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Developments of Earthquake Monitoring and Early Damage Assessment Systems in Japan

by

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ABSTRACT

This paper highlights recent developments of earthquake monitoring systems and early damage assessment systems in Japan. Recently, several earthquake monitoring networks have been established in order to use earthquake information for early warning or damage assessment of urban systems. UrEDAS of Japan Railway (JR) group and SIGNAL of Tokyo Gas Company are the pioneers of such systems. A few other early damage assessment systems were also developed by local government agencies. After the 1995 Hyogoken-Nanbu Earthquake, installation of seismometer networks and development of early damage assessment systems by national and local governments as well as utility companies in Japan boomed. Although some networks and systems are still under construction, this paper provides an overview of recent vintage and future directions of real-time earthquake hazard assessment are discussed.

1. INTRODUCTION

After the 1994 Northridge Earthquake, CUBE (The Caltech-USGS Broadcast of Earthquakes) system had drawn considerable attention in Japan as well as in the United States. The system determines earthquake locations and magnitudes soon after they occur using records from the Southern California Seismic Network and disseminates the information to CUBE subscribers via commercial radio pager service (Kanamori et al. 1991). It might be an innovative system in the United States.

However, in Japan, situation is different. The Japan Meteorological Agency (JMA) monitors the seismic intensity (JMA scale; calculated from accelerograms) at more than hundred locations throughout Japan and determines the hypocenter and magnitude within a few minutes after an event. The information from the JMA is broadcasted nationwide by public TVs and radios soon after an earthquake. Although CUBE has some novel functions such as the use of paging system and display of epicenters on computer, its basic function has been covered by the JMA for many years.

The first practical tool of real-time seismology may be the UrEDAS (Urgent Earthquake Detection and Alarm System) of the Railway Technical Research Institute (RTRI), which was proposed more than ten years ago (Nakamura 1986). Detecting the arrival of the P-wave by their own network at near source, the system estimates the location and magnitude of an earthquake very quickly. Then the system uses this information to stop high speed trains before the arrival of S-wave. The first UrEDAS network started operation in 1989 in Tokyo Metropolitan area.

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Using the geographic information system (GIS), EPEDAT (the Early Post-Earthquake Damage Assessment Tool) was developed to estimate building and lifeline damage in Southern California (Eguchi et al. 1994). During that period, similar real-time damage assessment systems were also developed in Japan. SIGNAL (the Seismic Information Gathering and Network Alert) system of Tokyo Gas Company performs damage estimation of a natural gas network based on extensive earthquake monitoring and GIS (Yamazaki et al. 1994). In the system, identification of the magnitude and location of an event is also conducted using data from their own accelerometers and radio network. Kawasaki City and Tokyo Fire Department also developed their own early damage assessment systems for emergency management. These systems in Japan has been functioning since early 1994, about a year before the Hyogoken-Nanbu (Kobe) Earthquake of January 17, 1995.

After the Hyogoken-Nanbu Earthquake, counter-measures against earthquake have got higher priority than before. With good financing, thousands of strong motion accelerometers will be installed within a few years. A number of damage assessment systems are also being developed by different organizations using the data from the JMA or their own seismometer networks. This paper provides a recent overview of seismometer networks and early damage assessment systems in Japan and their future directions are discussed.

2. PIONEER WORK

2.1 *UrEDAS and HERAS*

The first practical tool of real-time emergency countermeasures in the world may be UrEDAS of the RTRI mentioned above. The first UrEDAS network with five instruments was installed in the Tokyo Metropolitan area in 1989. Since then, several UrEDAS networks have been deployed for rapid railway systems in Japan as shown in Fig. 1. The first UrEDAS network for rapid railway systems began operation with 14 instruments in 1992 on the Tokaido (between Tokyo and Osaka) Shinkansen (bullet train). Triggered by the Kobe Earthquake, a UrEDAS network for the Sanyo (between Osaka and Fukuoka) Shinkansen was introduced. Other UrEDAS networks, e.g., Seikan (between Aomori and Hakodate) Tunnel, a test site in Pasadena, California, have also been in operation. If an earthquake occurs, trains should be stopped as soon as possible to avoid disasters. UrEDAS is considered to be one of the most important earthquake counter-measures for railway systems in Japan.

The RTRI also developed a system named HERAS (Hazards Estimation and Restoration Aid System), which estimates the degree of damage to railway systems caused by an earthquake based on the synthesized information from UrEDAS as shown in Fig. 2. Using the database on characteristics of ground and railway structures and damage experiences of past earthquakes, HERAS can provide damage estimation of railway systems within five minutes after an event (Nakamura 1996). A prototype of HERAS was completed in 1992. Information on UrEDAS and HERAS is available on the Internet.

2.2 *SIGNAL*

The first early damage assessment system actually introduced for lifeline systems may be SIGNAL of Tokyo Gas Company (Yamazaki et al. 1994). Since the service area of the natural gas system became very large (with 8.1 million metered customers), the earthquake monitoring and early warning system was introduced to avoid secondary disasters. The unique feature of

