Journal of Japan Association for Earthquake Engineering, Vol.4, No.3 (Special Issue), 2004

EARTHQUAKE ALARM SYSTEMS IN JAPAN RAILWAYS

Kimitoshi ASHIYA

Member of JAEE, Laboratory Head, Disaster Prevention Technology Division,
Railway Technical Research Institute,
Tokyo, Japan, ashiya@rtri.or.jp

ABSTRACT: This paper gives a history of research and development concerning earthquake disaster prevention systems in Japan railways. Railway Technical Research Institute (RTRI) has established a new algorithm in evaluating quickly seismic source parameters (magnitude and epicenter location) from the initial part of P waves and developed a new earthquake quick alarm system (EQAS) which utilizes prompt earthquake information that will be provided by JMA.

Key Words: Earthquake quick alarm system, P-wave, Epicenter, Magnitude

INTRODUCTION

Japan is an eminent country as a place where large-scale earthquakes occur frequently. In order to reduce earthquake disaster of railways, we should improve the earthquake-proof performance of facilities. The other way of reducing earthquake disaster is to control the train operation promptly and appropriately in case of an earthquake. In this paper, we report a history and the state of art in the research and development concerning train control systems at an earthquake in Japan railways.

HISTORY OF EARTHQUAKE ALARM SYSTEMS

Fig. 1 shows a history of research and development concerning earthquake disaster prevention systems in Japan railways. The first main system is an automatic train control system developed when Tokaido Shinkansen began operating. In this system, mechanical alarm seismographs, which were newly developed, were set up in the substations (about 20km intervals) along Tohoku Shinkansen. When the acceleration value of a seismograph exceeds a standard value (40 Gal), the supply of the electric power from the substation to the places along the railway is stopped automatically, and the emergency brake of the trains is operated.

A new earthquake alarm system was requested for Tohoku Shinkansen in the latter half of 1970's as a measure against large earthquakes which occur frequently in the Pacific Ocean coast in the Tohoku region. In this system, seismographs were set up along the coastline near the epicentral region of the targeted earthquakes. Once the seismographs at the coastline detect an earthquake, the system immediately issues the warning to Tohoku Shinkansen in the inland. Then, the control of the train operation becomes possible before the predominant motion by the earthquake reaches Tohoku

Shinkansen. This system is the first "Earthquake early warning system" and it is named "Coastal earthquake observation system". However, in this system, the judgment of warning is still done by the amplitude of S-wave (predominant motion). New seismic accelerometers, which indicated the maximum acceleration values after an earthquake, were introduced together into substations along the Shinkansen lines at this time. Then, the train operation restart judgment was sped up by promptly consolidating the maximum acceleration values along the railways.

