# STRATEGY FOR TAKING FULL ADVANTAGE OF EARTHQUAKE EARLY WARNING SYSTEM FOR EARTHQUAKE DISASTER REDUCTION

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**ABSTRACT :**

On October 1st 2007, the Japan Meteorological Agency (JMA) started disclosing Earthquake Early Warning (EEW) information to the general public. Although this information can be very useful to reduce damage in coming earthquakes, if used inappropriately, it could, in the worst case scenario, be more damaging than no information at all. In order to avoid this situation, it is important that the general public understands the meaning and limitations of the information that is being provided therefore avoiding false expectations.

The EEW system uses the difference of wave velocity between Primary wave (P-wave) and Secondary wave (S-wave), to disclose the seismic intensity and arrival time with considerable accuracy before the strong ground motion is felt. As many seismometers have been installed in Japan, when an earthquake occurs, the nearest location seismometer can detect P-wave and this information will be immediately be sent to the JMA. Using the information, JMA can calculate the location and magnitude of the earthquake from which the observed P-wave is generated within 4 seconds since the P-wave detection time. With occurrence time, location and magnitude of the earthquake, seismic intensity and arrival time of the expected ground motion can be estimated and informed to the persons who are located at some distance from the earthquake source.

The EEW system has six steps: a) P-wave detection by the nearest location seismometer, b) data transmission to JMA, c) calculation of location, magnitude and occurrence time of the event by JMA, d) delivery of the information to dissemination and disaster-related organizations by JMA, e) delivery of the information by these organizations to users, f) use of the information for disaster reduction by the users. In this paper, issues with the current EEW system will be classified following to these steps and discussed. Then, their solutions will be introduced for proper use of EEW system.

**KEYWORDS:** earthquake early warning, real-time earthquake information, disaster imagination, Japan Meteorological Agency

## 1. INTRODUCTION

The Japan Meteorological Agency (JMA) started disclosing Earthquake Early Warning (EEW) information to the general public on the 1st October 1st 2007[1)] almost one year after the advanced system, intended for special users, was launched. Since the start of the service, there have been some troubles and as a result EEW information was not delivered to the affected sites before strong ground motion arrived as expected. Many mass media repeated the limitation and negative aspect of the system and sometimes they reported that EEW system have no meaning.

Different from the advanced system, in case of ordinary EEW system, the general public, who are not trained well and do not understand well the meaning and the limitations of EEW information and how to use the information, are the potential users. There are many issues for proper use of ordinary EEW system. In this paper, I will summarize the issues and introduce their solutions for properly use of EEW information provided by ordinary EEW system. Issues will be classified into six following the six steps of EEW system. Also, I will explain the effects of EEW information and point out the importance of indirect effects of EEW system.

## 2. FUNDAMENTAL KNOWLEDGE ON EARTHQUAKE EARLY WARNING INFORMATION

### *2.1 Basic knowledge and terminology for EEW system*

Earthquake is generated by the rupture of the underground seismic fault. As shown in Figure 1, fault rupture is spatial and temporal behavior and the rupture starting point is called hypocenter and its right above ground surface point is called epicenter. During the rupture of the fault, stress wave is generated and propagated. This wave vibrates ground and is called seismic wave. There are two kinds of seismic waves, one is body wave and the other is surface wave (Figure 1). Body wave, traveling directly from the fault to the observation point, is composed of two type of the waves, primary wave (P-wave) and Secondary wave (S-wave). P-wave is longitudinal wave and its component is along the propagation direction. It is usually felt as an up-down movement. While S-wave is shear and transverse wave, its component is perpendicular to the propagation direction. It is usually felt as horizontal movement and is major cause of earthquake damage. Surface wave, traveling to the surface and then propagate along to surface to the observation point, is composed of two types of waves, Rayleigh and Love waves. It affects large tanks and bridge, and high rise buildings.

Although there are some varieties due to stress condition and asperity characteristics on the fault plane, definition of the magnitude, which explain the energy of the earthquake, can be generally discussed by the final rupture area of the fault. However, at the beginning and/or progress stage of the rupture, it is physically impossible to determine accurately the final magnitude of the event. There is a trade off the between available time and accuracy.

