EFFORTS OF EARTHQUAKE DISASTER MITIGATION USING INFORMATION BEFORE S-WAVE ARRIVAL

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Abstract

In Japan extensive seismic networks have been constructed nationwide composed of high sensitivity seismographic network (Hi-net), broadband network (F-net) and strong motion network (K-NET). All these data from NIED and those from JMA and universities have been collected and distributed through NIED to scientists and engineers through the Internet under the coordination of the National Seismic Research Committee of MEXT. As a practical application of those data MEXT, JMA and NGOs are cooperating to develop an earthquake early warning system (EEW) for the purpose of providing seismic parameters to any users concerned with seismic risk reduction. A content of information officially issued from JMA is seismic focal parameters, which are sent several seconds after detections of seismic signal at the nearest site at present.

Once earthquakes occur those focal parameters are calculated as soon as enough number of observation sites sense seismic waves, and are revised successively as seismic signals are received at larger number of sites in time, with the result that more accurate information is obtained. The transmitted parameters are used by application systems at sites to estimate specific information for particular users at particular site in order for triggering various disaster mitigation countermeasures including automated and/or half-automated responses.

Many of applications have been developed by consortium of concerned organizations as the Real- time Earthquake Information Consortium (REIC) and several companies. At present we are in the testing stage of the whole system consisting of official information issue from JMA, information transmitting using variety of media by several service organizations and testing of developed application instruments for several fields. From this summer on practical usage will start at least for the prescribed users. Full adoption of the system is expected to reduce a large portion of damages induced by major disastrous earthquakes amounting several tens percents.

Introduction

Two representative ways to reduce earthquake disasters is earthquake prediction and the construction of buildings capable of withstanding earthquake ground movements. In addition to this, various other reduction measures should also be employed, such as urban planning less vulnerable to natural disasters, speedy recovery and restoration systems, and mutual

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economical assistance in the form of insurance, etc. Comprehensive set of measures needs to be adopted in order to build a safe and secure society.

This paper will outline a new method for mitigating the damage caused by earthquakes, which involves the use of early warning information sent out immediately after sensing seismic waves at nearest sites to hypocenter. Although there may typically be a mere 1 to 10 seconds before the earthquake ground motion, it is thought that this brief lead time can be used not only for safety of lives, but also in a range of other ways for protection of property.

In Japan a R&D efforts aimed at developing practical applications for such systems are being carried out though collaboration between industry, academia and the government, as part of the Leading Project conducted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Here, we will provide an outline of this project to develop the early warning technology into effective utilization all over the country.

Previous real-time earthquake information for public use has focused on time ranging from several tens of minutes up to 24 hours immediately after earthquake hits, with the aim of providing information for emergency management products which helps local governments and enterprises to carry out disaster prevention activities. These R&D efforts came to the fore in the 1990s, and having learned lessons from the Kobe Earthquake. Those systems that are available work primarily for loss estimation using data obtained by strong-motion seismographs after large earthquakes begin.

On the other hands, after the Tokaido Shin-kansen sustained damage caused by earthquake activity, the Railway Technical Research Institute (RTRI) set about developing technology for detecting seismic occurrence and for using short lead time to secure only the safety of railway carriages in operation (Nakamura, S., 1996). After that, the UrEDAS (Urgent Earthquake Detection and Alert System), which would detect P-waves, predict the magnitude and epicentral position of the earthquake using single site data and then issue warnings, came into use. The Japan Meteorological Agency (JMA) and RTRI conducted research into making this system more advanced making use of real-time seismic data from the extensive network, i.e. NowCast Information System.

Then, from FY2001, NIED began another R&D of real-time earthquake information with the aim of using data collected from the high sensitive seismic observation network (High-Net) to issue earthquake EEW, not just to limited companies, but also to any organization and person in the whole country that would require it. This concept of general use with possibility of various customisations with cooperation of government and NGO (Figure 1) is different from similar previous efforts (e.g. http://www.seismolab.caltech.edu/early.html). After achieving several positive results, the system was introduced FY2002 for testing and trial by Fujisawa City of Kanagawa Prefecture in local governments.