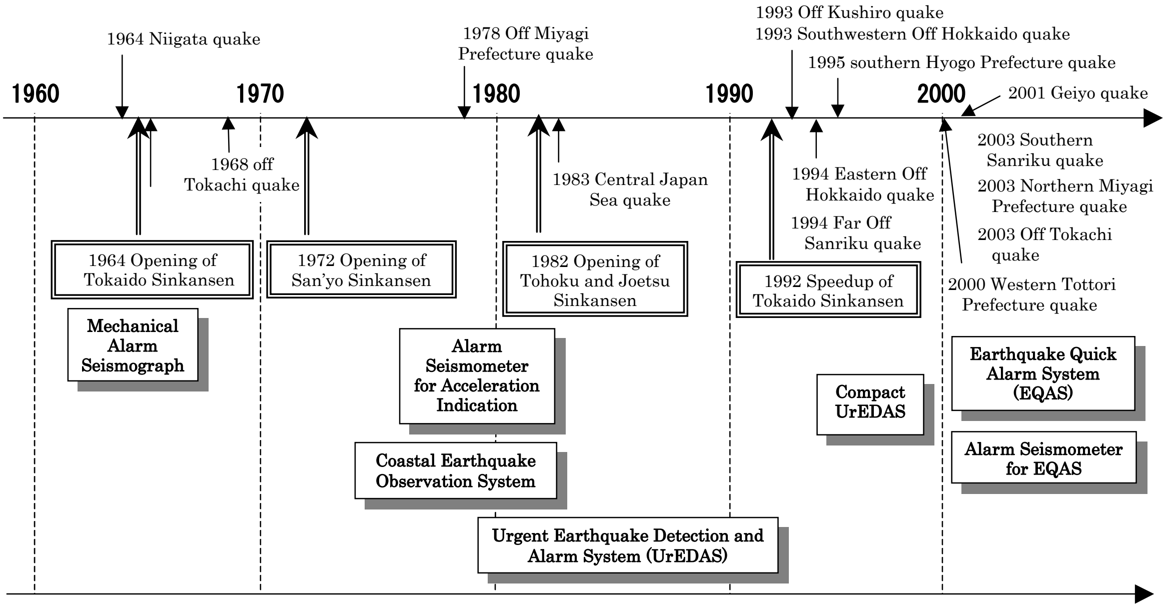

Fig. 1 History of research and development concerning earthquake disaster prevention systems

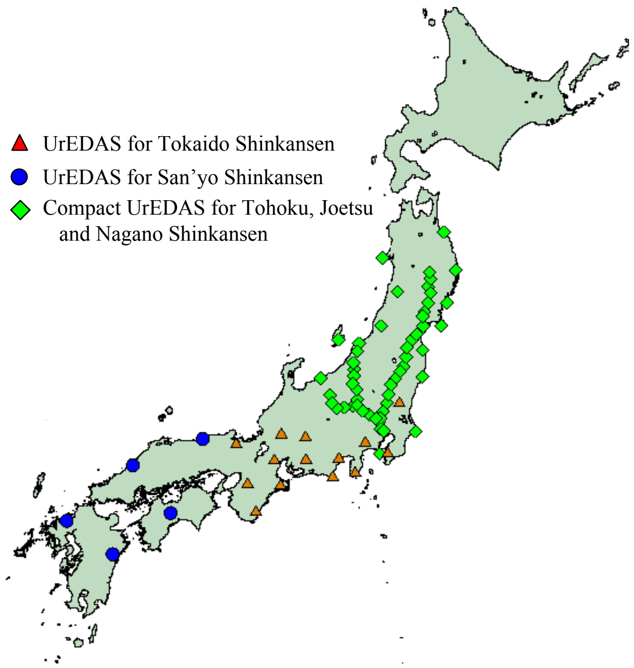

Fig. 2 Distribution of UrEDAS and compact UrEDAS

Later, further quick warning judgment was requested due to the need of the speedup of the Shinkansen lines and the urgent earthquake detection and alarm system (UrEDAS) was developed. UrEDAS estimates the position and magnitude of an earthquake from the data of several seconds of the initial part of P-wave of the single observation point, and judges the area that will suffer big vibration (Nakamura 1988). Besides, "compact UrEDAS" was developed after the southern Hyogo Prefecture earthquake in 1995, which shortened the time required to judge warning by simplifying the function of UrEDAS. UrEDAS and compact UrEDAS have been operating at about 90 places mainly along the Shinkansen lines (Fig.2).

A NEW EARTHQUAKE QUICK ALARM SYSTEM

The Railway Technical Research Institute (RTRI) developed the urgent earthquake detection and alarm system (UrEDAS) mainly for Shinkansen and put it into practical use. Recent development of the real-time seismology is remarkable. Further, the Japan Meteorological Agency（JMA）and other governmental organizations are improving the nationwide earthquake observation network and planning to distribute prompt earthquake information (Earthquake Early Warning information). Under the circumstances, RTRI has studied a new method of predicting seismic source parameters from the P-wave and developed a new early earthquake alarm system which utilizes the prompt earthquake information that will be provided by JMA.

New method of predicting seismic source parameters

The conventional system roughly estimates the magnitude and epicentral distance from the period and maximum amplitude of the initial part of P-wave measured at a single observation point, and issues the alarm before the arrival of the principal motion (Nakamura 1988). Recently, RTRI developed a new method of estimating the magnitude and epicentral distance from the amplitude increasing rate of the initial part of P-wave and the maximum amplitude (Odaka et al. 2003).

