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ON THE EFFECTIVE EARTHQUAKE EARLY WARNING SYSTEMS FOR BOTH DISTANT AND NEAR EVENTS

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Abstract: This paper describes the truly effective early warning systems with simulated results for disaster prevention against distant and near events. And the role of national or public organizations in earthquake disaster prevention will be discussed.

1. INTRODUCTION

It is clear that the basic countermeasure against earthquake strong motion is to reinforce buildings and other structures. However, even enough counter-measured facilities against expected strong motion un-expecting accidents may be occurred. Against the un-expecting accidents, the earthquake early warning system, *UrEDAS*, Urgent Earthquake and Detection and Alarm System, was developed 25 years ago. At first the system was adopted for the Seikan under-sea-tunnel as an earthquake information system in 1988, and then fully operated for safety of the Tokaido Shinkansen from 1992. After that we are developing and improving our systems on the experiences of the Kobe earthquake and etc., as the technical innovation group for the EEW, Earthquake Early Warning. As the results of our activities, *FREQL*, Fast Response Equipment against Quake Load, was developed. At the start of the *UrEDAS* operation, the processing time of warning was three seconds after the P-wave detection. Now the processing time of *FREQL* is shortened to 0.1 second in minimum. This shortened processing time makes possible to issue a quick alarm over one second leading for large motion against even an under earthquake. Although this time margin is very short, it is expected that significant effects will be generated for facilities operated under the ultimate situation as the bullet train or the elevator system of high-rise buildings. The ultimate EEW system as *FREQL* is useful for rescue activities just after the earthquake damage to prevent the second disaster by large aftershocks.

In 1992 Nakamura's Group of *RTRI*, Railway Technical Research Institute, proposed a project of *UrEDAS* network with 2000 stations not only for earthquake disaster prevention, but also for working as a node of communication network when natural disaster occurred. In 1992, TV news of NHK, Nihon Hoso Kyoukai (Japan Broadcasting Corporation) announced that a trial operation of EEW information service for Tokyo metropolitan area with UrEDAS information will start in 1993. But this project was not realized mainly because of objection of *JMA*, Japan Metrological Agency. *JMA* started the similar project in 2005 using a system developed by themselves. In this paper, not only the EEW of Japan, but also the present state of the information for earthquake disaster prevention will be described.

2. CONCEPT OF EEW

There are two kinds of earthquake alarms as illustrated in **Figure 1**. One is the "On-Site Alarm" which is an alarm based on observations close to the objects to be warned. The other one is the "Front Alarm" which is an alarm based on observations near the epicentral area, which is then used for the warning in possible damage areas away from the epicenter. Because the latter alarm concept requires the use of communication networks, it is also sometimes called

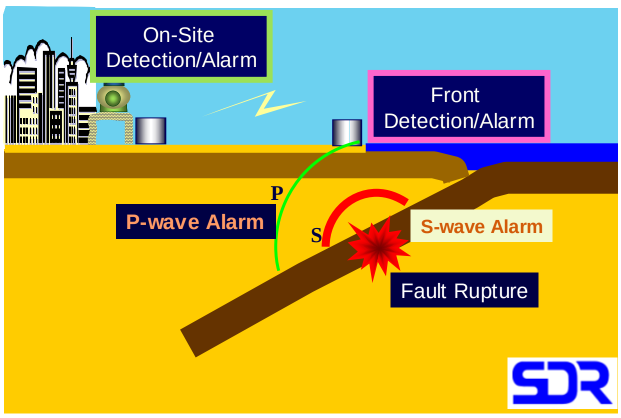

Figure 1 Concept of an EEW system

"Network Alarm". Both alarm types described can make use of two different triggers, also called "alarms". One is the trigger/alarm exceeding a preset level, the so-called "S-wave Alarm" or "Triggered Alarm"; the other one is the trigger/alarm during the preliminary motion, the so-called "P-wave Alarm" .

3. *UrEDAS*

The idea of disaster mitigation by the EEW depends on the progress of science and technology during 19 and 20 centuries. Earthquake is a vibration caused by the results of the crust destruction. Although the earthquake prediction obviously brings numerous benefits to the disaster prevention, this kind of destructive phenomena is a stochastic phenomenon and is impossible to predict its occurrence with enough accuracy and reliability applicable to disaster prevention. Instead of the prediction the EEW is close up for disaster prevention.

The idea to minimize the direct effects of earthquakes by developing an early warning system was first published by Dr. J. D. Cooper (1868) with the aim of earthquake disaster prevention in San Francisco. It is interesting for me that he describes the idea of EEW based on the failure of the Japanese earthquake prediction method using a magnet at an earthquake in 1868. After Cooper various similar ideas has been proposed, but Cooper's and the other ideas were never realized and then basically forgotten.

About 100 years after Dr. Cooper's publishing, independently a similar idea was born from an idle talk at a tea time of an university laboratory. This is the detection system before 10 seconds for Tokyo metropolitan area proposed by Dr. Hakuno et al (1972). At the same time, many institutions and agencies including *JMA* started to research a possible EEW based on the existing automatic earthquake observation system consisting of a network of many monitoring stations.

JNR, Japanese National Railways, had also started to research possible EEW based on the same concept as *JMA*, while Nakamura at the *RTRI* of *JNR*, started to develop a different concept in 1979, using only a single station. He completed the prototype *UrEDAS*, pronounced "Yuredasu" meaning "shaking begins" in Japanese. This was the first actual P-wave detection and alarm system worldwide and was published in Nakamura (1984).

The main *UrEDAS* functions are the estimation of magnitude and location, vulnerability assessment and issuing warnings within a few seconds using initial P-wave motion at a single station. Unlike other automatic seismic observation systems, *UrEDAS* does not have to transmit the observed waveform in realtime to a remote processing or centralized system and is therefore comparatively simple. *UrEDAS* calculates parameters such as back azimuth, predominant frequency for magnitude evaluation and vertical to horizontal ratio for discrimination between P and S waves, using the amplitude for each sample in realtime. These calculations are processed in realtime without storing waveform data. The amount of processing of *UrEDAS* is almost constant regardless of whether or not an earthquake is occurring, so the number of computational processes does not increase in the event of an earthquake. Then UrEDAS does not cause any system down after big earthquake.