The service needs an extensive seismic network covering the area. At present, there are several earthquake observation networks that have been set up by the Japan Meteorological Agency (JMA) and some that have been set by Headquarters for Earthquake Research Promotion (HERP). The JMA operates observation networks that aim to provide information to help citizens and disaster prevention organizations in charge of earthquake and tsunami disaster prevention. The digital strong-motion waveform observation network is made up of around 600 monitoring and observation stations. Tsunami and earthquake early detection network stations (of which there are 200) are used to install seismometer enabling UrEDAS type notification of earthquake parameters. Of the basic observation networks set up by HERP, currently it is only the high-sensitivity seismograph network (Hi-Net) transmitting data in real-time, enabling use for emergency management.

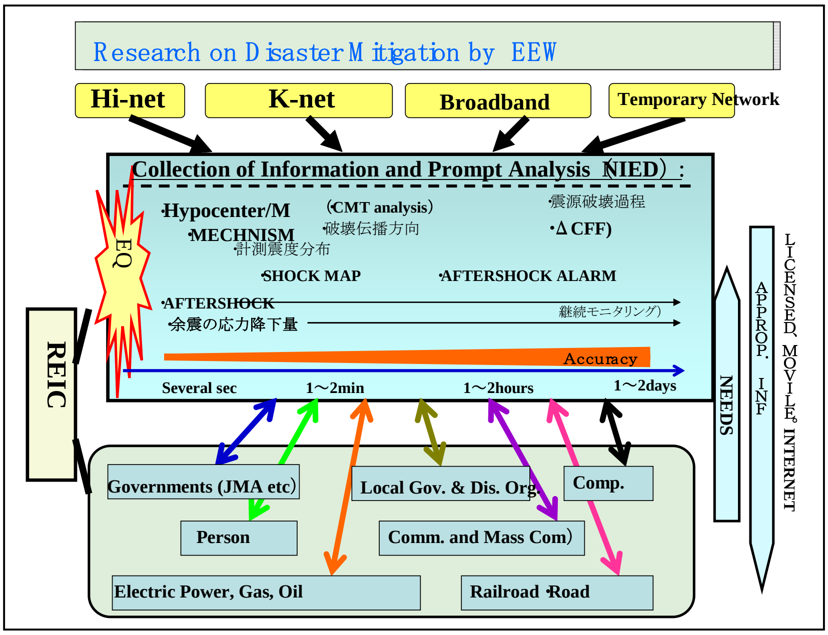

Fig. 1 Liaison system for the development project of EEW in Japan.

Earthquake Early Warning

In FY2003 the Research Project for the “Practical Use of Real-time Earthquake Information Networks” was launched as a five-year plan with the aim of integrating NIED's real-time earthquake information, with a view to developing practical applications for this information and putting it into practical use. The emergence and dissemination of a new disaster prevention system comes with high hopes, not only for the improvement of disaster prevention capabilities, but also in terms of the economic benefits it may yield. The project is expected to run for five years, with a planned budget of around 1 9 billion yen.

The structure of the project is outlined below (Hayama, 2005).
1) Research into processing of earthquake data

(1) Earthquake detecting system for Early Warning:
The aim here is to use earthquake waveform data to promptly analyse and provide information on the location of the seismic source occurrence time, and the magnitude of the earthquake.

(2) Development of Early Warning Information Generating System:
A system uses two kinds of algorithms of NIED (Horiuchi et al, 2005) and of JMA (Tsukada, 2005). The latter depends on the UrEDAS and territory method, the former arrival data as well as quasi-data that seismic waves have not yet arrived at residual sites.

(3) Transmitting system:
A system is developed enabling the speedy and highly reliable distribution of earthquake data for work operations. Use is made of dedicated line and satellite wireless communication system, as well as IP-VPN, local wireless, and mobile telephone network.

2) Development of basic data system for receiving side
A database is for underground (sedimentary) situation by using boring data collected by government and private companies in the past. The database is used in order to more accurately estimate site amplification factor of seismic waves to predict ground motion.

