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ON THE URGENT EARTHQUAKE DETECTION AND ALARM SYSTEM (UrEDAS)

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SUMMARY

This paper describes a new intelligent earthquake warning system, UrEDAS. Generally, conventional earthquake warning instruments issue a warning when the earthquake motion exceeds a preset level. The UrEDAS, in contrast, judges the destructive potential of the earthquake based on magnitude and location of the earthquake, and issues the warning only if neccessary. The UrEDAS estimates the magnitude and the location immediately after the P wave arrives by using the seismic motion of a single observation point. When the S wave arrives, UrEDAS re-estimates these values more accurately. Consequently UrEDAS has a two step warning: first a quick warning after the P wave arrival and second an accurate warning after the S wave arrival.

INTRODUCTION

In the morning of 19th September, 1985, a large earthquake strongly affected 17,000,000 persons in Mexico City. A newscaster on the Morning TV news announced, "Please wait until this earthquake has come to an end. It is 19 minutes 42 seconds past seven.". But the earthquake motion steadily increased and at last the TV image went blank, about 20 seconds later. At that time, buildings collapsed at various places in the city. This earthquake concretely shows that an unexpected disaster occurs when a large earthquake suddenly strikes a big city without protection. It is expected that disaster can be mitigated by protection and accurate prediction of earthquakes. As earthquake prediction techniques are still developing, it will take a long time before they can be used practically. If, on the other hand, an earthquake warning is issued immediately after a large earthquake occurs, we can behave rationally and mitigate the earthquake hazard. Therefore, there are many warning seismometers in Japan.

<u>Conventional Warning Seismometers</u> Most warning seismometers issue a warning when the seismic acceleration exceeds a preset level. Also warning seismometers that use vibration energy are developing. These warning facilities inform only of earthquake motion at a specific point, not informing of other earthquake factors. The relationship between earthquake motion and damage is very complex and unclear. Consequently, it is not clear what countermeasure should be taken after the warning is issued. The preset levels are set rather high to eliminate false alarms. The excess of the preset level generally appears after S wave arrival. Then the warning issued by conventional means is too late for many facilities, such as Shinkansen.

<u>P Wave Detection System</u> If an earthquake can be detected at the initial P wave motion, and, as long as the preliminary tremors continue, then the time available for preparation can be increased in comparison with the case by the conventional method. In the case of the P wave detection by which a warning will be issued while the earthquake motion is still low, it is important to judge whether the

detected minor tremors are the P wave portion of a large earthquake or the principal motion of a minor earthquake. This is due to the fact that many warnings could be issued in vain as minor earthquakes occur more often than large earthquakes. Therfore, in order to avoid the issue of false alarms, it is necessary to judge the destructive potential of an earthquake precisely. As shown in Fig. 1, the pattern of rail damage so far experienced during seismic motion indicates that the destructive potential of an earthquake can be roughly judged based on its magnitude and on the distance of the affected railway structure from the epicenter. The P wave detection system is named "UrEDAS", which stands for Urgent Earthquake Detection and Alarm System. In addition, the UrEDAS is pronounced "Yuredasu", and this literally means "shaking begins" in Japanese.

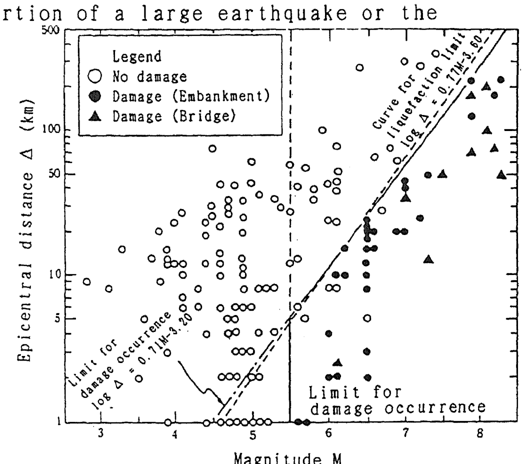


Fig. 1 Earthquake Damages on Magnitude(M)-Epicentral Distance(Δ) Plane.

CONVENTIONAL METHOD OF SEISMIC FACTORS ESTIMATION AND ITS PROBLEMS

Studies on systems automatically estimating seismic factors have been conducted by the departments of science in some universities, in conjunction with their earthquake predicting activities. However, the seismic waveforms obtained at three or more observation points are generally needed for estimating seismic factors, and these waveforms must always be transferred to a waveform processing center. The greatest problem is that the work of estimating the seismic factors cannot be started until after arrival of seismic motions from many observation points, and therefore it takes time to complete the estimation work.