When we measure the ground motion by seismometer, waves such as shown in Figure 2 are recorded. From the records, we ca understand that the order of the wave propagation velocity and predominant frequency is P-wave , S-wave and surface wave and that of the predominant period from longer one is opposite.

EEW system is that using the difference of wave velocity between P-wave and S-wave, before strong ground motion attacks the observation point, seismic intensity and arrival time is informed with considerable accuracy. As we have installed many seismometers in Japan, when an earthquake occurred, nearest location seismometer can detect P-wave and this information will be immediately sent to the JMA. Using the information, JMA can calculate the location and magnitude of the earthquake from which the observed P-wave is generated by around 4 seconds since the time of the P-wave detection. With occurrence time, location and magnitude of the earthquake, seismic intensity and arrival time of the expected ground motion can be estimated and informed to the person who is located a little far from the earthquake. This is EEW system.

Distance from the observation point to earthquake can be calculated by the Equation (1).

$$L = \Delta t \cdot \underline{Vp \cdot Vs/(Vp-Vs)} \qquad (1)$$

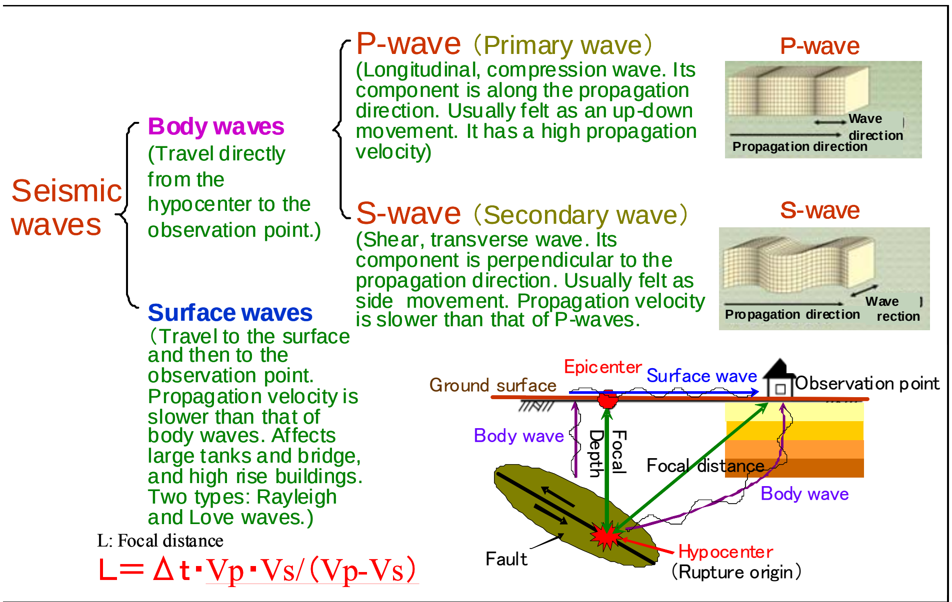


Figure 1 Types and characteristics of seismic waves

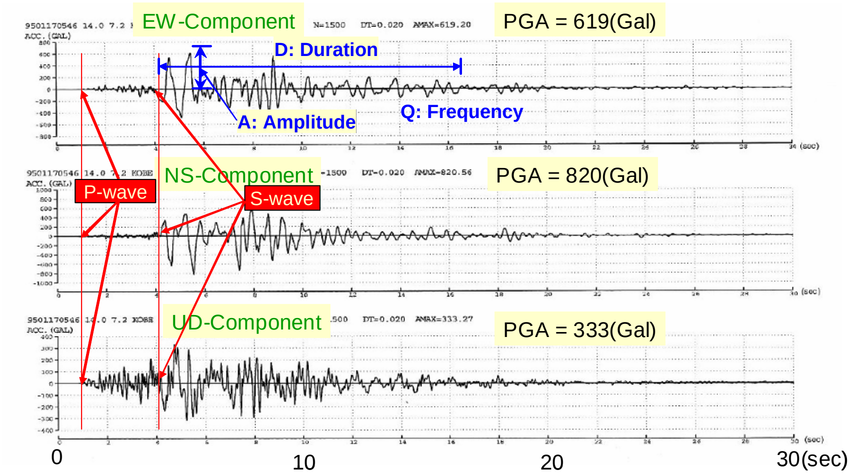


Figure 2 Three important characteristics of ground motion causing damage
(1995 Kobe ground motion observed at Kobe Marine Meteorological Observatory)

where $\Delta t$ is P-S arrival time difference, Vp and Vs are P-wave and S-wave velocity, respectively.