3) Tests and studies into practical use

(1) More than ten types of prototype systems have been developed and tested by REIC that is designed to support automated and semi-automated disaster-prevention responses using lead ones-several tens seconds before earthquake hits.

(2) Studies into impact of earthquake information
Studies and analyses are carried out into the effect on society of real time earthquake information when false alarm is sent.

EEW Systems

1) Methods for immediate seismic source determination
Earthquakes are the result of fault movements, and seismic waves spread outwards from the time when that fault movement is initiated (Fig 1) Ordinarily, if those waves reach three or more earthquake observation stations, seismological methods can be used to ascertain the location of the earthquake, the time of the quake and the magnitude of the quake. In the Earthquake Early Warning (EEW), uses are made of two types of seismic waves the primary (or longitudinal wave) called the P-wave that travels at around 6 km per second, and the transverse wave called the S-wave that travels at around 3.5 km per second. It is the S-wave that causes large horizontal ground movement referred to as the principal shock, which brings about earthquake damage. The S-wave is several times larger in magnitude compared with the P-wave If we are able to quickly estimate the location of the seismic source, occurrence time and the magnitude of the earthquake as soon as the P-wave reaches necessary number of observation stations and send that information out, then this may enable personal evacuation measures to be taken or protection activity to be shutdown prior to the offset of major ground motion.

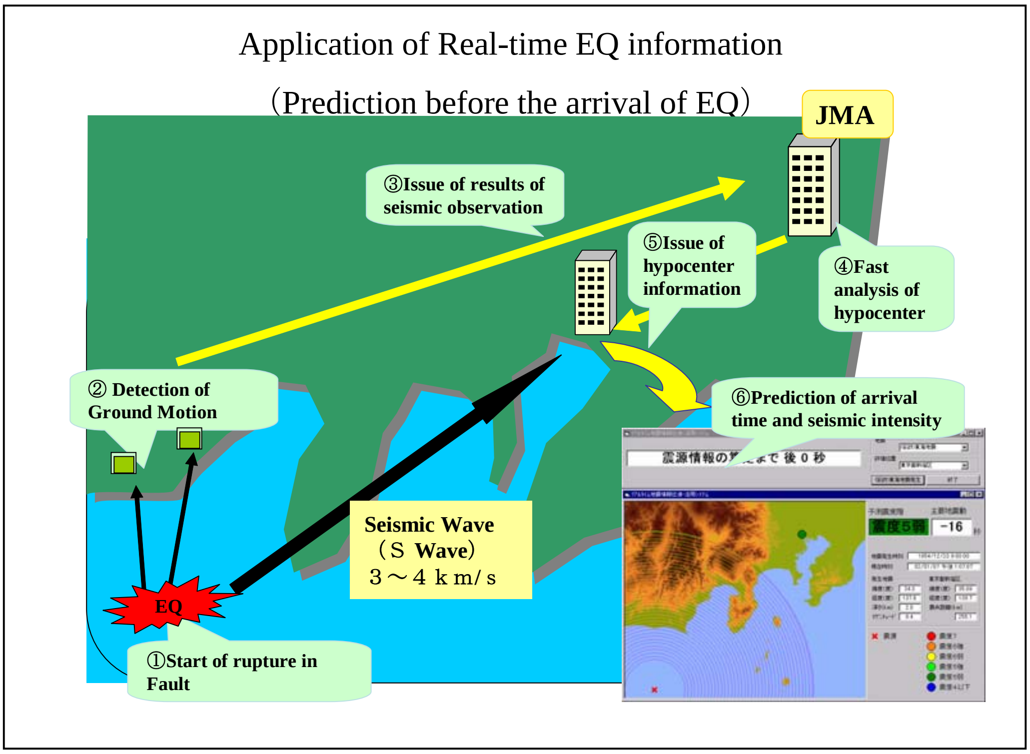

Fig. 2 Scheme of EEW in Japan and application image at any place of usage.