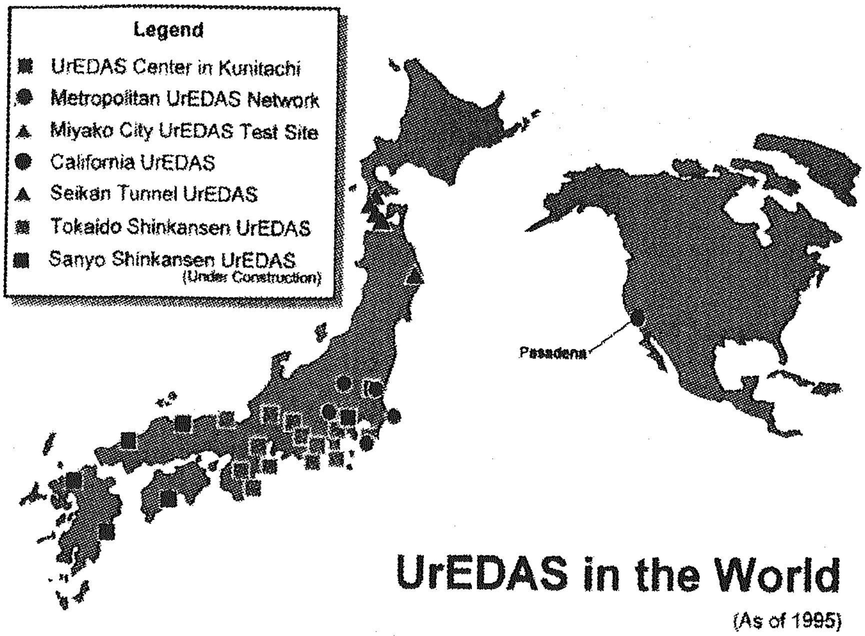


Fig. 1 UrEDAS network of RTRI in Japan (after *http://www.rtri.or.jp*)

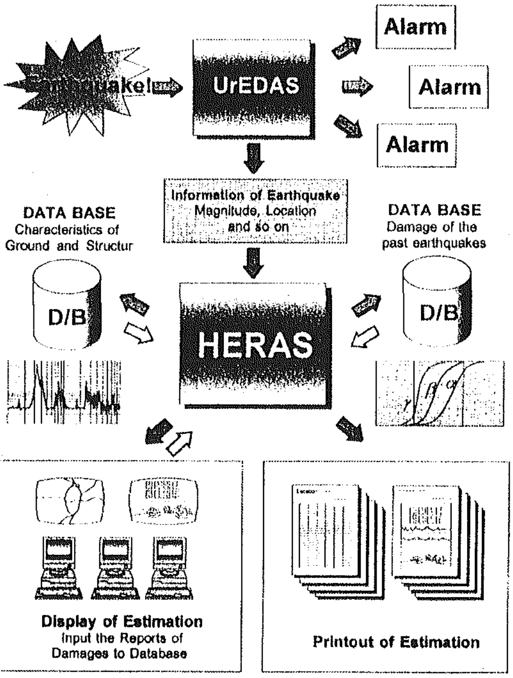


Fig. 2 Concept of UrEDAS and HERAS of RTRI (after *http://www.rtri.or.jp*)

SIGNAL is its extensive earthquake monitoring network, probably the largest in the world. The monitoring system measures the peak ground acceleration (PGA) and spectrum intensity (SI) at 331 locations in the service area by SI-sensors (Katayama et al. 1988) as shown in Fig. 3. Acceleration time histories at 5 locations and pore-water rises at 20 locations are also observed. Once an earthquake occurs, these values are sent to the supply control center of the headquarters by the company's radio and are used in decision making on the gas supply shut-off for medium-pressure trunk lines.

The early warning system consists of sub-systems for damage estimation, hypocenter estimation, spectrum evaluation, and decision. The monitored earthquake ground motion data are fully employed in these sub-systems. For the damage estimation, data on the service area, e.g. soil conditions, customers' buildings and pipelines, are stored on a workstation using GIS of 175 m × 250 m square mesh (Fig. 4). The prototype of SIGNAL was completed in 1992 and the actual system has been operating since June, 1994. Information on SIGNAL and the recorded PGA and SI values from recent earthquakes are available at the homepage (*http://www.tokyo-gas.co.jp/signal*).

2.3 *Damage Assessment System of Kawasaki City*

As a part of emergency management system, Kawasaki City has developed a damage assessment system (Mochida 1994) for the city with a population of about 1.2 million. The system consists of three modules: 1) estimation of the distribution of seismic intensity, 2) prediction of various hazards, structural damage and human casualties, 3) suggesting policy for crisis management. This system is unique in the sense that it not only predicts damage statistics but also serves as an emergency operation manual.

The earthquake information is collected through the city's radio system from seismometers placed on each ward office as well as from the JMA. The damage assessment system using GIS predicts hazards such as tsunami, liquefaction and landslide, damage of buildings, roads (Fig. 5), bridges, river embankments and lifeline systems (power, water, gas, telephone), and human casualties. A 500 m × 500 m square mesh, which is commonly used in damage assessment in Japan, is employed in the system. The system was installed at the Disaster Prevention Center in the city hall and a terminal system was installed at each of the seven ward offices. Test operation of the system started in April, 1994.

2.4 *Damage Assessment System of Tokyo Fire Department*

Tokyo Fire Department also developed an early damage assessment system for fire fighting and rescue operations. The system is basically a computer package of a damage assessment tool for scenario earthquakes. The system has a database for soil conditions, buildings, fire occurrence risk, and time-dependent population. If the magnitude and location of an earthquake are given, the system first estimates the distribution of PGA, seismic intensity and liquefaction hazard throughout Tokyo Metropolis by 500 m × 500 m square mesh using an attenuation relation of earthquake ground motion and soil classification. Then the number of collapsed buildings, fire breakouts (Fig. 6), and human casualties are estimated based on empirical formula for each mesh. The area which the fire might cover one hour after an event is also estimated. The results of the estimation will be used to prepare for fire-fighting and search-and-rescue in an early stage. The first version of the system was completed in 1994. Using data from the new seismometer network of the department, the system was upgraded recently.