As the underline part of the Equation (1) is normally 7 to 8 km/s, considering four seconds required for calculation, distance, L becomes around 30 km. Therefore, even if seismometer is located at the site of the earthquake, it is impossible to deliver the warning before strong ground motion arrives within 30 km focal distance.

### *2.2 Relation among earthquake damage and ground motion characteristics*

Figure 2 shows the 1995 Kobe earthquake ground motion recorded at JMA Kobe marine observatory station. Effects of ground motion on earthquake damage can be discussed by three major parameters, such as A: maximum amplitude, D: duration and Q: frequency characteristics of the strong ground motion. Damage becomes severer when the maximum amplitude is larger, duration is longer, and frequency characteristics are close to those of target system and structure as resonance may occur. JMA seismic intensity, the most popular index to discuss the effect of ground motion in Japan is also defined by basically these three parameters.

There are also three major parameters that strongly affect above mentioned three parameters of ground motion. These are 'source characteristics', 'wave propagation path from source to the observation point', and 'site effect of observation point.' Each of them can be discussed by mainly, magnitude of the earthquake, focal distance, and surface soil condition of the site, respectively. Table 1 describes relations among these three by three parameters. Understanding these relations is the key to use well of EEW system.

Table 1 How do ground motion characteristics affect damage?

| | Source characteristics | | Propagation path and distance | | Local site effect | |
|---|---|---|---|---|---|---|
| Representa-tive parameters | Magnitude（M） (Source effect) | | Focal distance (Between observation point and fault) | | Ground conditions Topography | |
| | Larger | Smaller | Longer (Further) | Shorter (Closer) | Hard soil | Soft soil |
| A: Maximum amplitude | Becomes larger | Becomes smaller | Becomes smaller (Attenuated) | No change | No change | Amplification (However, if soil liquefies, the shaking becomes less intense) |
| D: Strong motion duration | Becomes longer | Becomes shorter | Becomes longer (However, amplitude becomes smaller, then damage decreases) | No change | No change | Becomes longer |
| Q: Frequency content | Low frequency component increases | High frequency component increases | Low frequency content increases (Because high frequency component attenuates faster) | No change | No change | Low frequency content increases (Predominant period becomes longer, low frequency waves amplify) |

When you discuss the effects of magnitude on ground motion, the other two, i.e. focal distance and surface soil condition should be fixed. When a magnitude is lager, maximum amplitude becomes bigger, and duration does longer and relatively lower frequency component, which affects strongly structural damage, does predominant. About the effects of focal distance, when it is longer, maximum amplitude becomes smaller, and duration does longer but its effect is less as amplitude becomes smaller, and relatively lower frequency component does predominant as high frequency components attenuate. About the surface soil condition at the observation site, when the ground is softer and thicker, maximum amplitude becomes lager, and duration does longer, and predominant frequency does lower.

### *2.3 Relation between ground motion parameters and EEW system*

Based on characteristics discussed above, the relation between ground motion parameters and the EEW system may be found as summarized in Table 2. For instance, when an earthquake with large magnitude occurred close to the observation site, it is difficult to deliver EEW information to the site before ground motion attacks the site. Good condition earthquake with high efficiency of EEW system is large magnitude one but focal distance is some long. As distance is long, available time is longer but because of large magnitude, damage may occur.