NIED's new seismic source determination system allows focal parameters to be estimated when P-waves are detected at the first two observation stations. The parameters of the seismic source are determined to a reasonably high level of accuracy (Horiuchi et at, 2005). The close spacing of observation stations at around 20-km intervals enables the algorithm effective. Seismic arrival data at some stations are used in conjunction with information that the earthquake has not yet hit other nearby stations (Arrival/non-arrival method). As time goes on, more observational data can be obtained, which can be used to recalculate the seismic source of more reliability. Once the estimation has been considered to be convergent the analyses finalized. The use of this method makes it possible to calculate in just a few seconds in most of cases, several tens times faster than ordinary method.

JMA uses a method to estimate the seismic source based on the envelope shape of the P-wave at one observation station (UrEDAS method). They also use the results of another predictions to estimate the location of the seismic source (Territory method). A combination of these two methods is used when the seismic wave has only arrived at one or two observation stations. Then, once the seismic wave reaches a third observation station, they can look for the seismic source using a 0.1-degree scale grid search to ascertain the horizontal position of the source. (Tsukada; 2005). Seismic source estimates using this method are continued until the seismic wave has arrived at five observation stations, after which seismic source predictions for EEW are complete.

NIED and JMA are now engaged in joint R&D as part of National Leading Project aiming at practical use of the information to various kinds of users by integrating these two methods. In this R&D the two are looking into ways to preside cross-references between the two methods, and at how to and speed up these methods. By FY2005, results based on two methods are compared and prioritised on the basis of evaluation results, and from FY2006 the plan is to integrate the algorithms themselves.

2) Determination accuracy and reliability
In current observation networks, its takes around two seconds firstly to determine the seismic source from when the seismic wave is detected at the first observation station. As time passes, the seismic wave reaches more and more observation stations, enabling the seismic source are successively recalculated providing more confident estimation. Figure 2 illustrates the immediate source determination of an earthquake (M 5.3) that hit Tottori Prefecture on

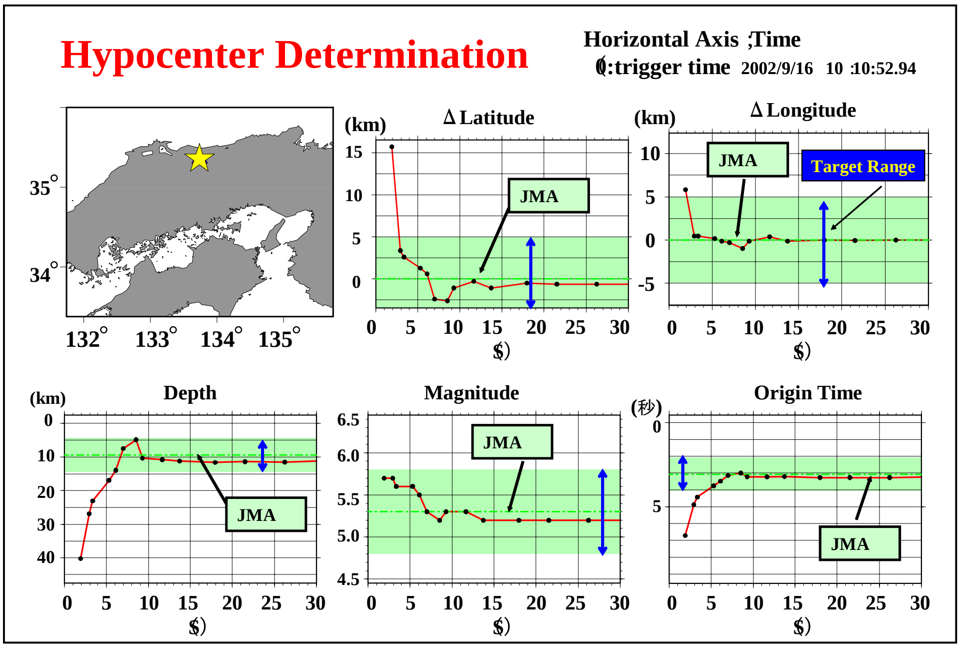

Fig.2 Example of seismic source determination as analysed by real-time systems for the Tottori Prefecture Earthquake (September 16, 2002). In the Figure dot denote EEW result, and "JMA" means the off-line official result reported by JMA ordinary after several days later.