UrEDAS can issue its alarm based on the *M-Δ* diagram in **Figure 2** immediately after the earthquake detection. The *M-Δ* diagram is derived from past damage experience to JNR facilities and equipment and aids in decreasing the number of false or needless alarms. This kind of alarm is referred to as the *M-Δ* Alarm. *UrEDAS* can also assist in decisions to safely restart train operations based on the detailed earthquake parameters.

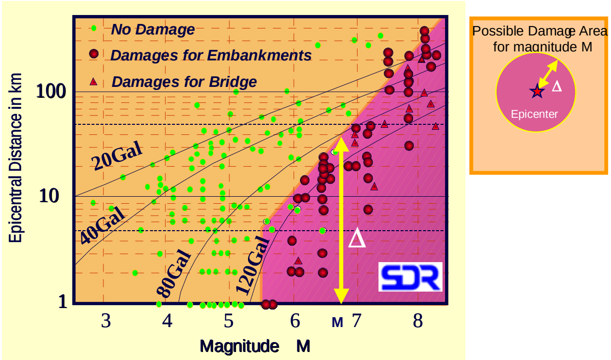

Figure 2 M-Δ diagram

After an initial testing period, the development of *UrEDAS* for routine use was completed and trial operations for the protection of the Shinkansen line, the bullet train, in central Japan were carried out commencing in 1990. These trials led to the implementation of some additional capabilities and functionality of *UrEDAS*. In 1992, *UrEDAS* started routine operations with full functionality for the Tokaido Shinkansen line (Nakamura, 1996). These *UrEDAS* issue a P-wave warning with a processing time of just three seconds after detecting the P-wave.

Other organizations, such as *JMA*, continued their research and development but without implementing operational systems. This made *JNR* the only agency to implement an operational and functioning actual warning system in the 20th Century.

4. THE 1995 KOBE EARTHQUAKE AND *Compact UrEDAS*

After the 1995 Kobe earthquake, it was recognized that an even shorter warning time would lead to even more effective realtime disaster mitigation. To achieve this, *UrEDAS* was developed further with the aim of being able to issue warnings within about one second after the detection of a damaging earthquake. The resulting system was the *Compact UrEDAS* which became available in 1997 (Nakamura, 1998) and commenced routine operations for the Tohoku, Joetsu and Nagano Shinkansen lines in 1998.

In contrast to *UrEDAS* which estimates the destructiveness of the earthquake from the earthquake's parameters, *Compact UrEDAS* derives this from the earthquake motion directly 'in realtime' and then issues the alarm, if required. To estimate earthquake dangerousness, the power density *PD* (W/kg) of the earthquake vibration is calculated from the inner product of the acceleration vector $\boldsymbol{a}$ (cm/s^2) and the velocity vector $\boldsymbol{v}$ (cm/s). As this value is a large number, it is normally expressed in terms of the Destructive Intensity (*DI*) defined as the logarithm of absolute value of this inner product (*LPD*, logarithm of the power density) as Eq. (1). The concept of *DI* is illustrated in **Figure 3**.

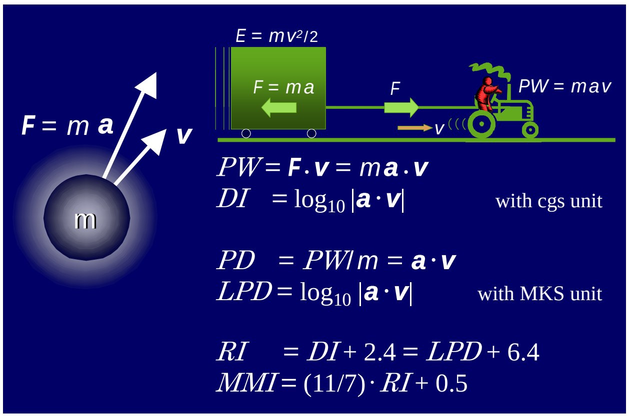

Figure 3 Relationship between various earthquake

$$DI = \log |\boldsymbol{a}\cdot\boldsymbol{v}| = LPD + 4.0 \tag{1}$$

The maximum value of *DI* during an event, DI_{max} relates to the earthquake damage and is similar to the instrumental intensity scale of *JMA*, I_{JMA}, with the constant difference of 2.4, and corresponds to *MMI*, the Modified Mercalli Intensity. These indices are referred as *RI*, Realtime Intensity, and *MMI*, respectively.

$$RI = DI + 2.4 \tag{2}$$
$$MMI = (11/7)RI + 0.5 = (11/7)DI + 4.27 \tag{3}$$

I_{JMA} can only be calculated after earthquake termination according to its artificial definition without physical background. Contrary to this, *DI* is defined as the logarithm of Power Density multiplied by a constant. Power Density is a physical variable related closely to earthquake damage. *DI* can be calculated in realtime and its value increases immediately after the P-wave arrival. Because *DI* is sensitive to the P-wave arrival, it can be used to define a P-wave alarm. **Figure 4** shows the change of *RI* as a function of time with the acceleration waveform and the change of *SI*, Spectral Intensity. *RI* is more sensitive than both, the acceleration and *SI*, because the value of *RI* increases drastically at the P-wave detection, about one second prior to the other indices.

When the P-wave arrives, *RI* increases dramatically, followed by a further but slower increase until the arrival of the S-wave, by which time it reaches its maximum, called RI_{max}. The *PI*-value is defined as the maximum *RI* within *t* seconds after P-wave detection. This *PI*-value seems to be applicable as a trigger for the P-wave alarm. Furthermore, it is possible to estimate RI_{max} from the *PI*-value approximately.