BASIC CONCEPT AND CHARACTERISTICS OF UrEDAS

A warning system presently being developed by the Railway Technical Research Institute (RTRI) promises to be completely different from the conventional warning systems in that it issues an earthquake warning based not only on its maximum seismic motion but also on an estimate at the initial stage of seismic motion of the destructive potential of the earthquake . The warning system's task is to estimate the magnitude of the earthquake as well as its epicenter based on the seismic motion measured at a single earthquake observation point. Unlike the existing automatic seismic observation systems, this warning system does not have to transmit the observed waveform in real-time to a remote processing center and, as such, the system can be considerably simplified.

Epicentral Azimuth Of the seismic wave motions, the one which reaches the observation point most quickly is the P wave, and in this case, the direction of seismic motion and the direction of wave propagation coincide. Therefore, the epicentral azimuth can be estimated from the direction of the initial motion projected on the horizontal plane. But the azimuth estimations derived simply from the amplitude ratio of EW component to NS component show large dispersions and are not accurate. The following method is therefore proposed (Ref. 1).

①To estimate the cross-correlations at lag time $\tau = 0$ between vertical motion and horizontal motions, $R_{ud.ew}$ and $R_{ud.ns}$, as follows.
②The epicentral azimuth Θ is derived from the ratio $R_{ud.ew}/R_{ud.ns}$ for each time step.
③Average of steady part of Θ after the P wave arrival is defined as the epicentral Azimuth of the detected earthquake.

$$(R_{ud.ew})_i = (R_{ud.ew})_{i-1} \cdot \alpha + (X_{ud})_i \cdot (X_{ew})_i \quad , \qquad (1)$$
$$(R_{ud.ns})_i = (R_{ud.ns})_{i-1} \cdot \alpha + (X_{ud})_i \cdot (X_{ns})_i \quad , \qquad (2)$$

$\Theta_i = \tan^{-1}((R_{ud.ew})_i/(R_{ud.ns})_i)$ (3)

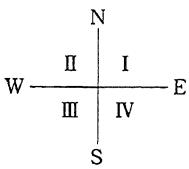
where $(X_{ud})_i$, $(X_{ns})_i$ and $(X_{ew})_i$ are amplitudes of UD, NS and EW,

α is smoothing parameter; $0 \leqq \alpha < 1$,

i shows time step,

Table 1. gives the relationship between the signs of $(R_{ud.ew})_i$ and $(R_{ud.ns})_i$ and the quadrant of Θ_i.

Table 1. Relationship between the Signs of $(R_{ud.ew})_i$, $(R_{ud.ns})_i$ and the Quadrant of Θ_i.



$R_{ud.ew}$	$R_{ud.ns}$	Quadrant
−	−	I
+	−	II
+	+	III
−	+	IV

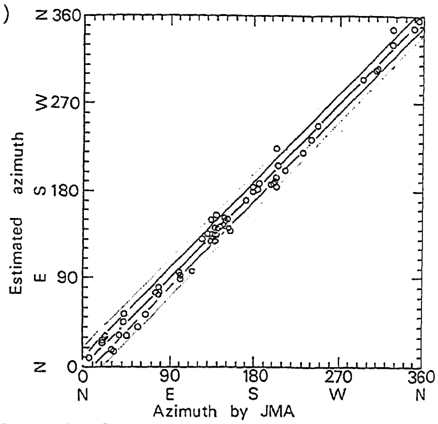


Fig. 2 Comparison of the Epicentral Azimuth Estimations

Fig. 2 compares the epicentral azimuth estimated by the Japan Meteorological Agency (JMA) and that by the proposed method using the data of a single observation point. They coincide within ±10 degrees.

<u>Magnitude of Earthquake</u> The magnitude of an earthquake relates to the size of a seismic fault: the larger the fault, the greater the magnitude. Also the duration and the predominant period of the shaking is proportional to the earthquake's magnitude. Therefore, the magnitude of an earthquake can be predicted from the predominant frequency in the initial motion. The predominant period of the initial motion can be estimated by the zero-crossing method. Here, a new quick method of estimating predominant frequency for each time step in real time is proposed (Ref. 2).

An example using observed motion X and its time differential (dX/dt) is shown as follows. From the analogy in the case of harmonic motion, the predominant frequency F_i can be defined as Eq.(4).

$$F_i = \{(dX/dt)_{ei}/X_{ei}\}^{0.5}/(2\pi) \quad (4)$$

$$A_i = \{X_{ei}(1-\alpha)\}^{0.5} \quad (5)$$

where $X_{ei} = X_{ei}\cdot\alpha + X_i^2$, (6)

$(dX/dt)_{ei} = (dX/dt)_{ei}\cdot\alpha + (dX/dt)_i^2$, (7)

subscript e means smoothed amplitude,

A_i is the amplitude corresponding to F_i.