September 16, 2002. Arrival time at the first observation station is taken as the starting point. In this example, seismic source determination begins 2.5 seconds, which is many times faster than in conventional methods.

Seismic sources were determined with around 95% accuracy in FY2003. This meant that of all noticeable tremors, erroneous information was sent out only for a few percent of cases. With subsequent R&D outcomes, the current success rate stands at around 99%, sufficiently reliable to be used in most of the situations. Through tests using the integrated data and the evaluation of contents of EEW, data is progressively being collected that can answer questions about how reliably automated control would be done, and how we can make the warning products more reliable.

These statistics are based on real-time information data prior to the integration of the two independent methods, and include statistics for small earthquakes as well. Since the integration of the two information systems, EEW is limited for earthquakes of magnitude of 4 or higher and estimated JMA seismic intensity of 3 or higher. If we look only at the statistics for information sent out for earthquakes with maximum intensity of 4 or higher, then we find that in the period from June to October 2005, there were zero cases of erroneous information being sent out (Sekita, 2005). Now many are of the opinion that this information has enough ability to put to use for at least to authorized users. However existence of small possibility of error causes JMA to deliberately consider how to use generally in country.

4) Distribution systems
On March 25, 2004, the JMA, which is in charge of the issue of information, began verification tests for EEW. The JMA and NIED are continuing to compare and investigate the various methods available and is continuing to work on integrating data processing methods to make the information more comprehensive, more reliable for the practical uses planned in 2006.

Since June 2005, JMA has been conducting trial distribution of the integrated information. At present, they select better results provided by the two processing methods with the result of establishment of order for priority. There are about 150 organizations receiving the EEW to develop systems for application of their own interests as users or vendors.

From FY2006, they will move on to the next stage, which will involve integrating the methods on the algorithm level to establish a consistent series of process to issue EEW. At this time, they will also look into new processing methods as well. The results of these verification tests are to be used to produce a processing engine for a next-generation Earthquake Early Warning operation system of JMA.

Development of disaster-prevention prototypes

REIC has been taking over the part of the project involving experimental study and research into making effective use of EEW, and is working on the development of earthquake disaster prevention systems tailored to the needs of different users. Their studies and research are field-specific and focus on 14 themes that span typical I I sectors. To achieve their aims, REIC has formed a working group (WG) for each field where systems are to be used that consists of members who are academic experts from universities, research institutes, governmental organizations, and related industries. An overview of the R&D initiatives is outlined below.

1) Database
Compiling research outcomes and technical information are to be shared amongst researchers and developers. It makes research activities more efficient, make effective use of information, and will alleviate problems such as development redundancies, etc.

2) Development of an earthquake disaster-prevention system.
Development efforts are divided up into two areas: earthquake disaster prevention, and data transmission. Research in the former area involves looking into the following 10 themes.

(1) Fire department systems,
(2) Medical systems,
(3) Home electronics system,
(4) School system,
(5) Plant system,
(6) LPG systems,
(7) Outdoor activity systems,
(8) Building maintenance systems,
(9) Elevator systems, and
(10) Dam systems.

For example, in the case of medical systems, the aim is to ensure that EEW is issued as soon as possible, so that the safety of patients, doctors, nurses and other staff is secured, unforeseen circumstances during surgery are prevented, medical testing equipment in operation is stopped. And initial emergency system is established as soon as possible to support mass relief and rescue efforts. The system supports to ensure that the safety of staff can be confirmed and that staff can be mobilized before communications lines become congested.

The design of information appliance of home electronics has involved investigating to what extent earthquake damage to households can be minimized, with survey data on damages incurred during the Kobe Earthquake. Those were used as the basis to identify prerequisites for minimizing such damage. Surveys and reports show that the moment an earthquake hits, people become panicked, and although normally they know that they need to extinguish all flames and open doorways and exits, at that moment all they can do is nothing but get down on the ground.