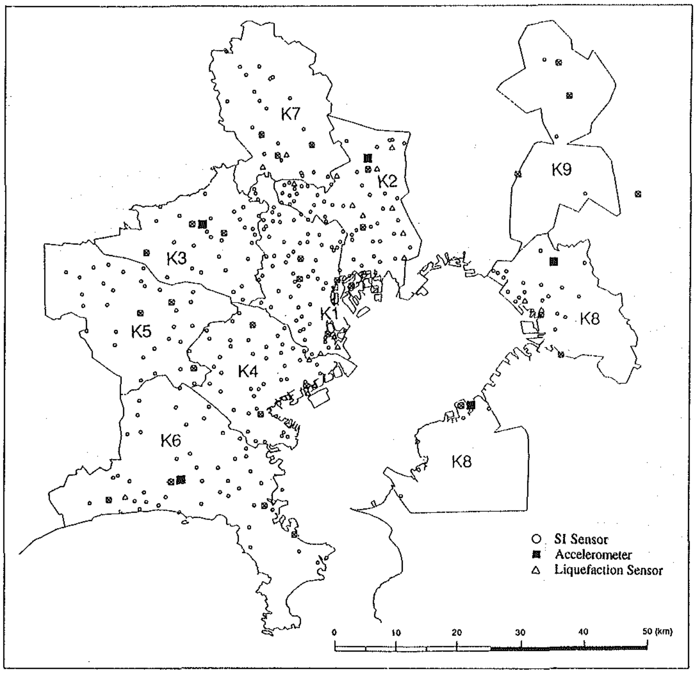


Fig. 3 Location of earthquake monitors of SIGNAL system of Tokyo Gas Company

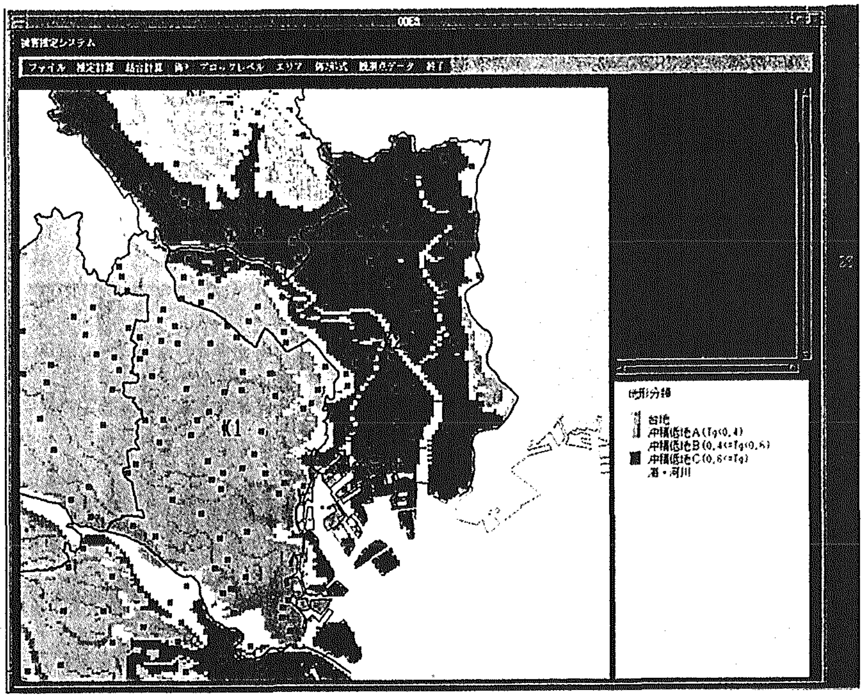
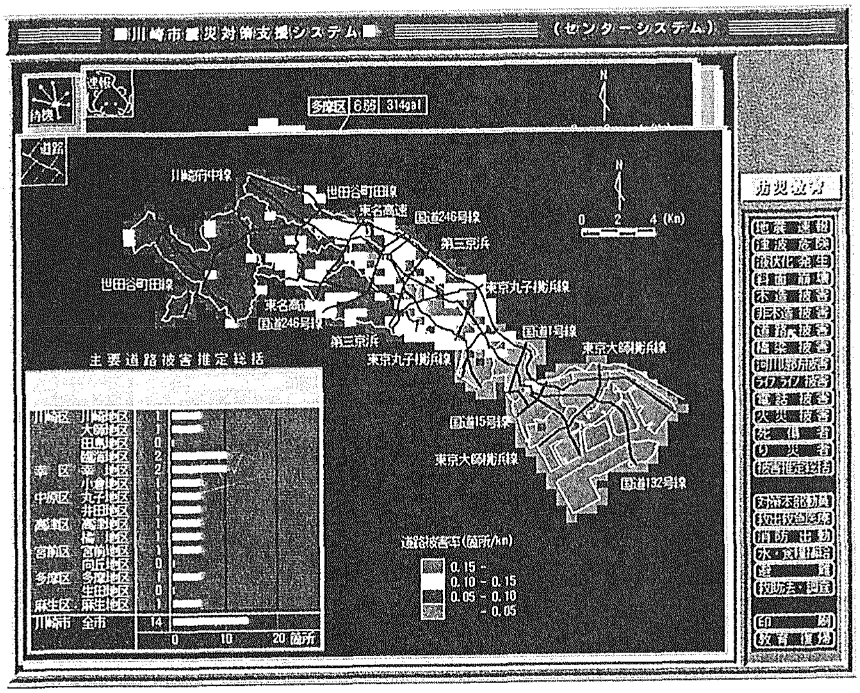