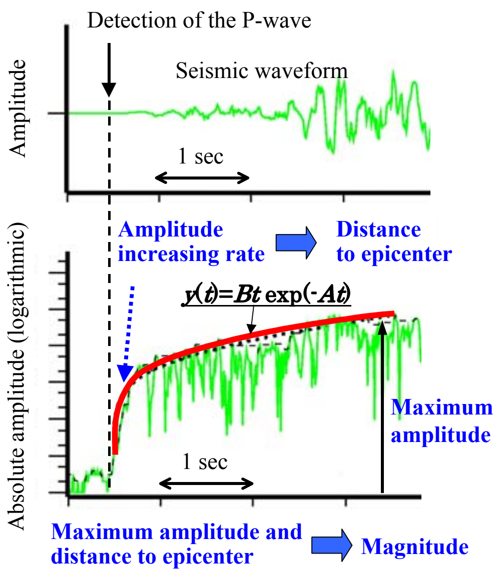

Fig. 3 Schematic illustration of a new method to predict seismic source parameters

The new method is based on the feature that the rate of increase in the envelope of the initial part of P-wave depends on the epicentral distance. In order to evaluate this feature quantitatively, we introduced a function Bt*exp($-At$) and determined the unknown coefficients A and B in terms of the least-squares method by fitting this function to the observed envelope waveform (Fig.3). The origin of time t is taken at P-wave arrival time. The coefficient B obtained by the fitting corresponds to the increase rate of initial part of the envelope. The epicentral distance is estimated from coefficient B, and the magnitude is estimated from the obtained epicentral distance and the maximum amplitude in the initial part of P-wave.

The relationship between the coefficients obtained by the fitting and the actual epicentral distances is illustrated in Fig. 4. The error distribution of the magnitude estimated from the initial part of P-wave (three seconds) by the new method is shown in Fig. 5. Figures 4 and 5 show the results of applying the new technique to about 1,000 acceleration records of 95 type seismic intensity meters of JMA. When compared with the conventional method, it estimates the epicenter distance and magnitude at higher precision.

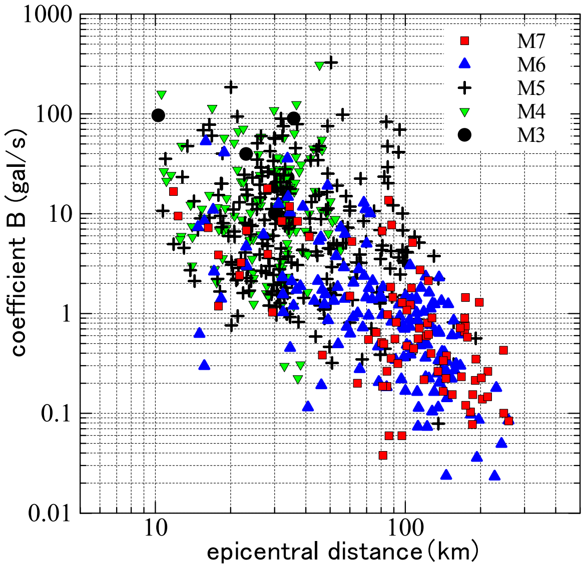

Fig.4 Relationship between the rate of increase in the envelope of initial P-wave (coefficient *B*) and the actual epicentral distance

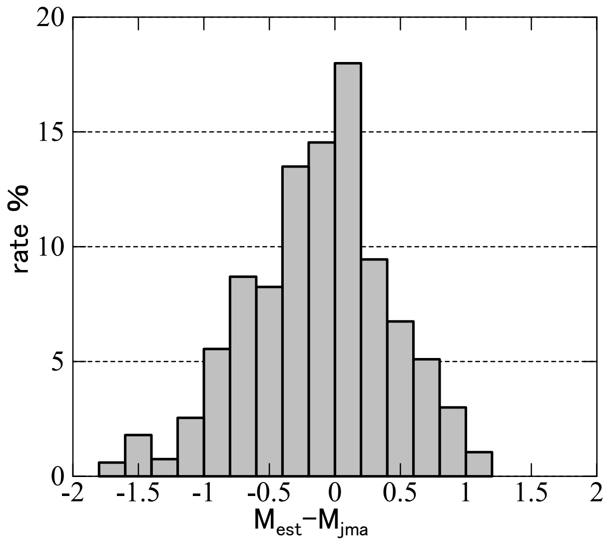

Fig. 5 Frequency distribution for the error of estimated magnitude M_{est} (Difference from JMA magnitude M_{jma})