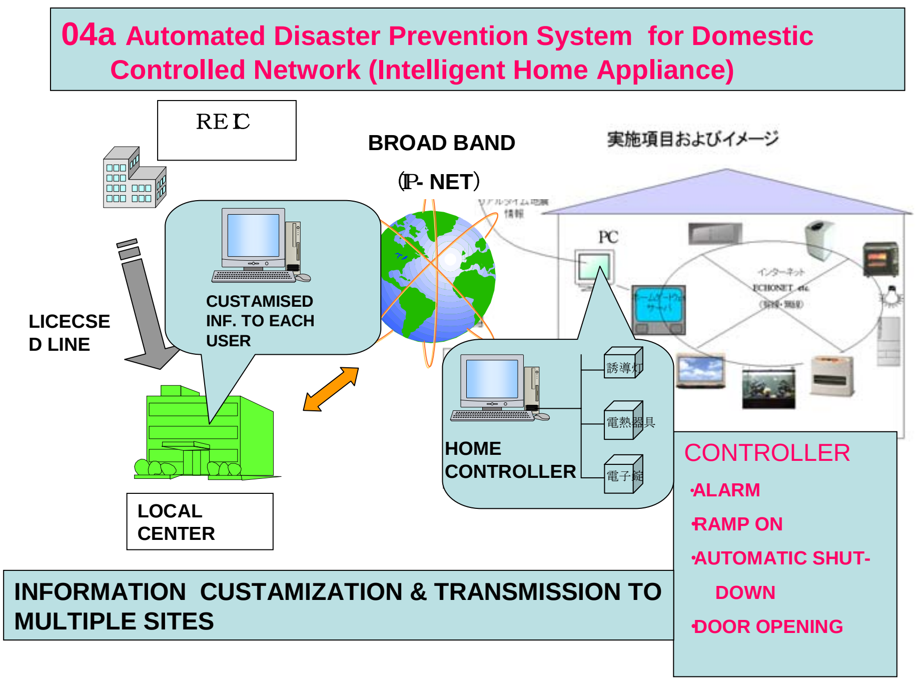

Fig. 3: Overview of automated disaster prevention system for information control appliances for household.

This finding lead to the idea that it is important and effective to automate, as best as possible, measures for cutting off heat sources and securing evacuation routes. During the development of systems, these findings are being incorporated into the design process.

For school systems, the first aim is to save lives of children, and the second aim is to use school education to promote the dissemination and use of EEW, in order to develop, as quickly as possible, a social environment in which emergency earthquake information is able to be used effectively. (Fig. 4) Through training and drills in schools, efforts are being made to mitigate the damage incurred at the time of an earthquake, and to educate around one million citizens a year to promote the use of emergency earthquake information.