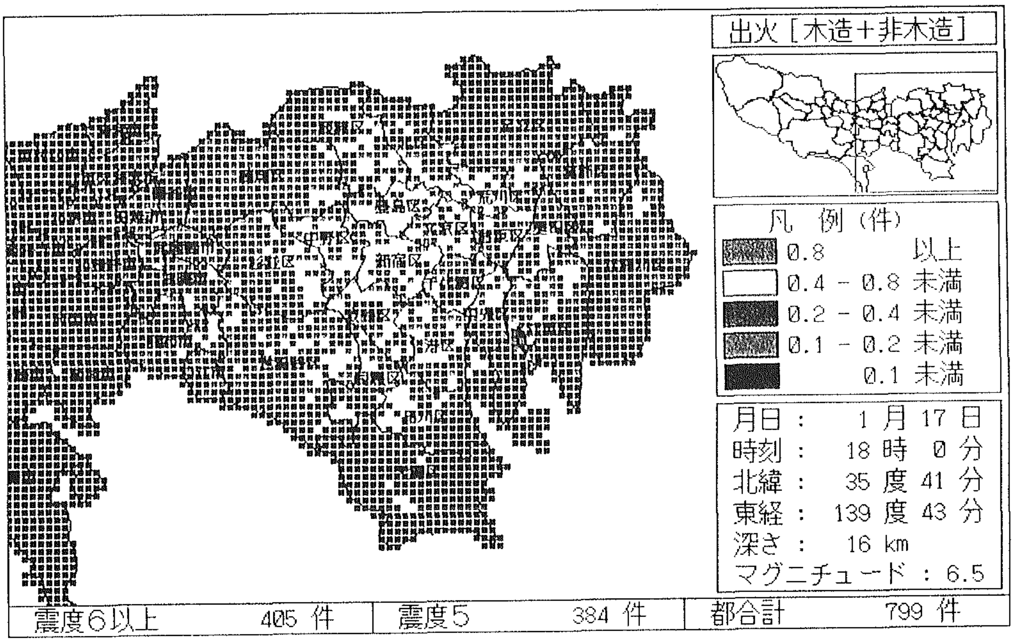
Fig. 4 Local topography and location of SI sensors in central Tokyo by SIGNAL



主要道路被害推定総括

川崎区	川崎地区	1	
	大師地区	1	
	田島地区	0	
	御幸地区	2	
幸区	幸地区	2	
	小倉地区	1	
中原区	丸子地区	1	
	井田地区	1	
高津区	高津地区	1	
	橘地区	1	
宮前区	宮前地区	1	
	向丘地区	0	
多摩区	多摩地区	1	
	生田地区	0	
麻生区	麻生地区	1	
川崎市	全市	14	
			0 10 20 箇所

Fig. 5 Damage assessment system of Kawasaki City - indicating the road damage ratio



月日 : 1 月 17 日
時刻 : 18 時 0 分
北緯 : 35 度 41 分
東経 : 139 度 43 分
深さ : 16 km
マグニチュード : 6.5

震度6以上 405 件	震度5 384 件	都合計 799 件

Fig. 6 Damage assessment system of Tokyo Fire Department - estimating the number of fire breakouts after an M=6.5 earthquake

3. NEW SEISMOMETER NETWORKS IN JAPAN

There had been thousands of seismometers of various kinds deployed in Japan. The number of new digital accelerometers is increasing although seismometers of older types still remain. After the 1995 Kobe Earthquake, installation of new seismometers was highly accelerated. Following are some of the new seismometer networks introduced.

3.1 *JMA's Network*

The JMA is in charge of earthquake information in Japan. The JMA used mostly displacement-type seismographs before. Since 1987, the JMA has been deploying new JMA-87-type accelerometers in recording stations throughout Japan (Molas and Yamazaki 1995). These new accelerometers have a flat sensitivity from 0.05 to 10 Hz and can measure accelerations from 0.03 to 980 cm/s^2 for periods 1 sec to 10 min. The network started with 76 stations. The recorded accelerograms were available from the Japan Weather Association in magnetic tapes.

In 1993 and 1994, several damaging earthquakes occurred in northern Japan (Yamazaki et al. 1995). Hence, mainly for early tsunami warning, the number of accelerometer stations was increased to 268. After the Kobe Earthquake, in order not to miss localized heavily damaged areas, the number of stations was further increased to 574 as of April, 1996 (Fig. 7). Using time histories from several stations, the JMA determines the location and magnitude of an event within a few minutes. The JMA intensities at these 574 stations are also collected by JMA's telecommunication system at the headquarters and disseminated nationwide through mass media. Since a telecommunication line connected to Kobe Observatory had a trouble soon after the Kobe Earthquake, the JMA recently strengthened the communication network to have a backup system through satellites.

3.2 *Kyoshin Net*

After the Kobe Earthquake, the National Research Institute for Earth Science and Disaster Prevention (NIED) of the Science and Technology Agency deployed a total of 1,000 strong motion accelerometers throughout Japan (Fig. 8). This network is named "Kyoshin Net" or "K-NET" and the average distance between stations is 25 km. Each station has a digital accelerometer having a wide frequency band and wide dynamic range. The maximum acceleration which can be measured is 2.0 g. Instruments are placed on free field. At each site, P and S-wave velocities were measured by downhole PS-logging as well as SPT N-values.

Each instrument has two communication ports. The first one is directly connected to a modem belonging to a municipality. The municipality can use the information for emergency management. The second port is connected to the control center of NIED. After receiving prompt information from the JMA, the control center acquires records using this port. The control center compiles these records and then makes the compiled data set available on the Internet. The center will distribute the data file through the Internet. The center also maintains a strong motion database and site information for scientific studies and engineering applications. The information about Kyoshin Net is available at the homepage of NIED (*http://www.bosai.go.jp*).