Seismograph for the new system

RTRI has developed a new seismograph by applying the new algorithm to the seismic-wave data processing. Since it applies the latest information technology, it has several merits when compared with the conventional one, in addition to the aforementioned improved precision in the detection of source parameters. A built-in PC, for example, makes the seismograph compact and lightweight and enables parallel processing and remote operation with a real-time OS. Circuits are designed to incorporate countermeasures against electromagnetic noise. This makes it possible to use the seismograph at observation points in wayside substations. Figs. 6 and 7 show a prototype seismograph and a practical system put into actual use for Kyushu Sinkansen, respectively.

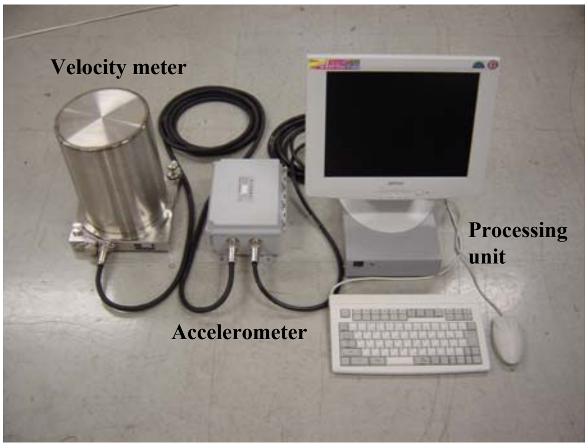

Fig. 6 A prototype of seismograph for the new system

Fig. 7 A practical system put into actual use for Kyushu Sinkansen

Prompt earthquake information provided by JMA

JMA has a plan to catch the seismic waves as quickly as possible by using 180 observation points installed widely in the country and issue the information on the epicenter, magnitude and predicted seismic intensity, which is called the Earthquake Early Warning (EEW) information, before the principal motion arrives. The EEW information will be issued when the P-wave has arrived at the nearest observation point from the hypocenter and repeatedly thereafter at certain time intervals. The information which is issued first (the 0'th information) may be on the seismic source parameters estimated from the data of the initial part of P-wave observed at the nearest observation point from the hypocenter within a few seconds. The new method mentioned above is used to process this information. After that, more precise information (the 1st information, 2nd information and so on) will be issued successively, as the seismic motion is observed at other observation points.

RTRI has developed a new earthquake quick alarm system (EQAS) which utilizes the prompt earthquake information that may be provided by JMA (Ashiya et al. 2002). The new system is designed so as to use the EEW information that may be provided by JMA in addition to the information obtained by railways. It is thought, therefore, that the performance of early controlling the train operation in case of an earthquake will be significantly improved. Its application to narrow-gauge lines may be possible at low costs. Fig. 8 shows a prototype of EQAS using the prompt earthquake information provided by JMA, which will be applied to a conventional line.

Fig. 8 A prototype of EQAS using the prompt earthquake information provided by JMA

CONCLUSIONS

Earthquake early warning systems in Japan railways have developed with the opening and the speedup of the Shinkansen lines. RTRI has presented a new method of predicting seismic source parameters from the initial part of P-wave and developed a new earthquake quick alarm system (EQAS) that utilizes prompt earthquake information provided by JMA. We have been doing the verification test of the system under the normal operation.

REFERENCES

Ashiya, K., Odaka, T., Tsukada, S., Yokota, T., Kato, T., and Kamigaichi, O. (2002). "Nowcast earthquake information and its application to early earthquake alarm system." *BUTURI-TANSA*, Vol.55, 485-494 (in Japanese).

Nakamura, Y. (1988). "On the urgent earthquake detection and alarm system (UrEDAS)." *Proceedings of Ninth World Conference on Earthquake Engineering*, *Japan*, Vol. VII, 673-678.

Odaka, T., Ashiya, K., Tsukada, S., Sato, S., Ohtake, K., and Nozaka, D. (2003). "A new method of quickly estimating epicentral distance and magnitude from a single seismic record." *Bulletin of the Seismological Society of America*, Vol. 93, 526-532.

(Submitted: March 31, 2004)
(Accepted: June18, 2004)