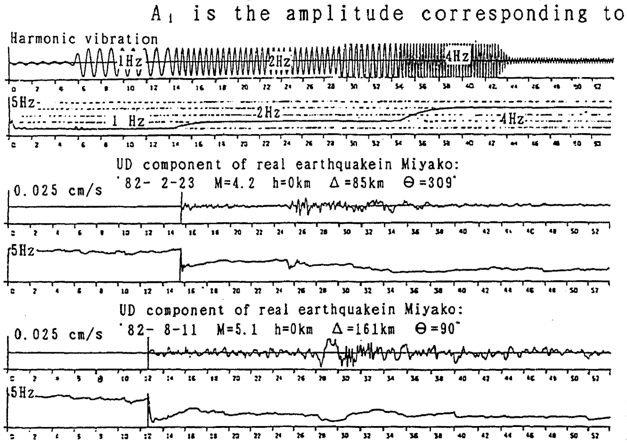
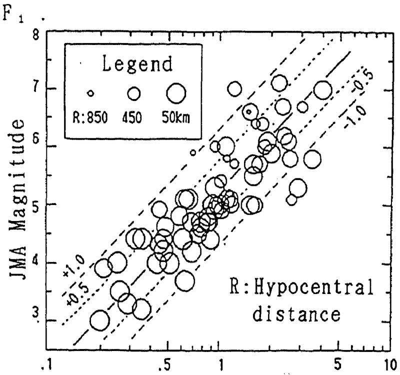


Fig. 3 Examples of Application



Period of initial motion T in sec.

Fig. 4 Relationship between Predominant Period estimated by proposed method and JMA Magnitude

There may be considerable variation. The method proposed here is typical. Using this method, the predominant frequency can be estimated continuously in real time. Fig. 3 shows examples for harmonic motion and for actual seismic motion. In Fig. 4, a comparison between the initial motion periods automatically read by the UrEDAS and the magnitudes given by JMA is given.

<u>Hypocentral Distance</u> In general, the magnitude of an earthquake is predicted from the amplitude of the initial motion and the distance from the hypocenter. As the amplitude of an initial motion can be automatically measured (for instance by using Eq.(6)) and the magnitude of the earthquake can estimated from the frequency of the initial motion, the hypocentral distance can be estimated from this information about initial motions. Although the accuracy of estimating the hypocentral distance in this way is not high, a highly accurate estimation of the hypocentral distance by using the duration of preliminary tremors is possible after the arrival of the principal motion.

<u>Identification of P Wave and S waves</u> The processing of the above mentioned information is based on the premise that the detected seismic motion is a P wave, and identification of whether it is a P wave or a S wave is possible by utilizing the characteristics of the seismic wave motion incident from below, at approximately right angles to the ground surface. Namely, in principle, if the ratio V/H is greater than 1 (tentative value: vertical motion is predominant), it can be considered as the P wave, and if the ratio V/H is less than 1 (tentative value: horizontal motion is predominant), it can be considered as the S wave. V and H are vertical and horizontal amplitude smoothed by Eq.(6).

<u>Estimation of Epicentral Distance and Depth</u> The epicentral distance Δ and depth h can be estimated, based on the hypocentral distance R by using as a parameter the ratio of the vertical initial motion to the horizontal initial motion. Fig. 5 and Fig. 6 show the relations V/H and h/R, V/H and Δ/R respectively. By means of Figs. 5 and 6, h and Δ can be estimated from V/H and R.