3.3 *Network of the Fire Defense Agency*

Recently the Fire Defense Agency (FDA) of Japanese Government also ventured upon a project to deploy one accelerometer in each municipality (3,255 in total) in Japan excluding

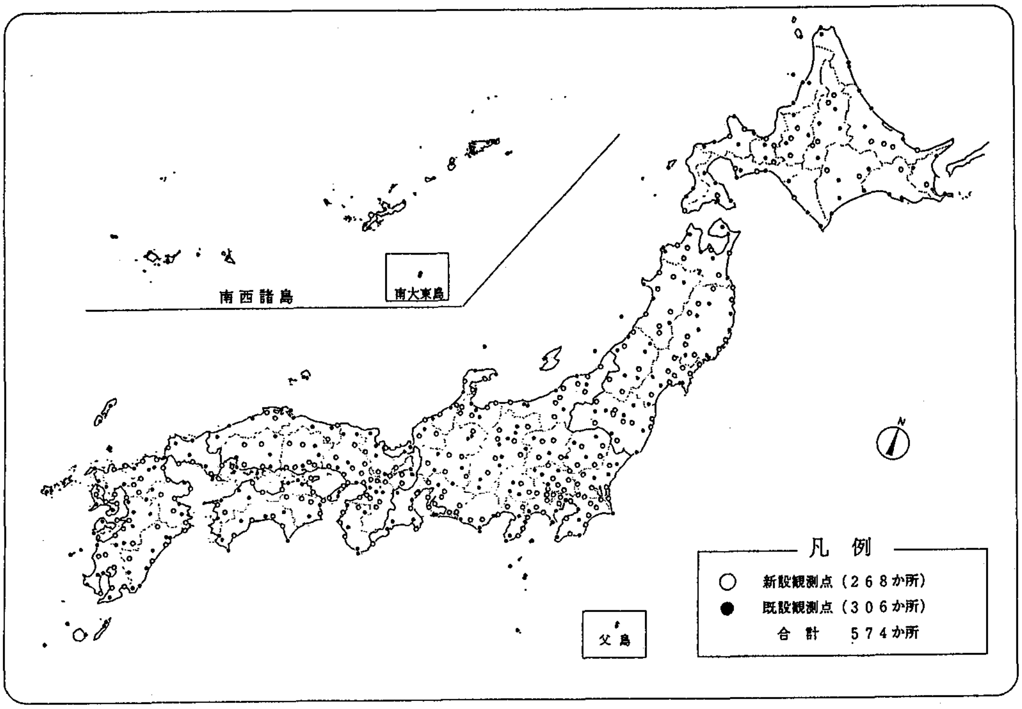


Fig. 7 Strong motion accelerometers of the JMA as of April, 1996 (574 sites in total)

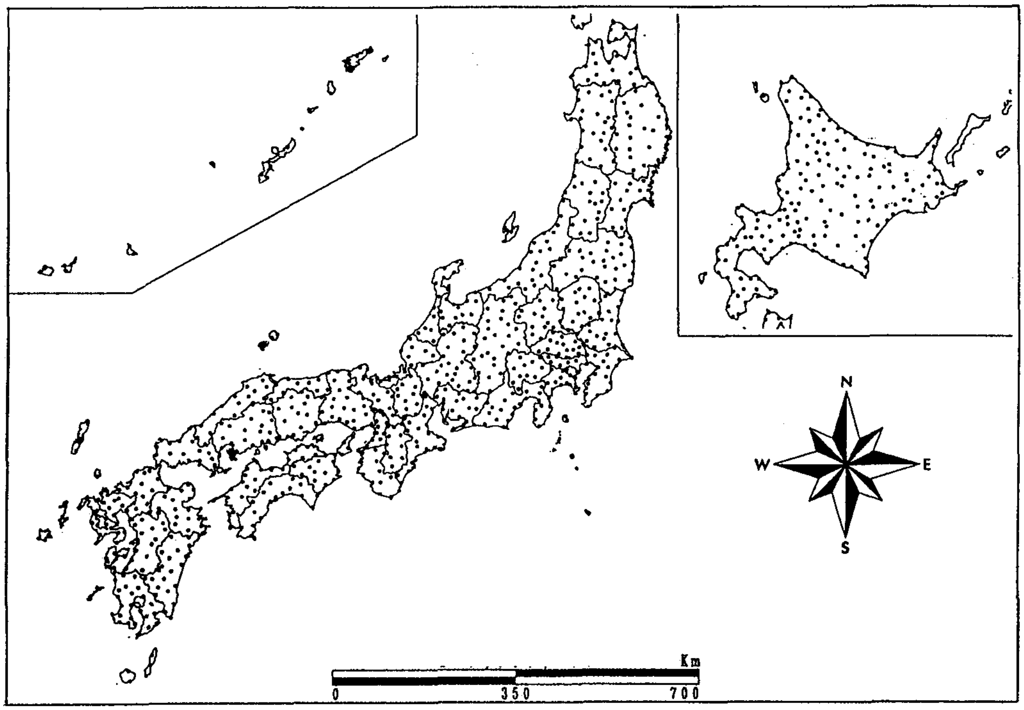


Fig. 8 Locations of 1,000 strong motion accelerometers of K-NET by NIED

municipalities having JMA's or K-NET's instruments as shown in Fig. 9. When this network is completed, the distribution of strong ground motion for an earthquake can be estimated even in case of a very localized event. Once an earthquake occur, the control center of FDA will collect the JMA seismic intensities calculated from records through ISDN (Integrated Services Digital Network) of NTT (The Nippon Telegraph and Telephone Corporation). The FDA and the JMA will also exchange their collected data through private communication lines. The FDA will use the collected information for identifying affected areas and preparing for crisis management at a national level.

3.4 *Other Networks*

In addition to the three national networks described above, many public and private organizations have started or are planning to deploy seismometer networks within their territories.

Kanagawa Prefecture installed their own strong motion observation and telemeter system with 16 seismometers in 1994. The control center will collect the seismic intensities obtained by the network through NTT's private lines. The collected data will be used for crisis management after an earthquake.

Yokohama City started a project to deploy a very dense strong motion accelerometer network with as many as 150 instruments and three control centers (Fig. 10). In the fiscal year of 1995, the main control center was constructed and 18 instruments were placed. The remainder of the system was completed by the end of March, 1997. Once an earthquake occur, recorded data will be sent to the control centers through ISDN and digital private lines within three minutes. The collected data will be used for crisis management of the city. Yokohama city is now planning to develop an early damage estimation system using the strong motion data from the network and GIS data of the city.

