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EFFECTIVE COLLECTION OF EARTHQUAKE DAMAGE INFORMATION AND ITS UTILIZATION TO FIRE FIGHTING JUST AFTER AN EARTHQUAKE

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SUMMARY

To enable an initial response to be conducted smoothly in case of a large-scale disaster, it is necessary to collect accurate disaster information immediately and transmit it to decision-makers such as the fire service headquarters. It is also important to create useful information based on the disaster information and a database such as water supply, hazardous material facilities, fire brigades and so on, and to disseminate such information to personnel in stricken areas. We have therefore developed a handy-type collection terminal, a digital communication system free from congestion, and real-time earthquake damage estimation system and fire-spreading and pertinent fire brigades-operating simulation system. By integrating these elements and information technology, we have constructed a prototype system that can support effective initial response activities just after an earthquake. Large-scale field experiment of the system performance was carried out to verify the validity of the system and to find out problems in operating the system. Furthermore, we tried to link our system with Fire-D net that Fire and Disaster Management Agency has constructed to share damage information quickly among the organizations such as fire departments and prefectural offices immediately after severe disaster.

INTRODUCTION

In order to conduct efficiently initial response activities such as fire-fighting and life-saving search-and-rescue operations just after a large earthquake such as the 1995 Kobe earthquake, it is important to make pertinent decisions based on actual disaster information and available resources. As to a method and operation for collecting damage information efficiently, we proposed a time-spatial framework based on an investigation into the process of gathering earthquake damage information in municipalities that suffered during the Kobe earthquake (Zama [1]). In order to verify the validity of the method and operation, we first developed a prototype system that can support initial response activities after a large earthquake, considering ease of introducing it to fire services. Secondary, we conducted

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large-scale field experiment to identify problems of the system for the practical use. Based on the experimental results, we have improved the system and applied to the link with the network that Fire and Disaster Management Agency (FDMA) has constructed since the 1995 Kobe earthquake in order to share the disaster information quickly, and provided fire departments with the system components such as damage estimation system, fire spreading simulation system, and so on.

CONCEPT OF BUILDING A SYSTEM

In the case of severe damage such as that caused by the Kobe earthquake, it is very difficult to ensure adequate personnel even for fire services, because firefighters and their families may have been affected and usual traffic access may not be available. Such situation will lead to an 'information gap' in which there is insufficient information to decide how to take rational countermeasures. Here, we consider a fire service headquarters as a base for information in and around a stricken site. A decision-maker must judge whether or not to set up a disaster countermeasure headquarters and to seek wide-area assistance and so on.

Fire brigades will naturally be eager to start fire-fighting activities. Under ordinary circumstances, a quick response to a fire is essential, but it is not always good to fight fires immediately after a large earthquake, because not all the fires can be identified. For example, in the 1978 Miyagiken-Oki earthquake, most fire brigades attacked fires that they had identified just after the earthquake. However, more fires then broke out over a wide area, and they were late in fighting them (Sekizawa[2]). This experience shows that it is necessary to optimize the operation of fire brigades considering the total number of fires, but it is very difficult to do this properly based on the decision-maker's experience and sense. Thus, a system is needed that can support the decision-maker, based on actual disaster information and the prediction of occurrence and spreading of fires. The 1978 Miyagiken-Oki earthquake highlighted the following information problems:

