utsu:1982)} \qquad (2,1)$$

(2) Peak ground velocity PGV600 on a firm basement with Vs 600m/s is calculated by using the empirical attenuation formula as follows(Shi and Midorikawa:1999)

$$\log PGV600=0.58Mw+0.0038D-1.29-\log(x+0.0028\times10^{**}(0.50Mw))-0.002x \qquad (2.2)$$

Here, D is depth and x is hypocentral distance

(3)Average shear wave velocity of subsoil down to 30m in depth is calculated by following equation (Matsuoka and Midorikawa:1994).

$$\log AVS=a+b\log H+c\log D \qquad (2.3)$$

Here, H is a ground level and D is a distance from a large river. Coefficients a, b and c are determined by micro geological and micro topographical conditions at the target site, shown in detail of the study by Matsuoka and Midorikawa(1994).

(4) Amplification factor ARV from firm basement to ground surface is calculated by

$$\log ARV=1.83-0.66\log AVS \qquad (3.4)$$

(5) Peak ground velocity on surface is calculated by formula (5)

$$PGV=PGV600\times ARV \qquad (2.5)$$

(6) Seismic intensity (Japanese scale) is estimated by equation (6) (Midorikawa et.al:1999)

$$I=2.68+1.72\log PGV \qquad (2.6)$$

Arrival time of principal motion (Postponement time) is calculated from a hypocentral distance and seismic velocity structure of underground.

2.3. Evaluation of amplification factor

The key point to accurately estimate the seismic intensity is to accurately determine the amplification factor ARV in (2.4). ARV is determined from AVS which is calculated by (2.3). It means that it is need to determine the geological and topographical condition at the just point of the target site. DPREC system determines those coefficients by using drilling data, aerial photo, topographic map, and field survey by exparts in the Institute.

2.4. Comparison of estimated and observed seismic intensity

It is essential problems to accurately estimate seismic intensity at the target site. DPREC has installed the strong motion seismometer network in the Tokai region to compare the estimated intensities with the observed ones. Fig.2.1 shows the seismometer locations installed by DPREC. DPREC uses two types of seismometers, ETNA and E-Catcher. Detail of network system will be described in the next section. Fig .2.2 shows the comparison on the seismic intensities (in Japanese scale) estimated and observed. The seismic intensities by ETNA and E-catcher are not so different. The relation between estimated and observed intensities is well, but estimated intensities seem to be a little bit higher than observed. Our target intensity range is over four. However, DPREC has not had the observed data of intensities over IV till now. The intensities observed during the 2011 Tohoku earthquake were less than intensity IV. The distribution of intensities in Fig.2.2 shows that differences between estimated and observed are large in low intensity range but converge in high intensity range. Most of the facilities of the companies determine that the threshold (trigger) intensity to start emergent measures is IV.

Figure 2.1. DPREC strong motion network Tokai region, central Japan.

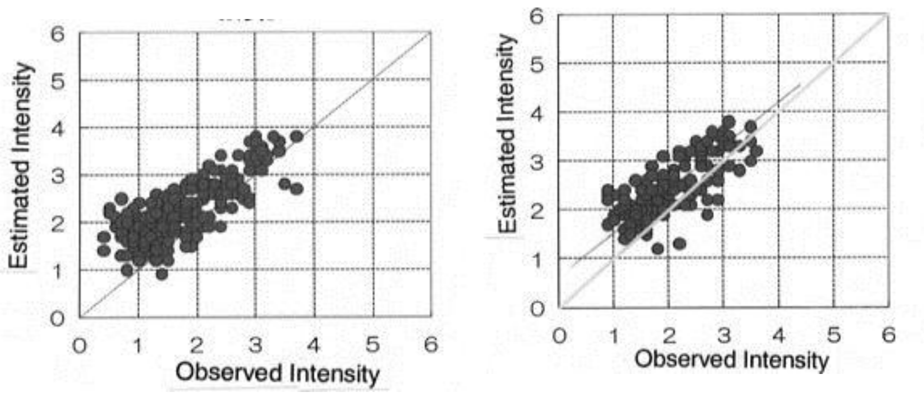

Figure 2.2. Comparison on the seismic intensities (in Japanese scale) estimated and observed

3. NETWORK SYSTEM

3.1. Network System

Fig. 2.1 shows the network system in the Tokai region installed by DPREC. Yellow circles show the sites (facilities) at where EEW receiving terminal system and E-catcher type small seismometers are installed. Blue circles show the earthquake observation sites where ETNA type seismometers and AIR type seismometers are installed.