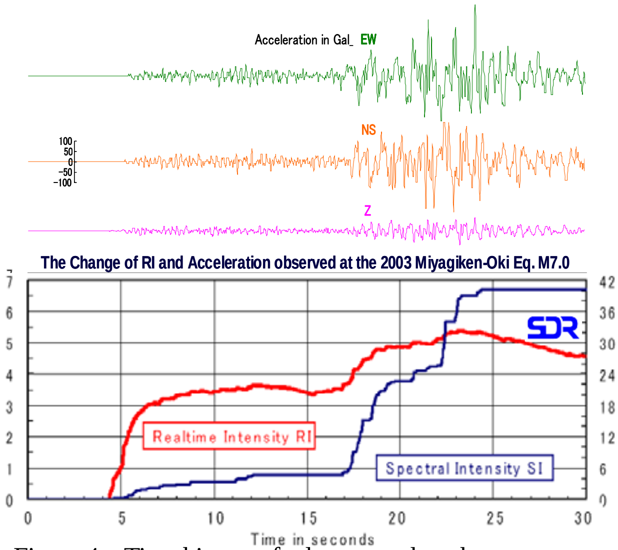

Figure 4 Time history of relevant earthquake

Because each facility has its own withstanding intensity level, each customer can determine the *PI*-value as the trigger of the P-wave alarm. In other words, with the continuous observations of *RI*, an earthquake alarm can be issued efficiently and the damage can be estimated reliably. In fact, the *PI*-value with its physical meaning of power related to destructiveness and dangerousness of the earthquake can thus be used for a P-wave alarm as realized in the *Compact UrEDAS* and *FREQL* (explained later in detail).

The function of the *Compact UrEDAS* is to issue an early warning for the area close to the instrument based on the risk of the detected earthquake motion, which is different from the alarm from the *UrEDAS* to the area of possible damage based on the estimated location and magnitude of the detected earthquake. The target area of the *UrEDAS* alarm is about 200 km around the location of the instrument, while that of the *Compact UrEDAS* alarm is only about 20km around the instrument. Thus, to maximize the effectiveness of the warning system, an ideal strategy is to use the *UrEDAS* (front alarm or network alarm) to respond to more distant large earthquakes and use the *Compact UrEDAS* (on-site alarm) to respond to nearby earthquakes.

5. EXAMPLE OF A SUCCESSFUL EEW BY *Compact UrEDAS*

The derailment of one Shinkansen train during the 2004 Niigata-ken Chuetsu Earthquake (M6.8) impressively demonstrated the effectiveness and benefits of the early warning system for Shinkansen train operations. The fact that there were no fatalities or injuries to the passengers and crew of the train is clearly a result of the availability of the early warning system. The circumstances and course of events of the derailment are described in the following. **Figure 5** shows a summary and timeline of the events.

The train line is built on many viaducts, and two of them with different characteristics are joined at 300m from

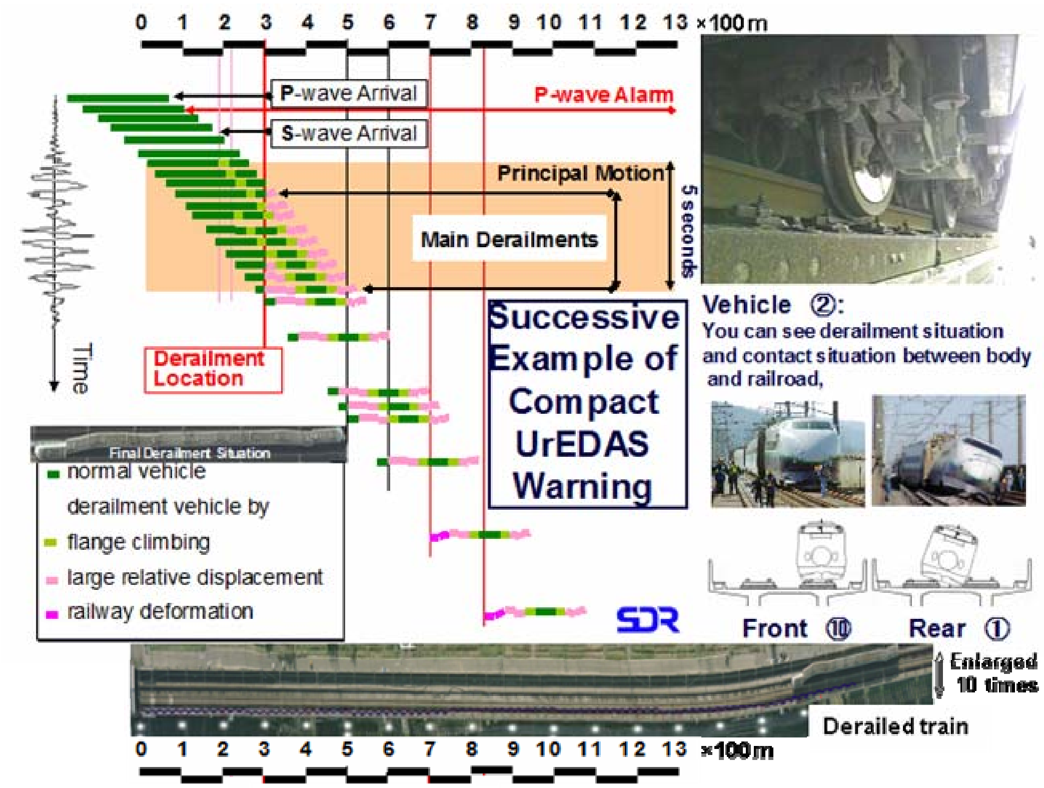

Figure 5 The Shinkansen Derailment during the 2004 Niigata-Ken Chuetsu Earthquake

the tunnel exit including the snow-shade (the 300m point hereafter). The earthquake effects on these viaducts were different from each other. When the train passed the 300m point, it is likely that the train derailed, because the joints in the rail tracks underwent different displacements.

The power supply to the train was interrupted by the P-wave alarm of the *Compact UrEDAS* installed at the substation (SS), 11km from the epicenter of the earthquake. The alarm was triggered about 2.5 seconds before the arrival of the S-wave at the location of the train. The large motion started one more second after that. So the P-wave alarm preceded the onset of the large motion by about 3.5 seconds. Without the automatically initiated emergency breaking triggered by the alarm the train would have arrived at the 300m point earlier and more vehicles would have passed that point during the large motion. With the very real possibility of the rails buckling while the train passed over them at great speed, this most probably would have caused a much more serious derailment destroying the rails completely which then might well have led to the train overturning.