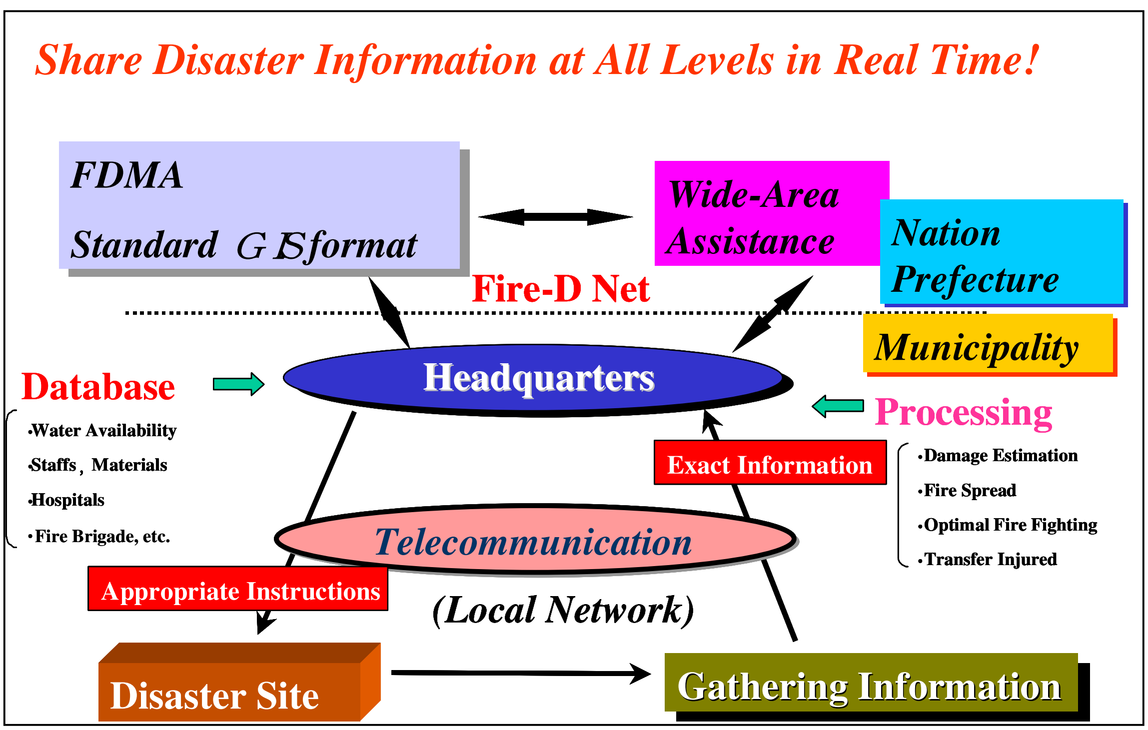

Fig. 1 Concept of support system for response activities

(1) How quickly do we search and collect disaster information?
(2) How reliably do we transmit disaster information to the headquarters?
(3) How pertinently do we analyze and utilize the information for fire-fighting and rescue activities?

We try to overcome these problems through constructing the information system shown in Fig. 1, which outlines the system concept and information flow. The system was designed based on the following considerations.

According to the result of a questionnaire survey of municipalities affected by the Kobe earthquake, staffs and residents collected most of the damage information as shown in Fig. 2, and informed the headquarters of fire departments or municipalities orally or by memos. However, this method is inadequate for visualizing the distribution of damage on a map instantaneously and for processing information because the data is in analogue form. Therefore, it is necessary to obtain digital data on damage rapidly. In addition, communication between headquarters and disaster areas must be secured in order to acquire damage information quickly. Since congestion of telecommunication routes always occurs after a large earthquake, it is necessary to develop a new communication network system between the stricken sites and headquarters without using public circuits.

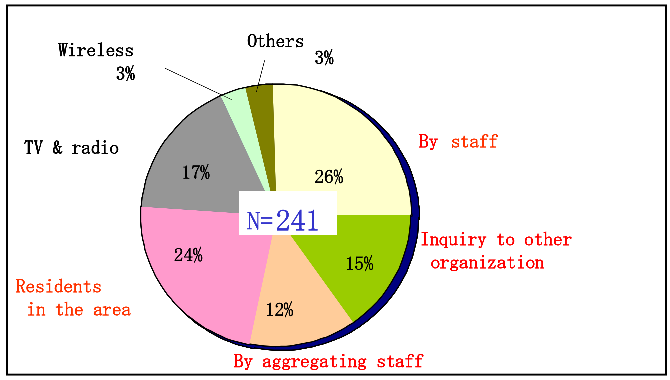

Fig. 2 Means of collecting earthquake damage information in the 1995 Kobe Earthquake

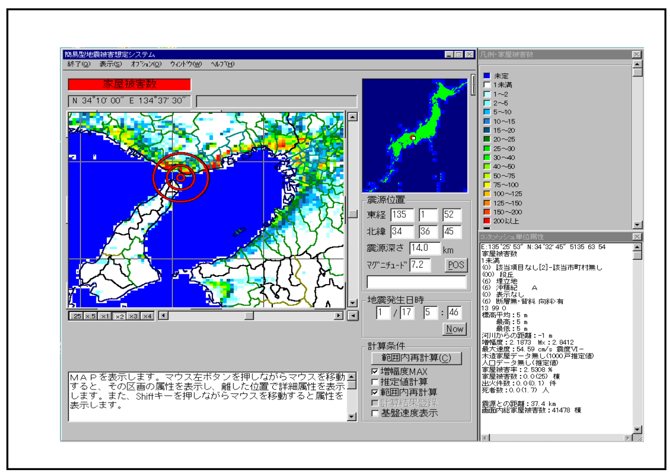

Fig. 3 Earthquake damage assessment system using PC

At the headquarters, disaster information should be integrated and visualized using GIS, and supporting information for the fire-fighting strategy and tactics should be created and disseminated to the stricken area, based on real-time estimation of the earthquake damage, simulation of the spread of fire, and so on. Although there are a few systems based on the similar concept at the fire departments in large cities such as Tokyo, Kyoto and so on, these are off-line systems.