E-Catcher type seismometer (Oyo seismic instrumentation Co.Ltd.) has on time communication function to send observed data including seismic intensity, maximum acceleration and spectral intensity SI into the server at DPREC through internet, however has only rough sensitivity of 1gal. ETNA type seismometer (Kinemetrics Co.Ltd.) can obtain high quality data with high sensitive sensors, however has not on time functions. The observed data are sent by PHS system several hours later into the DPREC server. AIR type seismometer (Oyo seismic instrumentation Co.Ltd.) has both on time system and high sensitive sensors, but installed at only five locations.

The EEW terminals (the set of PC server, monitor, modem, EPS, etc) are installed at about 100 sites (facilities of the companies), and three types of seismometers are installed at 60 sites (including the same location of EEW terminal) in the Tokai region. All the seismic data and EEW information are stored in the server at DPREC and comprehensively managed. The EEW terminals in the facilities are also managed by the server of DPREC. We called this system as Ai-system (Aichi Institute of Technology SYSTEM). By using this network system, EEW and observed seismic intensities are distributed to users who can confirm arriving of strong motions on-time.

3.2. Delivery System of EEW

Fig.3.1 shows the delivery system of EEW managed by DPREC. Japan Meteorological Agency (JMA) provides the Japan Meteorological Business Support Center (JMBSC) with EEW by the leased line. DPREC receives EEW from JMBSC through IP/VPN line and delivers it to the EEW terminal system in the office , the factories and other facilities of the companies through internet leased lines (ADSL, ISDN or optical fiber line) in 24 hours.

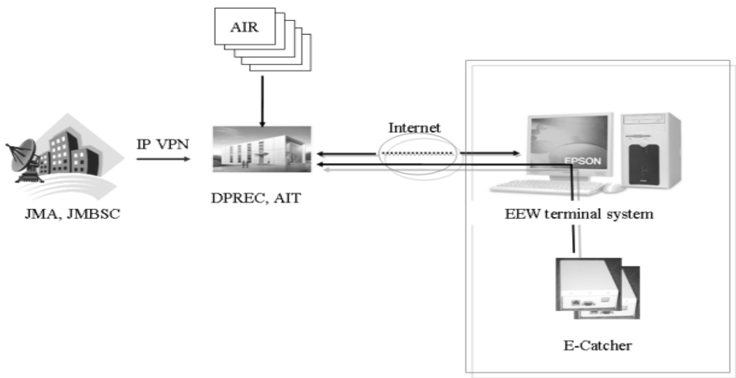

Figure 3.1. System for delivering EEW and observed seismic data.

3.3. EEW Terminal Devices

Photo 3.1 shows the server for receiving and delivering EEW installed in the DPREC office. The other servers for collecting seismic data observed at seismometers sites are also shown.

As shown in Photo 3.2(1), a terminal system is consist of a router, a main body of PC, a monitor, an alarm device(FTE), a pair of E-catcher seismometers and a uninterruptible power supply. The alarm system FTE in Photo 3.2(2) has the functions of alarm sound, light flash and a display which shows estimated seismic intensity and arriving time (or time until arriving) of S-wave. Photo 3.2(3) shows the monitor screen which can display the information as follows. The epicenter and dynamic state of propagating P-wave (yellow) and S-wave (red) and the target site marked by a diamond symbol(upper central figure). The Estimated seismic intensity and the time until S-wave arriving at the target site are displayed (upper left).The seismic intensities and the time until arriving of S-wave at other sites in the other regions are also displayed (upper right). The on time seismic intensities observing at the AIR seismometer stations are displayed (lower central). The uses can confirm the real time intensities which are useful to determine their measure in addition of EEW information.

Photo 3.1. Servers for receiving and delivering EEW in the DPREC office

(1) (2) (3)

Photo 3.2. (1) EEW terminal system installed in the user’s office, (2) FTE alarm display (monitor, flash light and alarm sound, (3) monitor display of PC: propagating P- and S-wave front, estimated intensity, time until arriving strong motion, etc.

4. PRACTICAL USE OF EEW SYSTEM

4.1. Users of DPREC system

DPREC has been delivering EEW information to 100 users such as: the offices, factories plants of companies of automobile, machine, chemical materials, etc. including large companies and small ones. The universities, the schools and the medical facilities are also included.

4.2. Example of system

Fig. 4.1 shows an example of EEW Emergent Alarm System installed in an enterprise which has factories, offices and other facilities in other sites. Through internet line, the EEW information is delivered from the server in DPREC into the terminal server installed in the headquarter office. The terminal server calculates seismic intensities and arriving times at headquarters, other factories, offices and facilities with in a second and send them in a soon through corporate LAN. The emergent alarm devices are triggered and inform warning.