If this happened to the lead vehicles, it could have been as catastrophic as the accident of the German ICE (InterCity Express) high-speed train in 1998 (Wikipedia). Consequently, although the derailment could not be prevented, this certainly illustrates the usefulness of the warning system impressively.

A subsequent simulation of the alarm behavior of a *FREQL* system using the recorded waveform showed that the train would have received the P-wave alarm another 0.8 seconds earlier, if a *FREQL* had been installed in Shin-Kawaguchi SS, because the *FREQL* would have issued the P-wave alarm already 0.2 seconds after the P-wave detection.

There are several more examples of successful warnings by *UrEDAS* or *Compact UrEDAS* in 1995, 2003, 2005 and as detailed in Nakamura and Saita (2007).

6. *JMA*'S EEW

In about the Year 2000, *JMA* started research on a single site detection system with the Railway Technical Research Institute. Their system concept was basically similar to the ideas behind the *UrEDAS*. However, in contrast to the *UrEDAS* which is a direct realtime system, the *JMA* development adopted an intermittent processing system by determining the necessary parameters using stored waveform data of several seconds duration to fit the estimated function. As such, *JMA*'s centralized system gathered information of each site and re-processed it using the stored information from many sites, and then issued an alarm, if necessary.

Therefore, *JMA*'s EEW can be regarded as a network-type alarm system that requires a normally functioning telecommunications network. Except for the cases of extremely deep earthquake events, the combination of processing time and telecommunication time (the time it takes for the observations to reach the central system) is too long to issue a meaningful alarm for the possible epicentral damaged area before the large earthquake motion from a nearby earthquake or an epicentral earthquake starts.

Therefore, this system is unable to issue a warning before the onset of the large earthquake motion at the damaged area. In some cases, the warning was even issued after termination of the earthquake motion. In the case of the 2008 Iwate-Miyagi-Nairiku Earthquake, for instance, it was impossible for the system to issue the warning for the damaged area.

7. ULTIMATE EEW SYSTEM: *FREQL*

The functions of *UrEDAS* and *Compact UrEDAS* were combined which not only reduced the size and weight of the system, but also improved its functionality. This development was completed in 2005 and given the name *FREQL*. In Japanese, *FREQL*, pronounced "furekkuru", means "wave coming". *FREQL* shortened the processing time required to issue an *UrEDAS* /P-wave alarm - based on the estimated earthquake parameters from three seconds (for *UrEDAS*) to one second. The previously minimum time for issuing a P-wave alarm based on the dangerousness of the detected earthquake motion by the *Compact UrEDAS* of one second was improved by the *FREQL* to just 0.2 seconds and further to 0.1 seconds in 2009. This enables *FREQL* to issue an alarm before a large earthquake motion even in the case of the epicentral area.

FREQL is not only very valuable in the detection of the initial quake, but is also used during rescue operations after the main shock by detecting, and warning for possible aftershocks. For instance, the Tokyo Fire Department Hyper Rescue Team pulled out a small child from underneath debris from a land slide during the 2004 Niigataken-Chuetsu Earthquake. After that they had contacted us for using *FREQL* to keep the safety of the rescue staff during the high risk of aftershocks. Based on their request, a portable version of the *FREQL* was developed in 2005, improving the system's capabilities further and making it more compact.

The Hyper Rescue Team examined *FREQL* not to cause false alarm because of the working heavy equipments. And also functional examination with the high quality three dimensional shaking table made skeptic person understand that *FREQL* should be useful for earthquake disaster prevention.

The portable *FREQL* is now in use by many fire departments nationwide, even accompanying international disaster rescue teams, such as to the 2006 Pakistan Earthquake and the 2008 Sichuan Earthquake, see **Figure 6**.

Figure 6 FREQL used by Japanese International Rescue Team at the Sichuan Earthquake

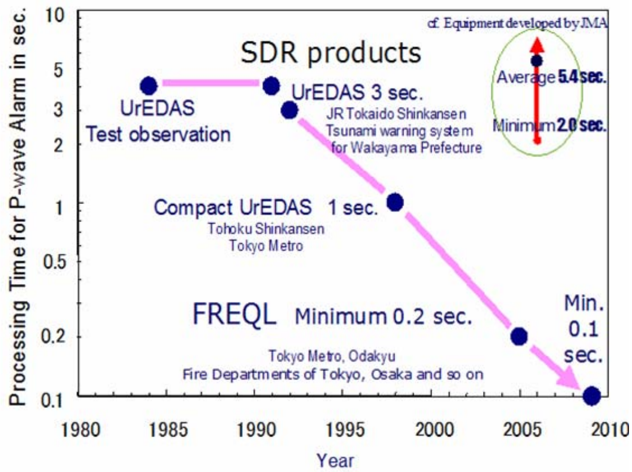

Figure 7 Processing Time of the EEW systems

Table 1 Comparison between SDR and JMA methods

Method	Products	P, S-wave Recognition	Processing Time Interval	Magnitude M from	Epicentral Distance Δ from	Warning based on	Alert Issueing after Trigger	Development / Practical Use
SDR	*UrEDAS*	Yes	1/100 s.	Initial Period*	Initial Amplitude and M (S-P Time after S)*	M-Δ	Set to 3 s.	1984/1989～
	Compact UrEDAS					Initial *RI*	Set to 1 s.	1997/1998～
	FREQL					Initial *RI* / M-Δ	Min. 0.1 s./ 1s.**	2003/2004～
	AcCo-PS					Initial *RI* / M-Δ	Min. 0.2 s./ 1s.**	2007/2008～
JMA		No?	1 s.	Amplitude and Δ	Initial Gradient of Amplitude	Estimated Sesmic Intensity	Average 5.4 s. (Minimum 2 s.)	2004/2007～

* except *Compact UrEDAS*.

** corresponds to warning based on Initial *RI* / M-Δ, respectively.

RI: Realtime Seismic Intensity.