COMPONENTS OF SYSTEM

The components of the system, sub-system, and element technology needed with the lapse of time after an earthquake are described as follows.

Earthquake Damage Estimation System

We have developed a simplified estimation system that provides an image of the damage just after an earthquake (Zama[3]). Figure 3 shows the result for the Kobe earthquake. This system has the following features.

(1) It is possible to estimate the number of deaths, injured, refugees, fires, and collapsed wooden houses,

(2) It can be used for the whole country,
(3) Existing data are used, namely Digital National Land Information and National Census Data,
(4) It works on Windows machines,
(5) It is easy to operate,
(6) It takes only several seconds to estimate the damage in a prefecture, and so on.

The system has already been deployed in more than 1,800 municipalities, fire services, institutes and so on as of November 2003. However, the existing databases used in the simplified estimation system have a spatial resolution of 1-km square, and so are useful for grasping the damage over a wide area, but not small areas such as cities. We have therefore developed a system that can estimate damage with high spatial resolution for Yokosuka City and Tokorozawa City near Tokyo. In constructing the system, we took the ease of introduction to other municipalities into consideration: databases associated with soil conditions, houses and population have been constructed so that they can be easily derived as follows:
(1) Soil conditions: The land condition map is utilized. Soil amplification factors are determined from the averaged S-wave velocity down to 30 m based on borehole data such as geology and N-values (Zama[4]). Digitalization was carried out by scanning the original land condition map for each soil classification.
(2) Houses: Commercially available Digital Urban Maps (Zenrin Co., Zmap-II) contain information on the number of floors of each house. We regarded buildings with a first and/or second floor as wooden houses, and confirmed the accuracy compared with the actual number of wooden houses.
(3) Household: We used the population numbers for small blocks provided by both cities. The number of people in a house was estimated by dividing the total population in each block by the number of houses in it.

The detailed damage estimation system was developed using GIS. The methods for evaluating the degree of earthquake damage were identical with those adopted in the simplified system. Figure 4 compares the seismic intensity distribution for the three different systems for the hypothetical Tokai earthquake. The results show that this system has a higher spatial resolution than the other methods.

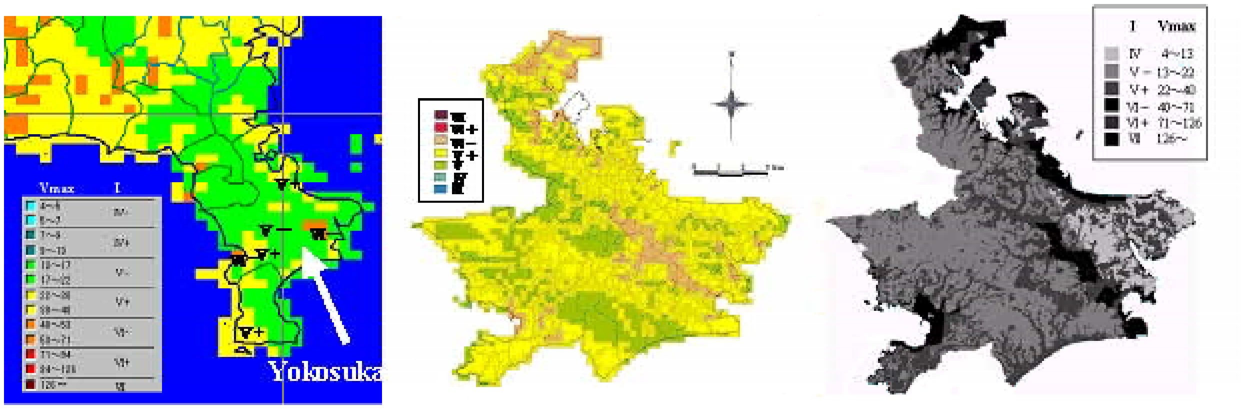

Fig. 4 Comparison of estimated seismic intensity distribution for the Tokai earthquake
Left: by the simplified earthquake damage estimation system using National Land Numerical Information
Middle: by Yokosuka City for 250m mesh
Right: by the present study

Information Collection Terminal

In big cities such as Tokyo and Yokohama, cameras in high positions and helicopters will be used to assess the damage just after an earthquake. However, it is difficult to use these in a small town for mainly economic reasons. In addition, the obtained information by such equipments is not sufficiently detailed such that an emergency response can be properly and smoothly conducted, so staffs in a municipality will organize information collection teams. Damage information including location should be digitalized so that it can be easily processed and displayed on the map. Visualization of the damage situation will lead to quick, pertinent responses and smooth restoration as well as reconstruction.