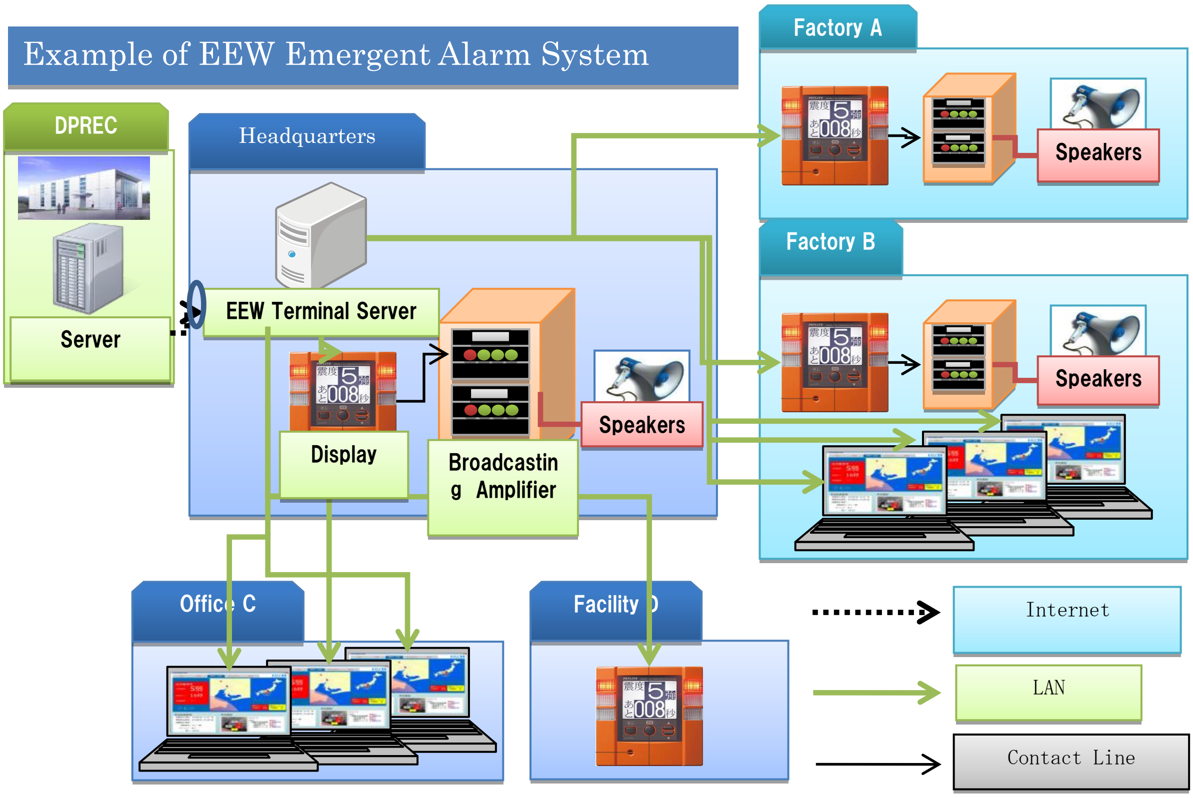

Figure 4.1. Example of EEW Emergent Alarm System installed in an enterprise which has factories, offices and facilities in other bases

4.3. Examples of alarm device

Fig. 4.2 shows several alarm methods to save workers and facilities from dangerous situation before strong shaking arriving such as (1) to stop the elevator on the near floor, (2) to start evacuation by broadcast, (3) to stop the machines and systems, (4) to alarm by flash lights and intense sounds and (5) to alarm by special watch which has vibration generators. The warning sound and warning statement for broadcast alert are also important to inform dangerous situation quickly, exactly and reliably. As there are big noises and strong lights in the factories, it is necessary to devise some methods and ideas.