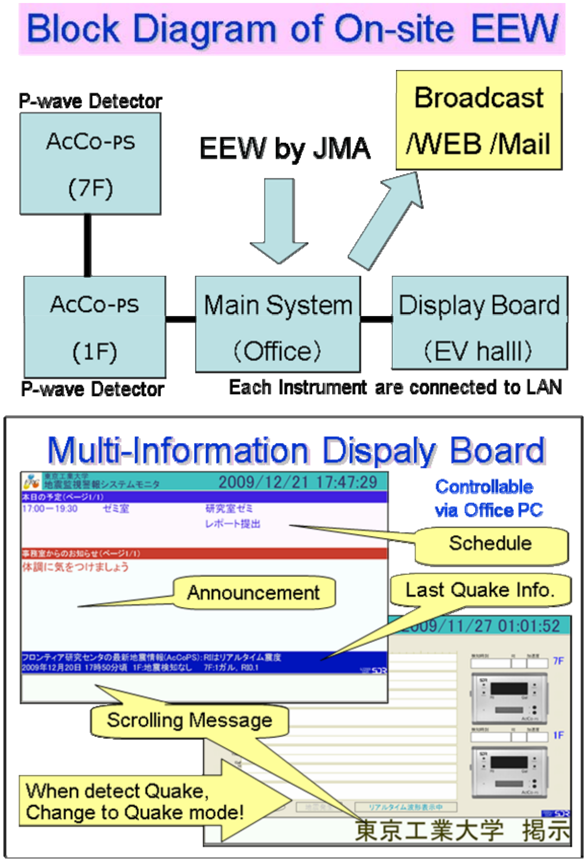

Figure 8 Block diagram of On-site EEW in Suzukakedai Campus of Tokyo Tech.

Rescue teams involved in the aftermath of the 2008 Iwate-Miyagi-Nairiku Earthquake also benefited greatly from the portable *FREQL*.

FREQL were used also in some private railway companies in Tokyo metropolitan area for EEW, and are testing now in a nuclear power plant, semiconductor facilities and so on. We expect in near future *FREQL* will be actively involved in plants and worksites to mitigate earthquake damage.

The alarm processing time of EEW Systems explained above is shown in **Table 1** and **Figure 7**, is the comparison of each EEW's functions.

Tokyo Institute of Technology has started operation of unique earthquake information system integrated with a display board. Normally this system shows general campus information with recent earthquake observed information. And if *AcCo-PS*, P-wave warning device with *FREQL* function, detects an earthquake, this system shows waveform and *RI* and *PGA* with frequency range between 0.1 Hz and 5 Hz (*5HzPGA*), see **Figure 8**.

8. SIMULATIONS OF *FREQL* ALARM

In this section simulated examples will be presented for damaged earthquakes; big near event, near event and huge distant event.

8.1. A Big Near Event

The 2008 Iwate-Miyagi-Nairiku Earthquake, M7.2 and 8 km depth, was occurred in north-east of Japan at 14th June 2008, around 8:43 of local time. This earthquake caused severe damage in the epicentral area, yet *JMA*'s EEW system was unable to issue an alarm before the start of shaking in the damaged area within approximately *25* km of the epicenter. **Figure 9** shows the time of the actual alarms issued by *JMA*'s EEW and compares them with alarms which an on-site *FREQL* system would have been able to issue, based on a simulation using the recorded waveforms. The depth of this earthquake was approximately 8km below the surface. The alarm from *JMA*'s EEW was issued *3.5* seconds after the event detection to the primary customer and one second later to the public, which is equivalent to about *10* seconds after the earthquake occurrence. Although the timing of the alarm in this case was faster than the averaged processing time of *5.4* seconds (see Figure 7), the

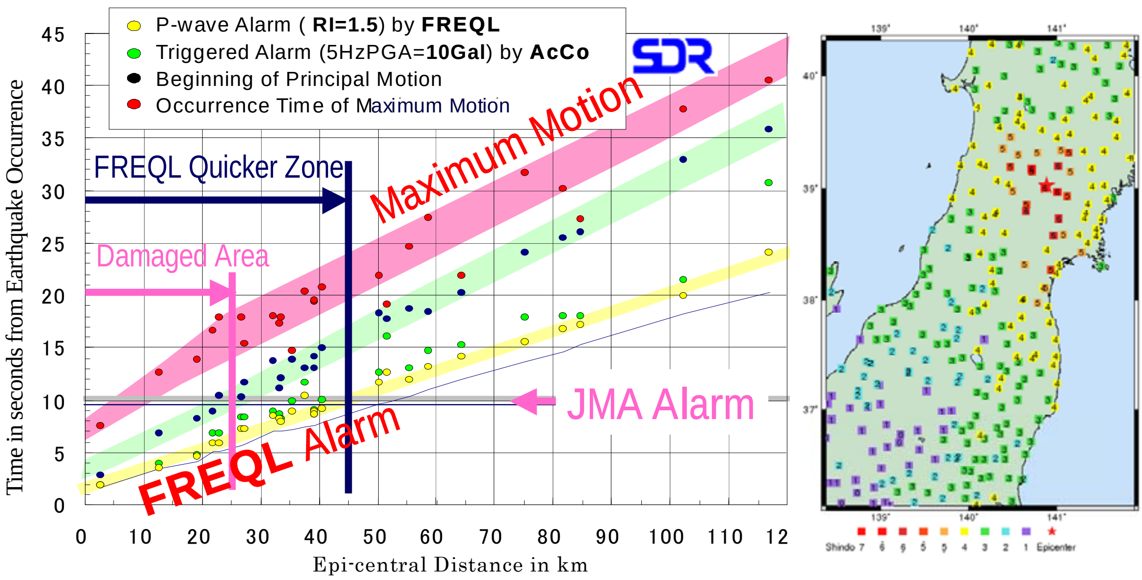

Figure 9 Comparison of EEW timing between JMA and FREQL/AcCo for the 2008 Iwate-Miyagi-Nairiku Earthquake