Tokyo Metropolitan Government also started to develop its own strong motion telemeter network with about 100 instruments (Tokyo Metropolitan Government 1996). These instruments will be placed at ward offices, city halls, and fire stations. Soon after an earthquake, seismic intensities calculated from records will be gathered at the headquarters of the Metropolitan Disaster Prevention Center and the Command and Control Center of the Tokyo Fire Department by the disaster prevention administrative radio network of Tokyo (Fig. 11). The exchange of collected information with other disaster prevention agencies is also planned. As the first step of the network, about twenty seismometers were deployed in the fiscal year of 1996. The early damage assessment system of the Tokyo Fire Department will also utilize the information from this monitoring system.

Some other large cities, such as Kyoto and Nagoya, are also planning to have their own strong motion observation and telemeter networks. Some public corporations, e.g. Japan Highway Public Corporation, and private companies, e.g. city gas and electric power companies, are also planning to have their own strong motion telemeter systems.

4. NEW DAMAGE ASSESSMENT SYSTEMS IN JAPAN

New early damage assessment systems are also being planned by a number of public and private organizations. After the Kobe Earthquake, there has been a boom on early damage assessment systems. Hence, it may not be easy to get information on all the systems which have developed recently or are being planned.

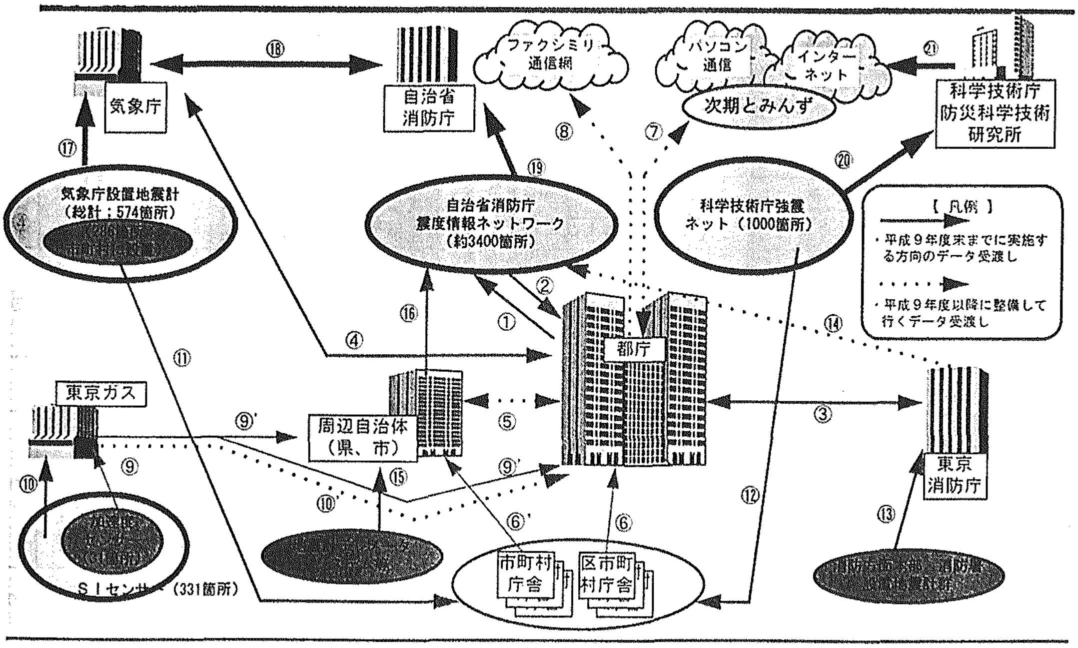


Fig. 11 Planned communication network of Tokyo Metropolitan Government for early earthquake information

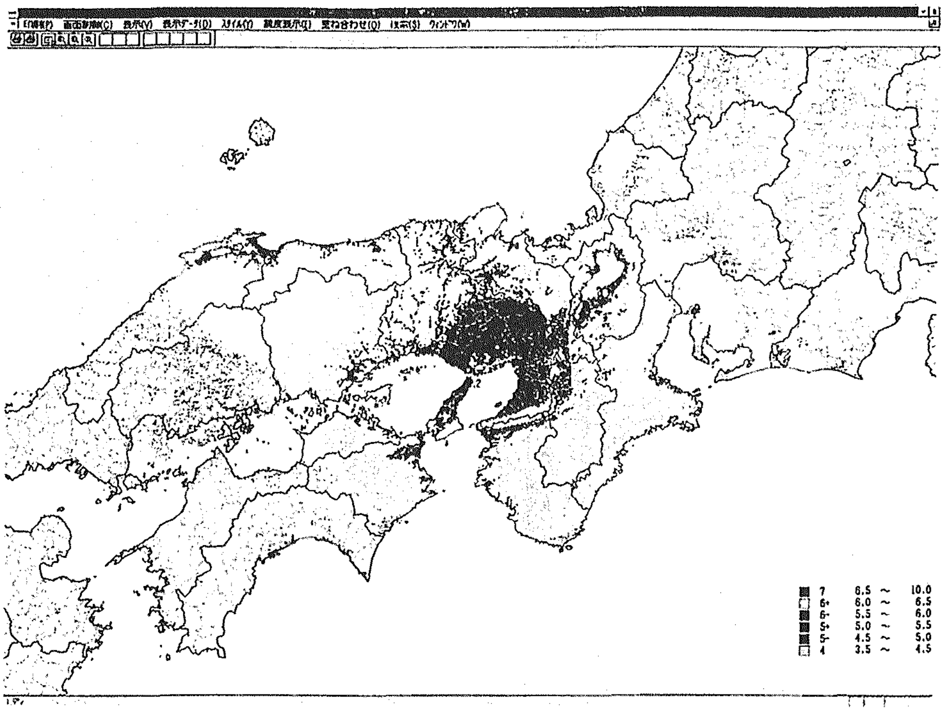


Fig. 12 Early damage assessment system of the National Land Agency. The figure shows estimated seismic intensity distribution in the Kobe Earthquake by interpolation of observed data.