Table 2 Relation between ground motion parameters and earthquake early warning

| | **Source characteristics** | **Propagation distance and path** | **Observation point topography, soil conditions, others** |
|---|---|---|---|
| **Relation to earth-quake early warning** | There is a trade off between accuracy and time. Earthquake is an spatial and temporal event and its magnitude becomes bigger as the fault plane area becomes larger. In case of a large earthquake, it takes time for the rupture to take place. As a result, it takes time to identify it and issue the warning, leaving shorter time for action. If the warning is issued sooner – with less certainty – more time for action is available but also a larger chance of an inaccurate evaluation. | The time between the warning and the shaking is shorter if the focal distance is shorter. The warning system is not so effective for locations close to the epicenter of large earthquakes. This areas are expected to have the largest damage. The system is most effective for locations not so close to the epicenter of a large earthquake. | Even for the same magnitude and focal distance, the shaking amplitude, frequency content and duration can be very different depending on the observation location. Even in the same building, the shake at the basement or at higher up floors is very different. In a car, on a viaduct or a bridge, the shake is affected by the dynamic response of the viaduct/ bridge. At a building construction site, the response changes with the changing characteristics of the structure being built. |

The effect of site condition on the ground motion characteristics is also very strong, for accurate ground motion information delivery and efficient response based on it, it is important to consider the user's location and his/her site condition beforehand. Even the same magnitude of the event same focal distance, when the soil condition is different, ground motion become different, even soil condition is also the same, shaking that the user will feel is quite different at under ground, ground surface, and upper floor of high rise building. The motion that a car driver will feel on elevated high way bridge, is driver's seat response due to response of driving car due to amplified structural response of bridge due to strong ground motion. The characteristics on the motion, that a person working at the building construction site will feel, is changing everyday based on the progress of construction of the building.

## 3. ISUSES FOR WELL USE OF EARTHQUAKE EARLY WARNING SYSTEM

### *3.1 Issues in general*

There are two levels of use of EEW system. One is an advanced system and the other is general public use system. Ideal use of EEW information is advanced one and is that first, ground motion intensity and arrival time are calculated accurately considering the user' condition, secondly, the information is delivered immediately and surely to the user, thirdly user uses them well based on pre-event good preparation and training and reduce the damage as much as possible. However, in case of ordinary system different from an advanced system, the general public, who are not trained well and don't understand well the meaning and the limitation of this information and how to use it, are potential users. Therefore, it is very difficult to deliver the information considering user's location, expecting seismic intensity, and available time before arrival of strong ground motion attack. Then in case of ordinary EEW system, JMA consider the conditions below for information delivery to avoid troubles.

a) the number of information delivery of one event is one in principle, b) information is delivered only when strong ground motion is expected, c) prevent false information delivery by mistake, d) deliver the information as soon as possible, e) proper description which can consider estimation error is adopted, f) confine areas with some accuracy where countermeasures such as evacuation is needed, g) include information that is necessary for information delivery by TV broadcast. Namely, JMA decided to deliver EEW information to the areas where JMA seismic intensity is expected 4 or more when at least two stations detect ground motion with JMA seismic intensity $5^{-}$ or more. National land is divided into 200 parts and each part is used for area unit for information delivery. Concrete value of seismic intensity and available time are not informed.

It is understandable that JMA decided to serve ordinary EEW system in the above mentioned manner. However, I think that in future even the system for the general public had better aim to be advanced system. Therefore, in this session, I will summarize the issues towards future advanced system and introduce solutions for them.

Figure 3 shows the total processes of EEW system. As shown in the figure, there are six steps from P-wave detection to use of EEW information by users. a) P-wave detection by the nearest location seismometer, b) send this information to JMA, c) JMA calculate location, magnitude and occurrence time of the event, d) JMA deliver them to information dissemination organizations and disaster-related organizations, e) information dissemination and disaster-related organizations deliver them to users, f) users use them for disaster reduction. All the issues on each step will be classified into two, i.e. information dissemination and receiving sides, and discussed.

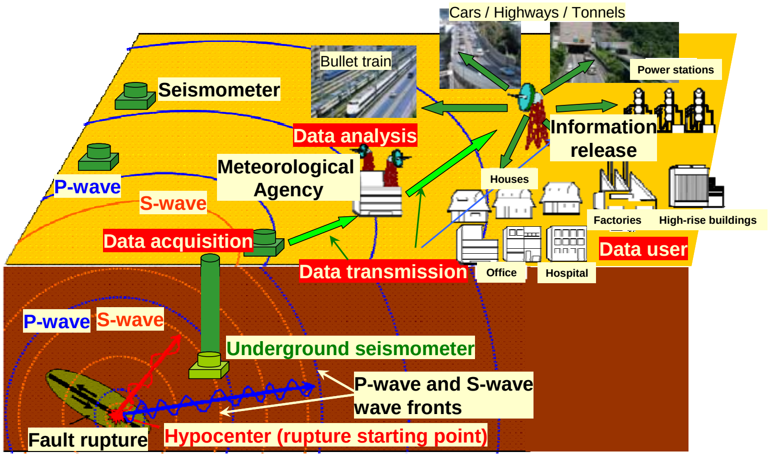


Figure 3 Earthquake early warning system (Processes and tasks)