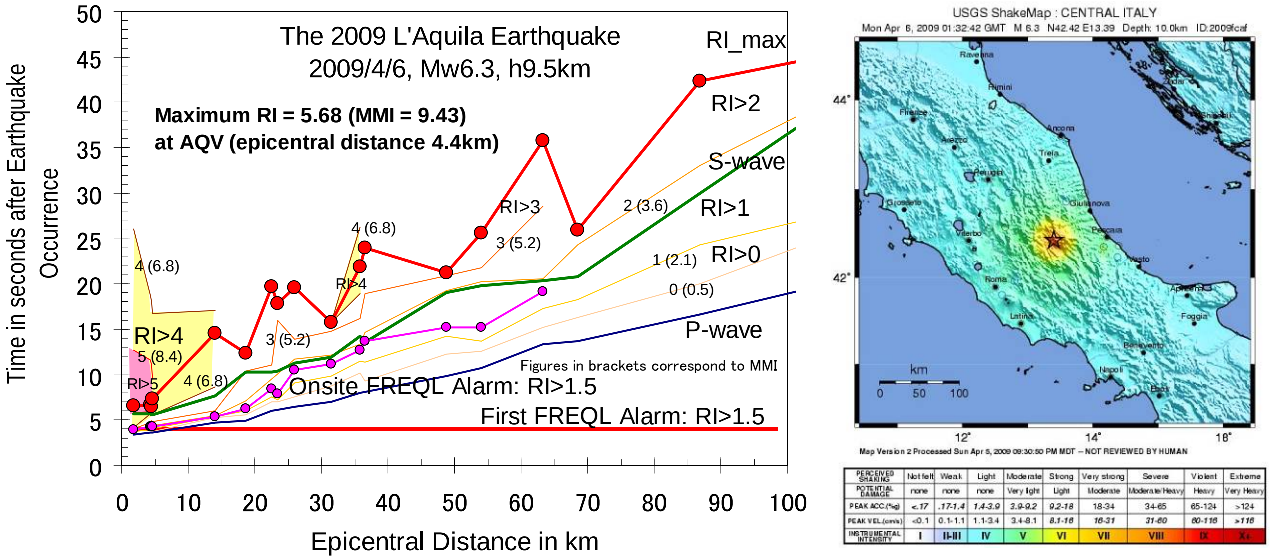

Figure 10. Timings of P wave arrival, FREQL warning, S-wave arrival and Maximum motion arrival: RI means Realtime Seismic Intensity; figures in brackets are corresponding to MMI.

warning was still only delivered after the beginning of the strong motion. In contrast to this, *FREQL* is expected to issue an alarm *0.2* seconds after the P-wave detection in the damaged area, i.e. the time margin before the beginning of the strong motion is several seconds, even at the epicenter itself.

In general, one can safely state that the on-site alarm issued by the *FREQL* is faster than that issued by *JMA*'s EEW within an area of about *50* km from the epicenter. For epicentral distances over *50* km, the on-site EEW of the *FREQL* is issued more than *10* seconds before the onset of strong motion. The average processing time of *JMA*'s EEW is *5.4* seconds, but to transmit the information from the detecting site to the processing center and the warning to the user will take some additional seconds. Typically, the transmitting time from the detecting site to the processing center, and from there to the users is estimated to be a total of around two seconds, increasing the time difference between receiving the warning from *JMA* and from *FREQL* even more. The experience of the 2008 Iwate-Miyagi-Nairiku Earthquake confirms this finding for locations with over 100km of epicentral distance. Until today, there has been no example where *JMA*'s EEW was able to effectively be used for disaster prevention by means of early warning

8.2. A Near Event-1

The 2009 L'Aquila Earthquake, M6.3 and 9.5 km depth, was occurred in central Italy at 6th April 2009. This earthquake caused severe damage in the epicentral area.

Figure 10 shows a result of simulation for the 2009 L'Aquila earthquake using strong motion records. According to this figure, FREQL was expected to get a few seconds as a leading time at even epicentral area. It is very short time, but during the leading time people could be evacuate into some sturdy desk before falling down the floor or the ceiling. It is needless to say that the most important measure is to build the structures enough earthquake-proof. Even after the reinforcement against the earthquake, because there is still risk on the falling objects, the repeated emergency drills are essential to acquire the image of the damage situation after the earthquake for the reasonable countermeasures. Anyway there is no system to issue the earthquake alarm quicker than on-site FREQL, so it is advisable to take proper countermeasures without exaggerating the effect of EEW.

8.3. A Near Event-2

The 2010 Jiansian Earthquake, M6.4 and 23 km depth, was occurred in mountain area of southern Taiwan at 4th March 2010, 8:18:52.14 of local time, according to the *CWB*, Central Weather Bureau. **Figure 11** shows distribution map of seismic intensity *RI* and *5HzPGA*. The strong motion was observed at the plane area apart from epicenter and damage was occurred in this area. This interested phenomenon was strongly reflected by the amplification of the sedimentary

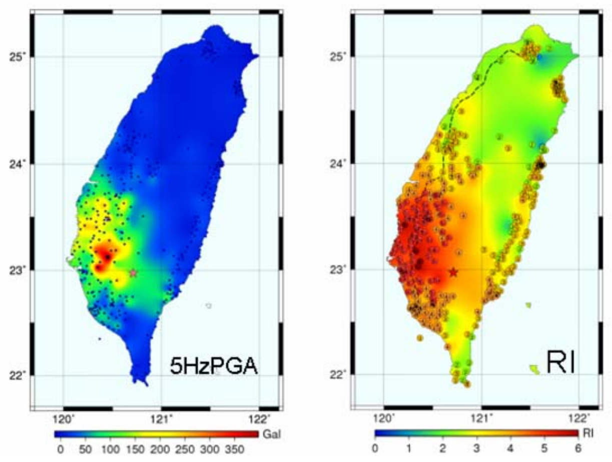

Figure 11 Distribution of Realtime Seismic Intensity and 5HzPGA of the 2010 Jiansian Earthquake, Taiwan