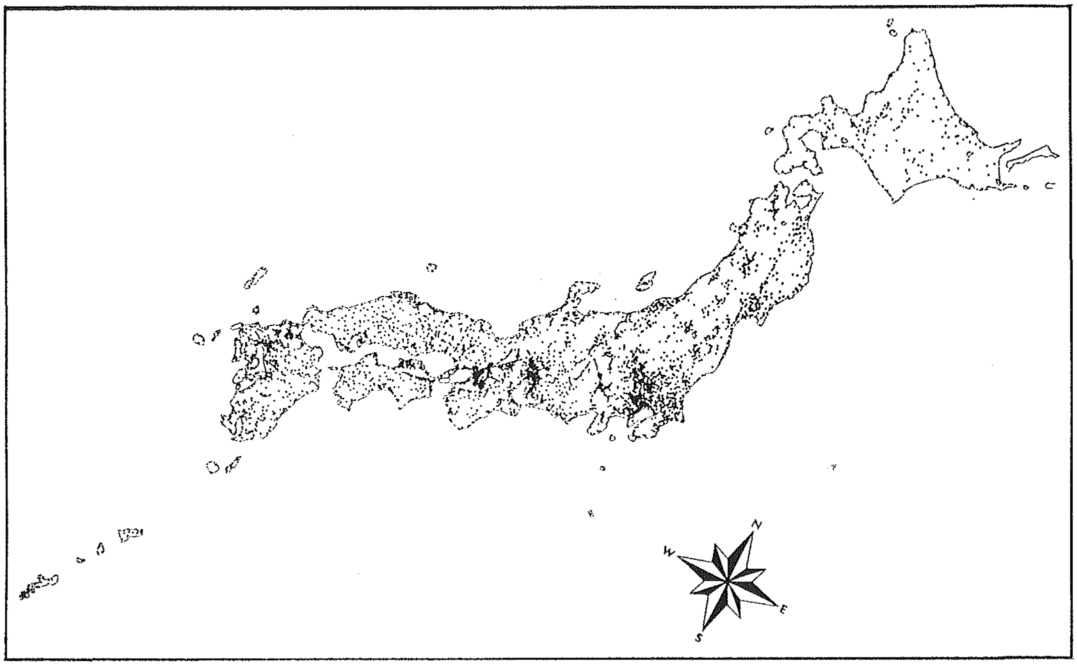


Fig. 9 New seismometer network for all the municipalities in Japan by the Fire Defense Agency

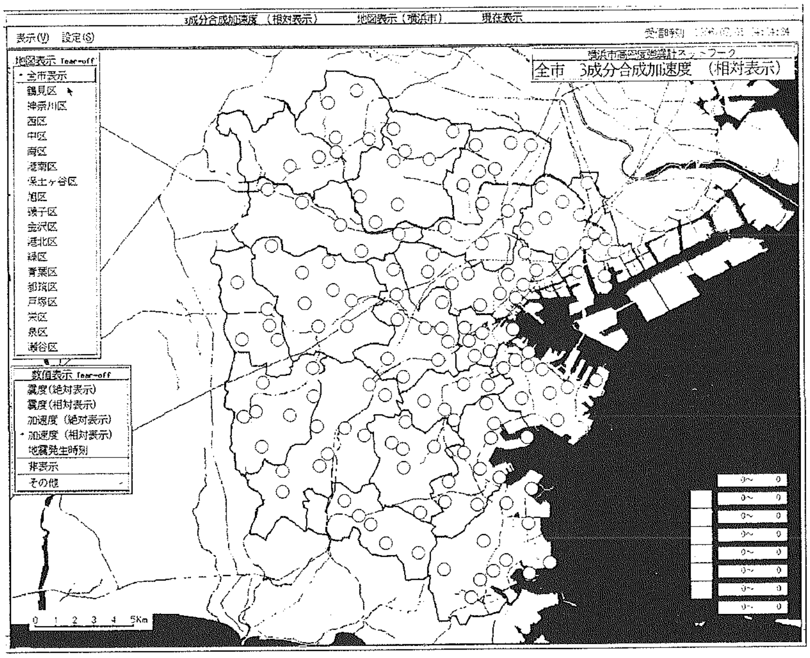


Fig. 10 Dense strong motion accelerometer network of Yokohama City with 150 instruments

As a typical example of such systems, the National Land Agency, which is in charge of disaster prevention administration in Japan, developed the first version of early damage assessment system (Fig. 12) and started its operation in April, 1996. Using the intensity and source information from the JMA and the GIS data of entire Japan by 1 km × 1 km square mesh, this system estimates the seismic intensity, the number of collapsed wooden houses, and the number of deaths due to collapse of houses in each mesh. Distribution of tsunami height and flooded area is also estimated by this system. In case of devastating disaster like the Kobe Earthquake, there is a delay in the flow of information on damage to the government. Hence, the result of damage estimation by the new system will be used in the crisis management by Japanese Government in an early stage. The National Land Agency is now developing a more integrated emergency management system called the Disaster Information System (DIS). The above mentioned damage assessment system will be a part of the integrated system.

The Fire Research Institute of the Fire Defense Agency developed a simplified earthquake damage assessment system in 1996. The system estimates the peak ground velocity and the number of collapsed wooden houses, fire breakouts, and deaths based on empirical relationships if the location and magnitude of an event are given. The system contains basic GIS data of Japan with a square mesh of 1 km × 1 km for strong motion and damage estimations as shown in Fig. 13. The system was distributed to all the municipalities in Japan by CD-ROM.

The National Land Agency is also developing a prototype damage assessment system for local municipalities (Fig. 14). The use of microscopic GIS is considered in this system since a square mesh of 1 km × 1 km or 500 m × 500 m is too large to show local geographical data. When this system is completed, it will be used for both disaster planning and post-earthquake operations of municipalities.