Fig. 5 Handy-type damage gathering terminal
Upper: Palm-size terminal
Lower: Display of total map, detailed map with icons showing damage, and input window

At the beginning, we developed the tool based on Windows PC with a function that staffs in a municipality, firefighters, and community leaders can easily input damage information such as place, time, damage item, extent and so on at disaster sites by a stylus pen (Zama[1]). Since the PC costs about 450,000 yens and weighs roughly 1.4 kg at that time, it seemed to be unsatisfactory on both ease of introducing it to municipalities and portability. Then, we have developed the advanced tool shown in Fig. 5, which has the following features.

(1) Palm-size PC is used for portability, because its weight is about 250 g.
(2) It costs about 7- 80,000 yens.
(2) Detailed map within a city, in which each house can be discriminated, is displayed by both manual and automatic operation based on the acquisition information by GPS.
(3) Position information can be acquired by clicking on the map.
(4) Damage data and extent can be input easily, and displayed on the map.
(5) A communication function enables data to be transmitted to a host computer.
(6) It can receive integrated damage information and simulation results such as fire spreading from a host computer.

For staffs responsible for collecting information in a part of the city, function (6) is particularly important, because they can assess their own situation throughout the city, and can also evacuate inhabitants to a safe place when the result of the fire-spreading simulation shows the danger situation. Firefighters can also take relevant fire-fighting strategy and tactics.

The persons in charge of gathering information search the damage situation and input data into the terminal as they walk around the disaster area. To support these operations, the terminal has three maps of different scale, so users can roughly grasp their positions on the large- and medium-scale maps. Furthermore, it has a function to acquire the position from the GPS and to display the map with a central focus on the position. For ease of input, every operation can be done by merely clicking or dragging.

In the field experiment in Yokosuka City, it took about 90 minutes to search on foot and to input the various information into the information terminal on the 18 cases of damage associated with houses, life lines, fires and so on, in the area of about 300 x 400 m^2 for the hypothetical Tokai earthquake.

Besides the handy-type terminal, we have developed a tool for cars. This can quickly and roughly search and collect damage information over a wide area. It can also help nationwide large-area fire brigades to arrive at the stricken site rapidly, to assess the state of the site, and thus to prepare for smooth activities before arrival, because it has GPS navigation system, car speed sensor, road-matching technology, as well as detailed maps with support information such as water supply facilities, hazardous material facilities, refuges, gas stations and so on.

Communication Network System

As mentioned above, it is important to ensure the communication between disaster sites and the fire defense headquarters or the disaster prevention headquarters without congestion. Our institute has developed the FiReCos (Fire and Rescue Communication System) that enables firefighters to communicate smoothly among them at a disaster site (Tamura[5,6]). FiReCos is high-performance and portable radio equipment based on PHS (personal handy phone system).

Since both digital wireless communication technology and multi-channel access system are adopted, FiReCos is free from both radio interference and congestion, and is thus ideal as the basis for the communication network in the system. Furthermore, since the standard TCP/IP (Transmission Control