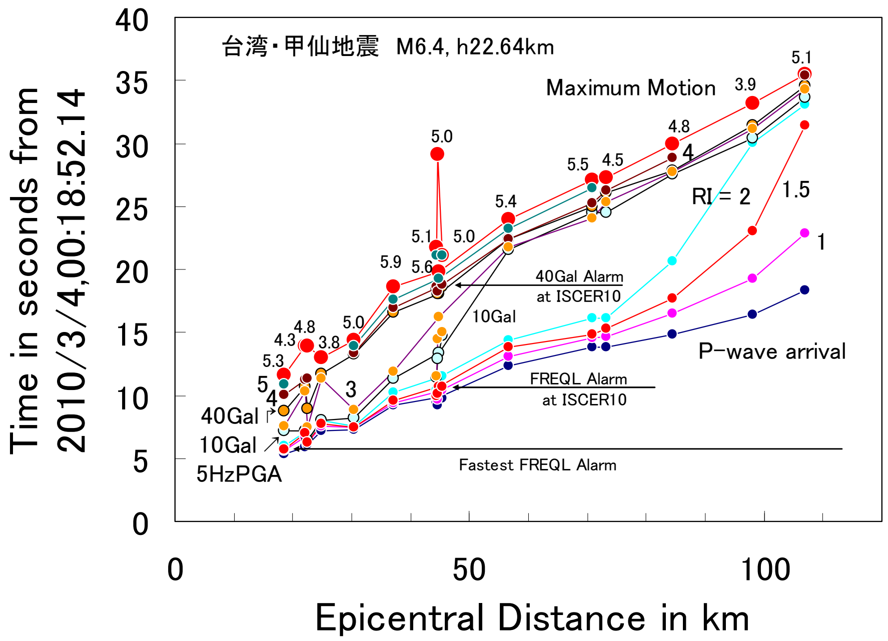

Figure 12 Simulation Result of FREQL Alarm for the Jiansian Earthquake

surface ground on the plane. In the area a running Taiwan Shinkansen train with 300km/h was derailed, but no injured passenger and no damage to the structures.

Figure 12 shows a simulation result of *FREQL* alarm using strong records of the *CWB* with changing of the *RI*. The 40 Gal alarm, which is a triggered alarm over 40 Gal of 5HzPGA, was issued at 8:19:10 to the derailed train. *FREQL* alarm should be issued at 8:19:02, 8 seconds earlier than the 40 Gal alarm. *FREQL* alarm issued *0.8* seconds after P wave detection proceeding to the strong motion with over *7* seconds. It is clear that the *FREQL* alarm proceeding to the strong motion with over three seconds at even the focal area.

8.4. A Huge Distant Event

A huge earthquake, Mw 8.8 and 47 km depth, with tsunami was occurred along the coastline of Chili in 27th February 2010, 3:34 of local time. **Figure 13** shows a simulated result using the waveform data set of Chili University. According to this the strong motion over *5* of *RI*, correspond to *8* of *MMI*, were maintained several tens seconds even at several *100* km apart from epicenter. This is the property of a huge earthquake of almost M_w *9*. The on-site alarm by *FREQL* in focal area will be issued just after P wave detection. In the area far from the epicenter, the on-site alarm by *FREQL* will be delayed from P wave detection. But the leading time proceeding to the strong motion over *4* of *RI*, correspond to *7* of *MMI*, were estimated as follows; over *7* seconds for the focal area and several tens seconds for distant area. Of course the leading time of a network alarm by *FREQL* will be longer, but the on-site alarm by *FREQL* will be present enough leading time needless communication facilities which often broken at big disaster occurrence.

9. WHAT INFORMATION IS REQUIRED FOR EARTHQUAKE DISASTER MITIGATION?

From the operational side, there are three pieces of information relevant to realtime earthquake assessment:

(1) an early warning before the onset of the strong shaking for the area of certain damage,
(2) information before the shaking starts about the area that will not be damaged, and
(3) a precise and detailed estimate of the location and extent of the area where serious damage can be expected.

The most important issue for public agencies is to have a reliable assessment as listed in Item (3) above, so that rescue activities in the damaged areas can be initiated immediately. For the public agencies it is impossible to deliver information as under Item (1) due to the long processing and communication times. Only on-site early warnings can deliver that information. In general, the early warning can only be used to trigger individual or locally based social group help or action. Governmental assistance will mainly focus on the rescue work in the seriously damaged areas evaluated by information as under Item (3). Information as under Item (2) has no relevance to damage, and is unnecessary information for disaster prevention. For most events, unfortunately, *JMA*'s EEW seems usually only capable to deliver information as under Item (2).

The warning must be delivered rapidly and be accompanied by information for a rational response to the event. The information as under Item (3) above is essential to decide on such actions. It is important to receive rapid and