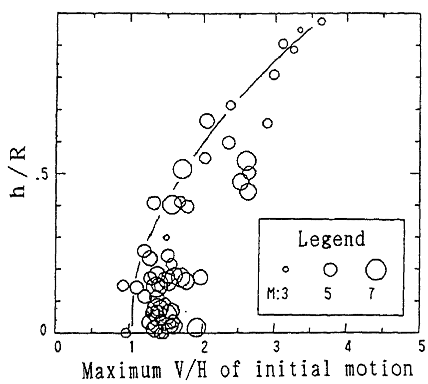


Fig. 5 Relation between V/H and h/R

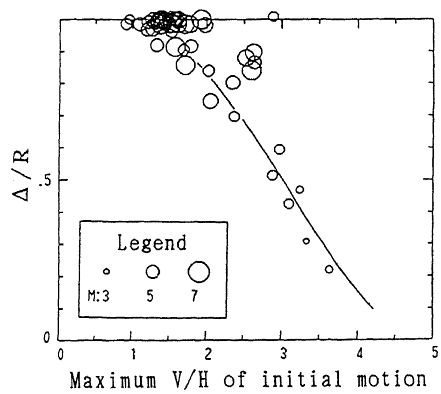


Fig. 6 Relation between V/H and Δ/R

ESTIMATION EXAMPLES OF SEISMIC FACTORS BY UrEDAS

Fig. 7 shows the comparison between the seismic factors estimated by the UrEDAS using waveforms recorded at RTRI's Miyako Seismic Observation Station, and the results of estimation conducted by JMA and Tohoku University. Estimation results of JMA and Tohoku University are given by processing the data of many observatories and by putting many hours in it. And the seismic factors estimated by the UrEDAS are given by real-time processing the data of one observatory. It has been found that these estimations are in good agreement. Therefore, the UrEDAS has sufficient accuracy for use with the earthquake warning and the operation resumption information.

Fig. 8 shows a real-time processing example of an earthquake by RTRI, not a pre-recorded one. The waveforms in Fig. 8 are the velocity waveforms of the UD component, the NS component, and the EW component, and fluctuations of predominant frequency, of V/H and of epicentral azimuth. Just after the P wave arrival, all values change and detect the earthquake arrival. Immediately the P wave is recognised, and the epicentral azimuth is estimated. The magnitude of the earthquake is derived from the predominant frequency of the initial motion. The magnitude and the amplitude of the initial motion are combined, and first estimation of seismic factors is done. Just after the S wave arrival, all values change and the S wave is recognized by the value of V/H. At this moment, the second estimation of hypocentral distance is made. The accuracy of this estimation is comparatively high. It is designed that the first estimations are done within 5 seconds, and the second is estimated within 30 seconds for hypocentral distances less than 300 km .

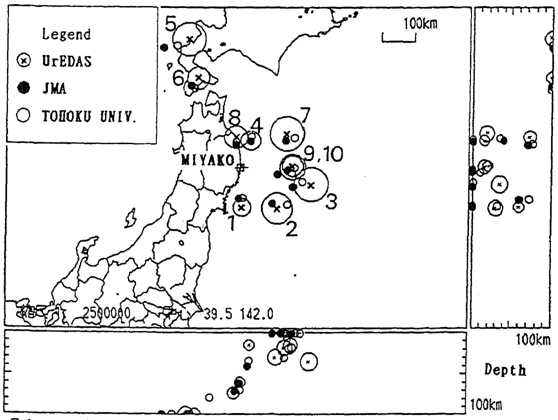


Fig. 7 Comparison Examples by the UrEDAS and Estimations of JMA and Tohoku University

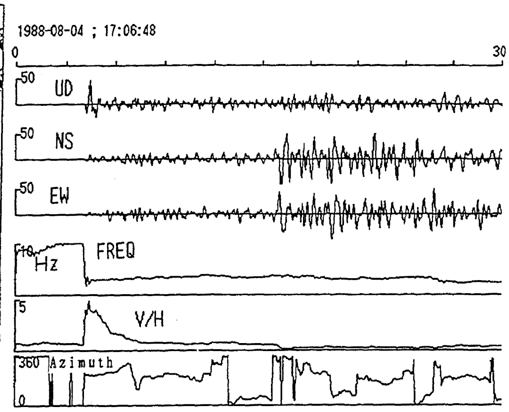


Fig. 8 Real-Time Processed Example of An Earthquake (not pre-recorded) by UrEDAS

EFFECTS OF UrEDAS FOR DISASTER PREVENTION

In the case of the Mexico Earthquake of 1985, a warning could have been issued at 19 minutes 5 seconds past seven, some 40 seconds before the arrival in Mexico City of the principal motion, if a UrEDAS were in Mexico City, located approximately 350 km from the epicenter. Fig. 9 shows accelerograms of the focal region and Mexico City. The time announced by TV newscaster was 19 minutes 42 seconds past seven and buildings collapsed about 20 seconds later. Based on this fact and fig. 9, the violent motion began from 20 minutes past seven, approximately 15 seconds after the arrival of the S wave.

Had a UrEDAS been located on the coast near the epicenter, the warning issued could have been transmitted via telecommunication, which travels much faster than the seismic wave, reaching Mexico City 60 seconds or more before arrival of the initial motion. Consequently times of over 100 seconds before the arrival of the S wave and of over 115 seconds before the arrival of the violent motion could have been secured. Although no major preventive measures can be implemented within such a short time, it is still long enough to provide countless individuals with the opportunity of seeking safe refuge nearby.