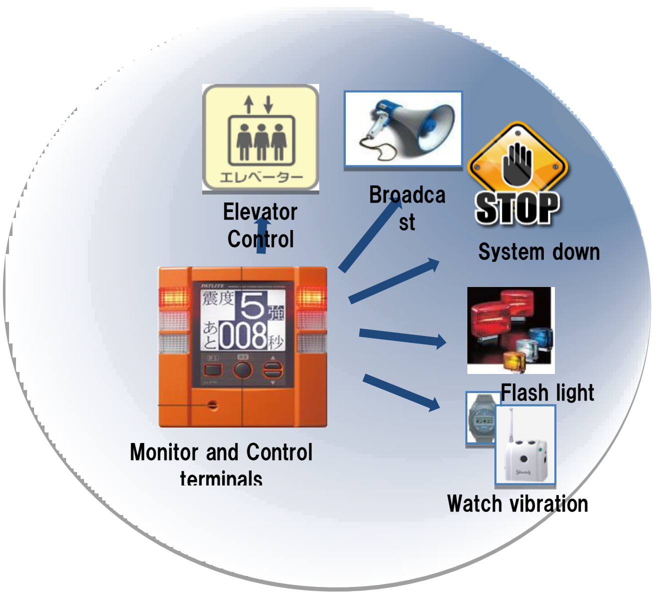

Figure 4.2. Alarm methods and devices

4.4. Examples of practical use

In Japan, EEW is used in many places, for examples: factories, trains, schools, hospitals, construction sites, shopping centers, etc.

Aichi Institute of Technology has started the alarm system for evacuation from lecture rooms and laboratories. The alarm buzzer and emergent broadcast are triggered. Photo 4.1 shows the evacuation training by using EEW emergent alarm system developed by DPREC. The students, professors and all in the university take action to protect themselves during strong shaking and after shaking weakened they evacuate to wide spaces such as football ground.

Photo 4.2 shows the example of shutdown system to close valves attached to a tank of toxic materials by EEW emergent alarm system in the case of the chemical factory. In some semiconductor factories, the same system is used to stop the supply of dangerous gas and materials.

Photo 4.1. Evacuation training by using EEW emergent alarm system alarm at author's university.

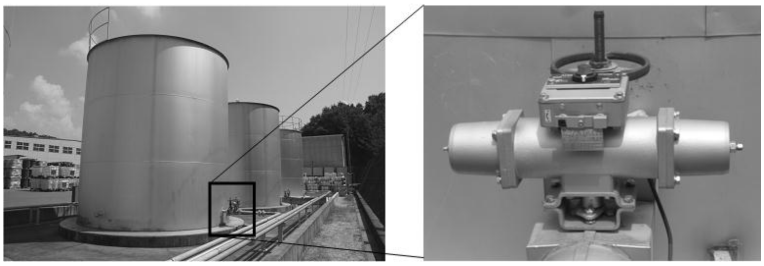

Photo 4.2. Example of shutdown system to close valves attached to a tank of toxic materials by EEW emergent system developed by DPREC.

5. CONCLUSIONS

Disaster Prevention Research Center, Aichi Institute of Technology, Japan, developed the delivering system of Earthquake Early Warning released by Japan Meteorological Agency and has started to deliver EEW emergent alarm to about hundred facilities of the companies in the Tokai region, central Japan, through internet. This alarm informs estimated seismic intensity and arriving time of strong motions several or dozens seconds before. The system has introduced into about a hundred companies and used for employees-evacuation, controlling facilities, stopping machines, etc. The system developed in this study should be very useful for earthquake disaster reduction not only at companies but also at other organizations such as schools, hospitals, social institutions, etc.

ACKNOWLEDGEMENT

This work has been supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT).

REFERENCES

Matsuoka Masashi and S., Midorikawa. (1994). The Digital National Land Information and Seismic Microzonation. 22th symposium on ground motion, 23-34.

Utsu Tokuzi.(1982). Relationships between earthquake magnitude scales. Bull. Earthq. Res. Inst., **57**:465-497.

Si Hongjun and S., Midorikawa.(1999). New attenuation relationships for peak ground acceleration and velocity considering effects of fault type and site condition, J. Struc. Constr. Eng., AIJ, **No.523,** :63-70, Sept.

Midorikawa Sabroh, K. Fuzimoto and I., Muramatsu.(1999). Relationship among measured seismic intensity, JMA seismic intensity and strong motion index, Journal of Institute of Social Safety Science

Kazuaki Masaki, Susumu Kurahashi and Kojiro irikura.(2008).Develop,ent of alarm network using Earthquake Early Warning, 14th WCEE, Oct. 12-17, 2008 Bejing, China

kazuki Masaki, Yuichiro Nishimura, Susumu Kurahashi and Kojiro Irikura.(2009). EEW distribution network developed by Disaster Prevention research center, AIT. Proc. of 2nd Intern, Work shop on EEW, 55-57. Apr.21-22.2009.Kyoto Univ.,Uji.Japan

Yuichiro Nishimura, Mikio Komatsu, Hiroshi ochiai and Kazuaki Masaki.(2009). EEW for Tokai industrial region-application to the manufacturing industry and these effects,: Proc. of 2nd Intern, Work shop on EEW,:60-61. Apr.21-22.2009.Kyoto Univ.Uji.Japan