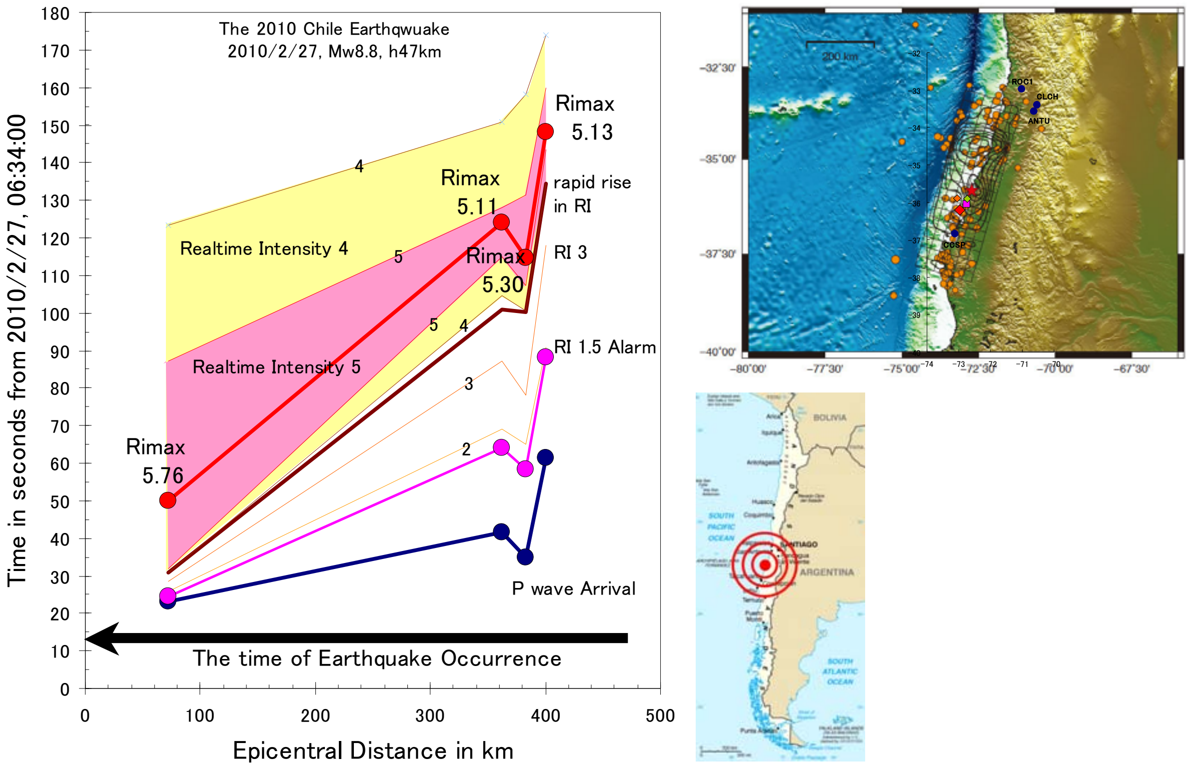

Figure 13 Simulation Result for the 2010 Chile Earthquake of Mw 8.8

accurate earthquake information from organizations such as JMA in Japan, but it is also important not to restrict the delivery of the information as under Item (3) from other organizations, such as local universities or Institutions.

As mentioned above, the best possible earthquake assessment (made in realtime) is essential information to specify the extent and location of the seriously damaged area, to enable the implementation of immediate and appropriate emergency response directly after the event. While earthquake observation systems designed for scientific research must be able to determine the exact location of the events, *UrEDAS* has deliberately been designed to estimate the earthquake parameter only in an approximate way to be able to issue the warning and the required response action in the shortest possible time.

Public organizations should deliver information on the earthquake parameters not only for the main shock but also for aftershocks as soon as possible. However, from the viewpoint of earthquake disaster prevention, it is more important to deliver accurate earthquake information as quickly as possible rather than to deliver a “late” early warning. For the most appropriate and quick response after the earthquake, the “actual observed” seismic motion as intensity, not an estimated value, is the most important information because the degree of damage can be estimated from it.

10. PROBLEMS IN THE DELIVERY OF EARTHQUAKE WARNINGS BY THE NATIONAL AUTHORITIES

If only one authority can issue warnings, all organizations and the general public must rely on it. This leads to the general public, as well as organizational managers develop the habit of waiting for the information from the authority instead of using some reasonable self-management for protection and mitigation. On the other hand, if other organizations are also permitted to issue warnings, all involved must be aware of that they do this on their own risk and must take full responsibility for their warnings and possible consequences.

If issuing warnings is based on a law or regulation, organizations and individuals responsible for issuing warnings develop a strong tendency to wait with the warning until the last moment (which may be too late). On the organizational level, promulgation of such warnings might be slowed down for fear of reprisals or bad reputation.

In Japan, this trend is quite obvious in the ways in which tsunami warnings or cautions are given. By law, only *JMA* is permitted to issue tsunami information in the form of an official tsunami warning. However, as it is commonly seen on TV news in Japan, the source of such tsunami information is not clear and in most cases, the accuracy of the information on which the warning is based is doubtful. This situation can lead to a considerable lack of reliability with many false warnings and cautions, commonly know as the “crying wolf syndrome”.

It became very obvious that an *M7* class earthquake causes catastrophic damage especially in the area close to the epicenter. Although *M7* class earthquakes are quite common in Japan, it is a potentially fatal flaw in the warning system that the *JMA*’s EEW cannot issue a timely and accurate estimate of the large motion in the catastrophically damaged area. If the early warning for the large motion is delayed too long (for whatever reason) it becomes meaningless.

For *M8* class events (which occur statistically once every several tens of years in Japan), the *JMA*'s EEW seems to be capable to issue a warning with a useful time margin for the strong motion. Yet such a warning is only useful, if it is readily available for the damaged area more than *50* km from the epicenter. This, however, might not be the case, because in such a serious situation it is quite possible that the information is lost or delayed by problems in the communication system. In contrast, an on-site alarm system is, by definition, not exposed to these problems and can issue a warning or alarm before the onset of the large earthquake motion.

On-site alarm equipment such as the *FREQL*, is capable to issue the alarm in as short a time as *0.1* seconds after the P-wave and can thus issue the warning before the onset of the large earthquake motion, even for locations close to the epicenter. If then a local FM radio station would broadcast the *FREQL* information, there would be a time margin for preventative action within the damaged area. Unfortunately, after December 2007, there is a hesitation for implementing of such a system because it might violate a law restricting the authority to issue warnings to *JMA*.

11. CONCLUDING REMARKS

Realtime earthquake warning was initially aimed at disaster prevention for the train system in Japan, but is by now used in many other environments as well. To be of wide-ranging benefit, the time margin of the warning must be very short on a time scale of seconds to enable quick action by the general public, such as to seek shelter (like under a sturdy desk) or to evacuate immediately to a pre-determined safety zone. The disaster prevention activity must be based on the actual seismic motion in the surrounding area, not an estimated one or one for some other location.

It is an open question whether or not an appropriate earthquake early warning system is in place in Japan today. Clearly, there has not been much discussion about this issue until today. It seems that the (so far futile) attempt to develop a reliable earthquake prediction system is getting much more attention than the fact that an effective and reliable earthquake early warning system is a reality and readily available.

It is clear that the primary preventative action by the people at the time of the earthquake is to keep away from places where they could be hit by falling or loose objects. To be able to do this obviously requires a timely and immediate warning to be issued.

The earthquake information including warning is not effective for disaster prevention to be provided exclusively as a national project. A warning cannot prevent the possible collapse of structures, but it can most definitely assist people evacuating from collapsing facilities. A prompt and reliable earthquake warning should become part of the daily life of the people in Japan. National organizations should be able to specify the area of expected catastrophic damage accurately and initiate rescue operations without delay based on information from responsible and capable organizations in realtime.

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