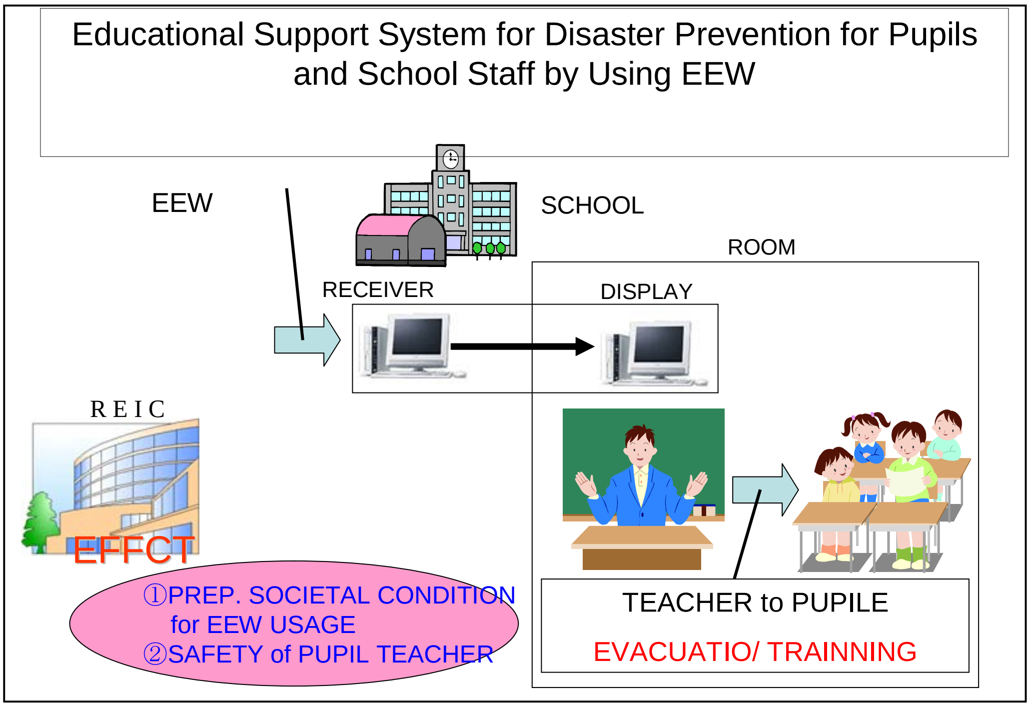

Fig. 4: Overview of disaster-prevention education support system for school students and staff using earthquake early warning (EEW).

3) Development of data transmission methods
The following four themes are being focused on in the development of data transmission methods.

(1) Disaster prevention wireless systems,
(2) IP telephone systems,
(3) Public mobile communications systems, and
(4) FM broadcasting systems.

In the development of these systems, new data transmission systems are not being developed, but rather, for the mean time, development is focused just on finding ways to transmit EEW basically over existing data transmission systems. Enough fund is expected to be prepared by communication companies as the market expands. For FM broadcasting systems, the aim is to distribute information using existing FM broadcasting systems for the transmission of information to a large number of registered users with minimum transmission delay. We expect digitalisation of FM radio will open the road to use of the channel for a transmission of the warning.

Discussion

It is without saying that any of people should be given chance to use the information. As to the EEW, however, the information has intrinsic limitation as possibility of error and false alarm making the general use difficult. So that the practical usage is going to start from registered users postponing the warning by broadcasting a little while. .

The issue to be considered now is how to make such systems (a) cause less confusion, and (b) more helpful. It is highly likely that when information is provided to people in a form that they are not used to, then even if this information does not cause con-fusion, it still may not be very helpful either. For safety managers such as of departments and hotel, to better fulfil their responsibilities, they may simply decide to use such systems just to provide information only to own staff not to public. However, it may be problematic that while warnings can be issued to registered staff within a building, there is no way of warning to those people passing outside the building where the broken window glass is expected to be showered down. There is no doubt that further investigation how to use for passengers or mass at arbitrary "time, place and opportunity" is needed.

Even when earthquake prediction becomes possible, the best choice would probably be to rely on EEW and continue on with certain societal activities after earthquake prediction information has been issued, being aware that the earthquake could hit at any time. This idea involves using earthquake prediction information and EEW together as a pair. Studies into what is needed to make effective use of EEW have shown that there is a high need for earthquake prediction, and that many people want prediction information that will give them several hours or several days warning, as opposed to the 10 or so seconds available to them by using EEW are issued. The earthquake disaster prevention community needs to address these demands in earnest.

Conclusion

With the establishment of intense earthquake observation networks, it is become increasingly possible to predict strong ground movement before earthquakes wave hit, enabling disaster prevention measures to be employed in advance. The development of prototype systems designed to make effective use of EEW through automated or semi-automated operations is also progressing steadily, with practical applications for registered users due to emerge in FY2006. However, issues still remain that need to be resolved before applications for indiscriminate people can be started. These issues must be resolved through collaboration between relevant organizations, and understanding and cooperation on the part of users. Service companies, organizations, and individuals need to get involved in order to find practical applications of EEW so as to minimize the damage that will be caused by large earthquakes to occur at unexpected time.

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