### *3.2 Issues for information dissemination organizations to deliver information quickly and correctly*

Among the six steps of EEW system, five ones from a) to e) are issues for information dissemination side issues. However, step e) has both aspects as the organization receives the information from JMA. Information dissemination organizations are required to detect P-wave as soon as possible after earthquake, calculate the location, magnitude and occurrence time of the event accurately and immediately as much as possible, and deliver them to users as soon as possible. I will explain briefly about relations between these missions and all five steps from a) to e).

P-wave detection by the nearest seismometer of above a) is for quick monitoring of ground motion, therefore, it is important to install seismometer at the site close to event. To implement this situation, installation of dense seismometer array network, deep bore hole seismometers, ocean bed seismometers, are important. In case that target seismic fault is recognized, seismometer network near to the fault is effective. Sending P-wave information to JMA of b), Analyzed data delivery by JMA to information dissemination organizations and disaster-related organizations of d), and EEW information delivery by information dissemination and disaster-related organizations to users of e), etc. are all issues related with quick information transfer and its reliability. On the calculation of location, magnitude and occurrence time of the event by JMA of c), improvement of method and system is a key issue. About EEW information delivery to users by information dissemination and disaster-related organizations of e), consideration of users' situation and purpose of EEW is key as contents and accuracy of EEW information are different. About the use of EEW information by users for disaster reduction of f), disaster imagination of user is the key issue.

### *3.3 Issues for information receivers to use EEW information smoothly and correctly*

For information receivers to use EEW information smoothly and correctly, disaster imagination is a key issue as well as understanding the meaning and limitation of EEW information. It is impossible for people to respond well for unimaginable situation. To improve disaster imagination capability, I have developed some tools, such as Meguro-method[2)] and Meguro-maki[2)] which is simplified version of Meguro-method. With the Meguro-method, table as shown in Figure 4 is used. Vertical axis shows the typical daily life pattern and horizontal axis shows the time since the occurrence of the earthquake. When the daily life patterns are prepared, seismic capacity of the house, furniture layout, environment around your home and your working company, location and actions of other family members depending on time, etc. are also checked. Moreover considering the case that transportation system cannot be functional, check the time needed for walking. Then, assuming season, weather, day of the week, with the condition that earthquake occurred at each time of your action, imagine what will happen around you as time passes, and consider what you should do in such each situation. Many people cannot write anything as they can imagine nothing. This means that they cannot perform well in case earthquake occurs. Strong points of Meguro-methods are; a) people can understand fully that earthquake is their own problem, b) People can understand that ordinary, abled person is considered as temporally disabled person, c) people can understand multiple tasks that individual person has, and d) people can consider the story after they died in disaster. By these points, people can improve their disaster imagination capability.

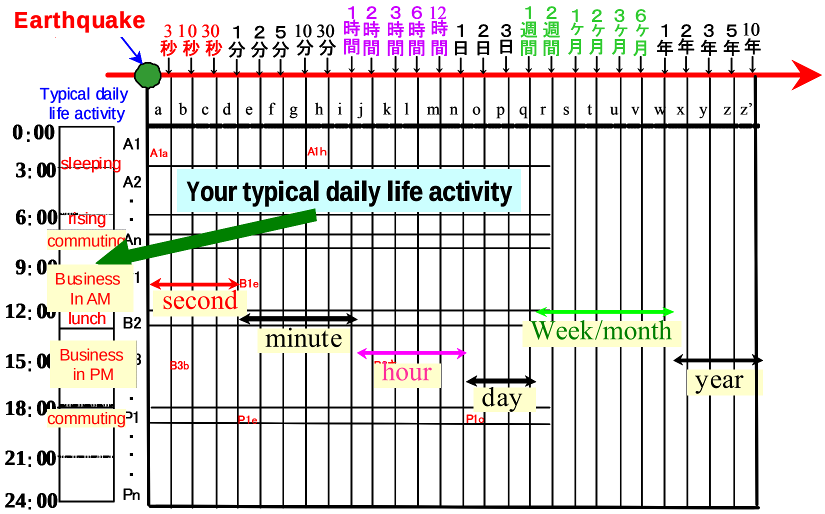


Figure 4 What will happen around you when you feel strong ground motion?