5. DISCUSSIONS AND CONCLUSIONS

Earthquake monitoring and real-time damage assessment systems in Japan have rather long history. The first such system in the world, UrEDAS of Japan Railway Group, was developed more than ten years ago. SIGNAL of Tokyo Gas having the largest scale strong motion monitoring started operation in 1994. Kawasaki City and Tokyo Fire Department also developed early damage assessment systems almost at the same time. As introduced in the preceding sections, triggered by the Kobe Earthquake, so many new strong motion monitoring networks and early damage assessment systems are being developed in Japan. Some of them have already started test operations.

Although the number of instruments in Japan may be by far the largest in the world, problems still remain to be solved. The first issue is information sharing. Since the pioneer systems were made by private sector or local governments, the systems and associated earthquake information have been considered to be used only within the organization. To establish an information sharing system for all the disaster prevention agencies and companies in an early stage may be very important. Considering mutual aid in case of disaster, the coordination between neighboring cities and prefectures is also very important. Establishment of communication measures is necessary in order to realize such coordination. New communication tools such as ISDN, satellite communication and the Internet may be promising for the purpose.

Since Japan has a lot of experiences of scenario earthquake studies, damage assessment often means calculating damage statistics using empirical formulas. However, such estimated damage has a wide range of variability. To give a range of estimation may be better than to predict a single number. The use of story simulation (scenario) is also important since the feature of disaster is

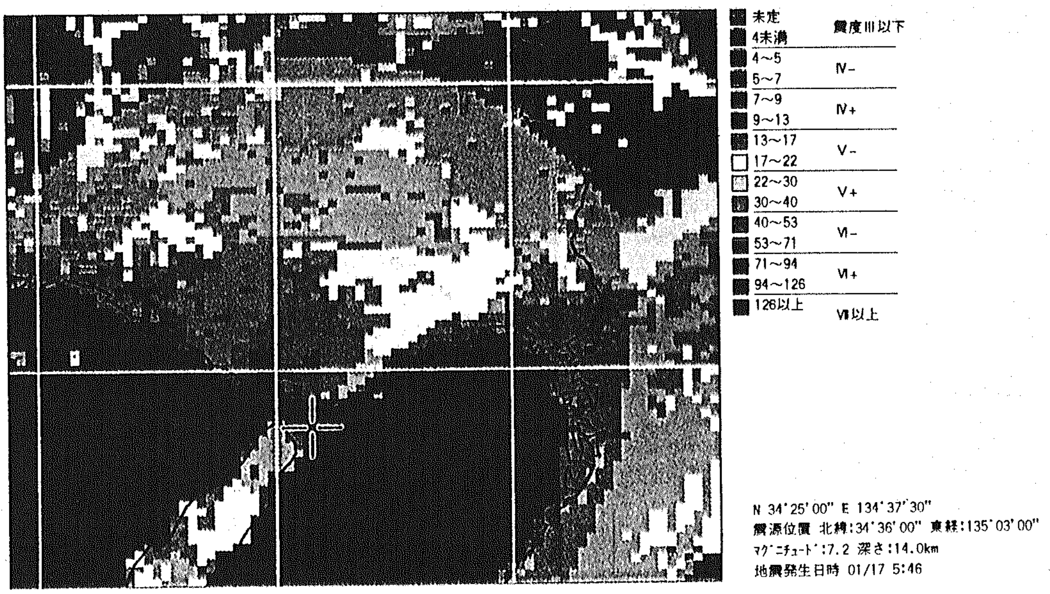


Fig. 13 Simplified damage assessment system for municipalities by the Fire Defense Agency. The figure shows the estimated peak ground velocity in the Kobe Earthquake by this system.

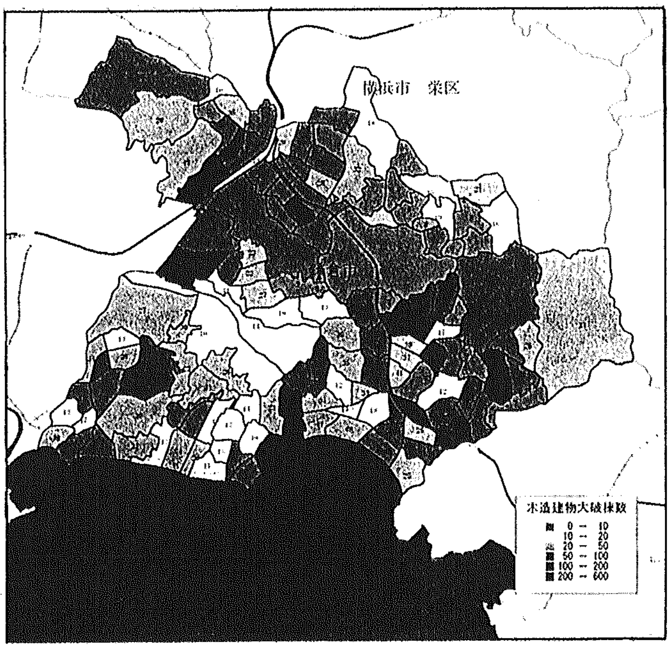


Fig. 14 Prototype of damage assessment system for local municipalities by the National Land Agency. The figure shows the estimated number of collapsed wood-frame houses in each district of Kamakura City.

difficult to describe using only numbers. It is obviously very important to revise damage estimation functions by introducing recent experiences, especially those from the Kobe Earthquake.

Japan had been rather well prepared for earthquake disasters. However, the damage in the Kobe Earthquake was much more than expected and the weakness of crisis management in Japan was revealed. Lessons learned from the earthquake should be used in disaster mitigation. In order to avoid a lack of information just after an earthquake, early damage assessment systems with intensive earthquake monitoring are expected to play a vital role in the near future.

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