It is expected that the UrEDAS will play an active role, in the near future, as a seismic disaster prevention system, applicable in many fields: railways, including the Shinkansen; vehicular expressways; nuclear power generation facili- ties; large-scaled petro-chemical complexes; elevators in high-rise buildings and in such urban and indus-

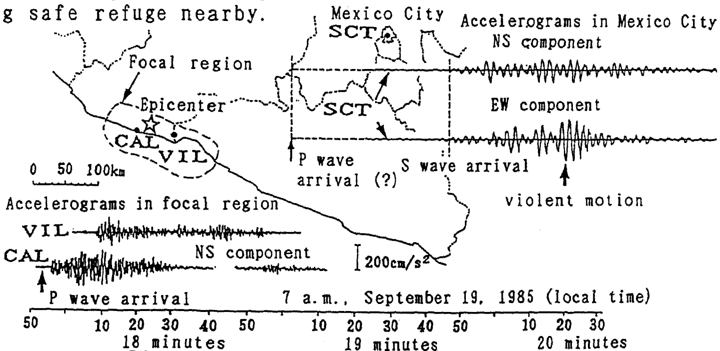


Fig. 9 Seismic Wave Propagation in the Mexico Earthquake of 1985

trial facilities. Since the UrEDAS can detect both large earthquakes all over the world and micro-earthquakes in the local area, then the UrEDAS is applicable to monitor tsunami occurrence, seismisity and volcanic eruptions.

ESTABLISHMENT OF A COMPREHENSIVE EARTHQUAKE DISASTER PREVENTION SYSTEM USING THE UrEDAS IN TOKYO METROPOLITAN AREA

Tokyo metropolitan area is a fiscal and political center. Approximately 20,000,000 people live there. There are many seismic regions in the area. More than anywhere else in Japan, this area needs countermeasurements for earthquake hazard. Therefore, the establishment of a comprehensive earthquake disaster prevention system for the metropolitan area, as in Fig. 10, has been planned. Now, this plan will be completed by March 1991 with the aid of Ministry of Transport.

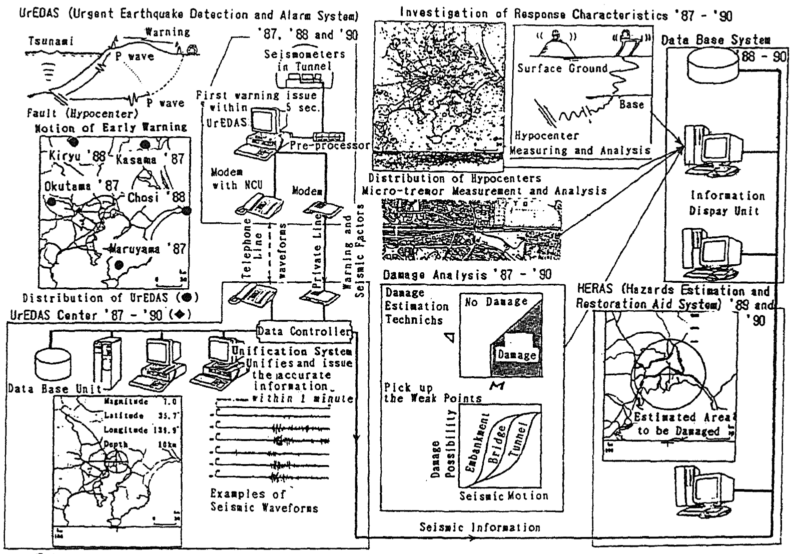


Fig. 10 Development Plan of Comprehensive Earthquake Disaster Prevention System

This disaster prevention systems consists of five UrEDAS (approximately 100 km apart from each other), Unification System (UrEDAS Center) and Hazards Estimation and Restoration Aid System (HERAS, pronounced "herasu", means "mitigate" or "reduce" in Japanese.) based on the seismic information of the UrEDAS Center.

CONCLUSION

In this paper, the outline of the earthquake warning system, the UrEDAS currently undergoing development has been described. The UrEDAS, unlike the conventional warning seismometers which issue a warning based only on the maximum earthquake motion, automatically estimates in real-time the magnitude, epicenter and depth of the earthquake, to judge its destructive potential, and then issues a warning. The earthquake disaster prevention system using the UrEDAS is will be adopted for Tokaido Shinkansen, in the near future.

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