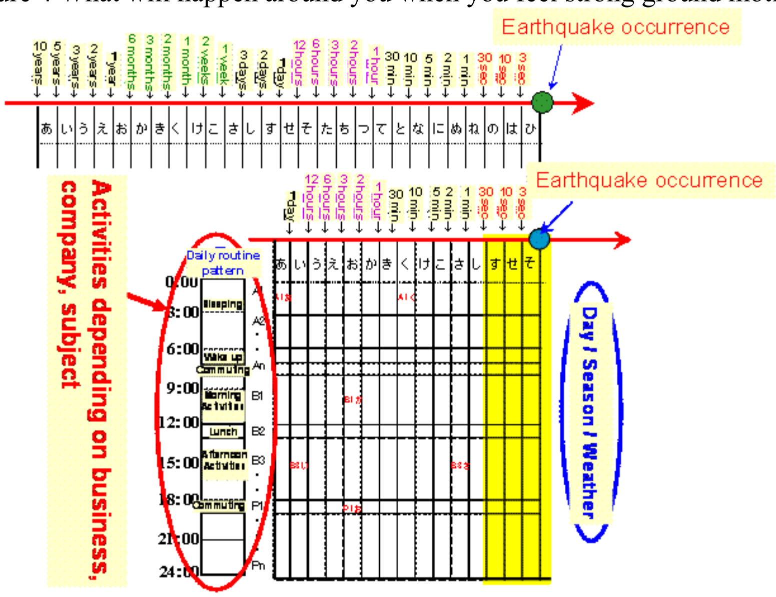


Figure 5 What can you do before an earthquake occurs?

As the next step of the method, different table as shown in Figure 5 which shows the time up to the future earthquake is used. Once disaster imagination capability is improved, people can understand their own current problems and they start thinking seriously about solution of the problem and can use the time before earthquake comes to solve these problems. Then, their disaster resiliency can be increased before an earthquake and damage due to future earthquake can be reduced. While conventional style of disaster training such as 'Do A, do B, don't do C' may stop the people thinking disaster seriously and has less education effect. What we should do from now as disaster education is to increase the number of the people who can really imagine what happens around them and what they should do in disaster as time goes since it happens considering the conditions, such as, time of occurrence, season, weather, location, and their roles at the time, etc. When the available time becomes less than tens of seconds, this is a time range for EEW system as shown in the bottom table in Figure 5. To use efficiently this limited time, detailed information of user's situation is essential. People recognize the importance of pre-event preparation.

## 4. DIRECT AND INDIRECT PLUS AND MINUS EFFECTS THAT EEW SYSTEM HAS

The effects that EEW system has can be classified direct and indirect, and each plus and minus. So far, direct effects have been focused as major discussion points. However, I believe that indirect effects are the more important and we should pay much more attention to indirect effects. I will introduce direct and indirect effects, and their each plus and minus aspects.

Direct plus effects are that many people expect. With better understanding of meaning and limitation of EEW information and preparation for efficient use of EEW information, EEW information can be used for disaster mitigation. Typical examples are human casualty reduction by proper evacuation guidance based on EEW information, structural damage reduction by vibration control based on EEW information, Machine trouble prevention such as elevator and industrial machines by automatic stoop system based on EEW information, fire problem reduction by automatic stop system of gas and electric heater by EEW system, damage protection by over turning protection devices automatically controlled by EEW system, Start of action and preparation of emergency operation of fire fighting offices and of hospitals, traffic accident prevention of train and cars by EEW system.

Direct minus effects are also well known. In case that people don't know well about meaning of EEW system and how to use it, EEW information may give some trouble to the people and they cannot use it well for reduction of damage, they may increase damage, especially in the case that they become panic. This situation should be avoided and a key is education and training beforehand. Improvement of disaster imagination capability is essential issue for education and training as explained before.

Indirect plus, which was not so far used widely, but only limitedly used for education. However, I think that for ordinary EEW system, this indirect plus effects should be considered the most important. EEW information dissemination is an initial opportunity for the general public to promote real disaster mitigation countermeasures. With the start of EEW service, people start thinking how to use EEW information. If we have two seconds, five seconds before strong ground motion attacks us at living room, what we can do for save us and disaster mitigation. How about sleeping time? If the house is collapsed, furniture is over turned, we cannot evacuate. When the people's imagination capability is high enough through such as Meguro-method and/or Meguro-maki, they can recognize the importance of pre-event preparation and countermeasures, and understand that there are many damages that cannot be prevented only by EEW system. Finally, people conclude that pre-event countermeasures such as installation of furniture over turning protection device and retrofit of structure, creation of disaster resilient city are very important and these countermeasures are promoted. Then, in both cases that EEW system can and cannot give time before strong ground motion arrival, damage can be reduced by pre-event countermeasures.

About indirect minus effects, I think that this should be absolutely avoided. The effects are that EEW information reassures the general public about earthquake risks without any valid evidence. This hinders the general public from promoting pre-event countermeasures. As the result, future earthquake damage increases. Also, the effect on the stock market is considered a kind of indirect minus effect. Besides the earthquake damage, big negative economical impact can be given to the affected area and the country by EEW system. To make EEW system popular in the world for earthquake disaster mitigation in the world, we should prevent such a situation. A new stock market regulation should be established from international viewpoint.

Table 3 Effects of early earthquake warning
(Direct effects are usually discussed. However, indirect effects are also very important, often overlooked, and should be discussed.)

| | Direct effect | Indirect effect |
|---|---|---|
| **Positive impact** | Early earthquake warning can reduce damage | Opportunity to promote disaster countermeasures before the event |
| **Negative impact** | Improper use of the disclosed information may lead to more damage. | -Unreal sense of safety hampering disaster countermeasure implementation<br>-Influence on stock market etc. |

## 5. CONCLUSIONS

In this paper, I summarized the issues and introduced their solutions for properly use of EEW information provided by ordinary EEW system. Issues are classified into six, following six steps of EEW system from P-wave detection by seismometer to end user's EEW information use, and discussed. Also, I explained the effects of EEW information and pointed out the importance of indirect effects.

Different from an advanced system, in case of ordinary EEW system, the general public, who are not trained well and do not understand well the meaning and the limitations of EEW information and how to use the information, are potential users. JMA's current principle on EEW information service is understandable. However, for better use of it, we had better pay much attention to indirect effects that EEW information has. Efforts for increase indirect plus and decrease indirect minus lead the general public to increase direct plus and decrease direct minus. For implementation of this environment, disaster imagination is also a key issue as well as understanding the meaning and limitations of EEW information. It is impossible for people to respond well for unimaginable situation. To improve disaster imagination capability, I recommended using the tools, such as Meguro-method and Meguro-maki. With these tools, when they improve their capability, they can understand their current problems and can use the time available before an earthquake to solve their problems.

Also, when they try to find the good way to use EEW information considering their own situation, they can recognize that there are many damages which cannot be reduced or prevented by only EEW system, and can realize that they should take actions long before an earthquake occurs. The most important and effective actions should be taken much earlier. The public should recognize that EEW information alone cannot reduce much of the damage unless there is good preparation before the event. We should never face a situation in which we visit an elementary school after an earthquake and realize that the well prepared and warned students protected themselves under their desks just to be killed by the collapsed structure. Only if structural measures are taken before the earthquake, it will be possible to take fully advantage of any EEW information. The launching of this type of system is offering a unique opportunity to discuss disaster countermeasures and to increase disaster awareness among the general public.

I believe that the ideal use of the EEW information is that dissemination of this information becomes a good opportunity for the general public to consider more seriously about earthquake problem and improve disaster imagination capability. As a result, EEW information becomes a driving force to promote disaster mitigation countermeasures, such as retrofitting of low earthquake resistant structures, and to increase our society resilience. We should not have false expectations that EES information alone will reduce earthquake damage.

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