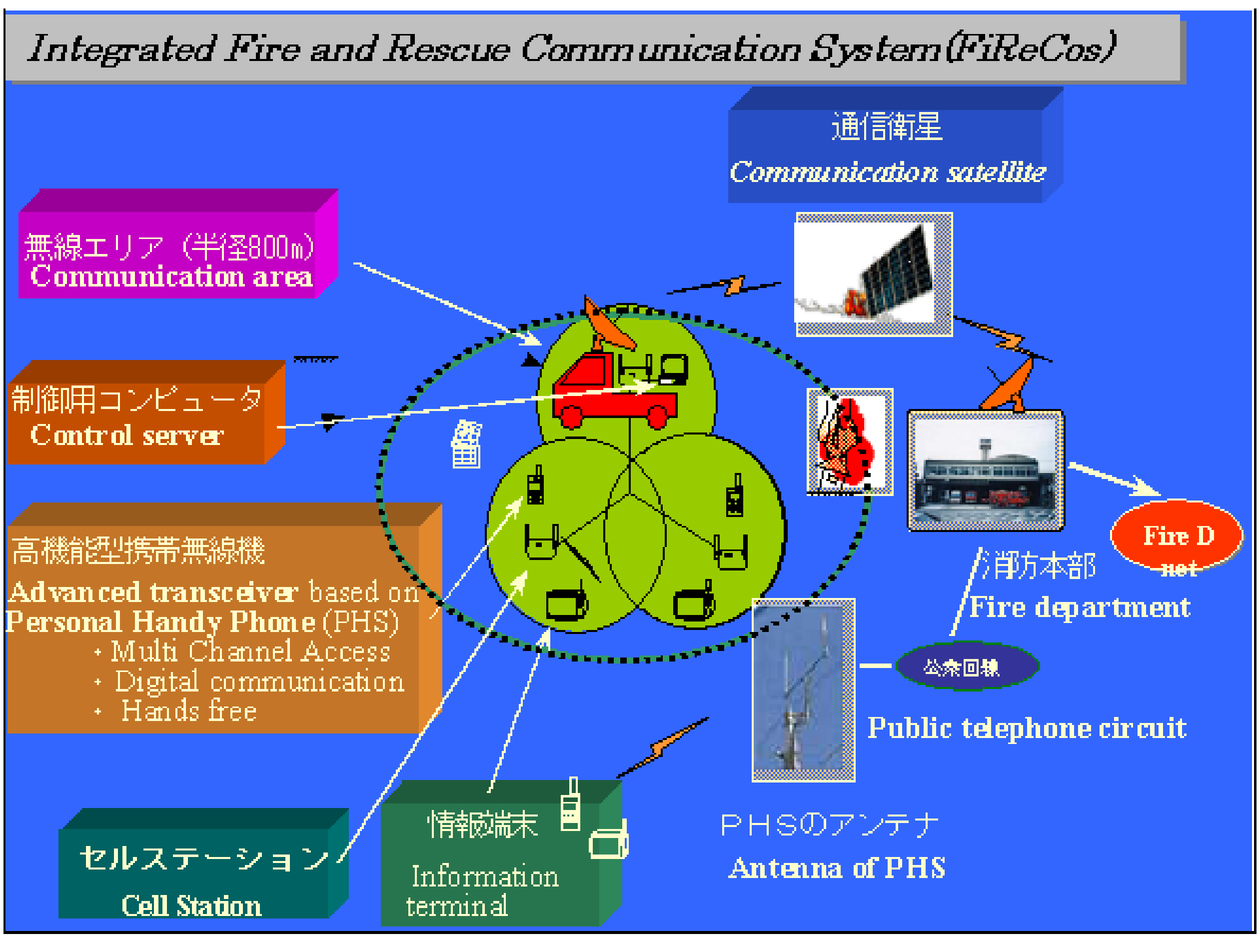

Fig.6 Integrated radio communication system (FiReCos)

Protocol/Internet Protocol) used in computer networks is adopted, the system can be easily connected to terminals and host computers that support TCP/IP for communication. FiReCos uses an extension mode, because it is not necessary to offer the usage of public radio waves. The transmission capacity is 32 kbps, the number of channels is 140, and frequency used is automatically selected by the multi-channel access method, so smooth transmission without congestion is ensured.

The network is constructed by connecting many cell stations each with an IP address using Ethernet LAN, which enables long-distance communication as shown in Fig. 6. With the aim of making practicable, Tamura[6] constructed a network combined several wireless LAN units and carried out field communication tests in Yokosuka City, and confirmed that the data communication can do via three wireless LAN units in about 1.5 km span between a field and the fire department.

Real-Time Simulation System of Fire-Spreading

There are many wooden houses within small areas in Japan. Once a fire occurs, it tends to spread as seen in the 1923 Kanto earthquake, in which about 100,000 people were killed by fires. As many fires break out simultaneously in a large earthquake, fire brigades are often under-equipped to deal with them. Nevertheless, fire activities must be conducted to minimize the total burnt areas by appropriately operating fire brigades. To devise the optimum fire-fighting strategy, it is indispensable to predict how the fires will spread as soon as possible based on actual information on the locations of fires and weather such as wind speed and direction.

In developing the real-time fire-spreading prediction system, we considered applicability to other areas, cost and labor. We obtained building data from commercially available Digital Urban Maps (Zenrin Co., Zmap-II) as in developing the detailed earthquake damage estimation system.

Since the result must be produced quickly for supporting fire activities, we increased the processing speed by making the following simplification:

(1) Fire spreads from house to house without flying sparks,

(2) Fire spreads from the wall to the center of a house, and spreads to another house which burns most rapidly,

(3) Wind speed and direction are constant during burning,

(4) The fire-spreading paths are calculated in advance.

Figure 7 shows an example of the fire-spreading simulation results. The calculation time for a fire for three hours is a few seconds by using a personal computer with a CPU of 1GHz.

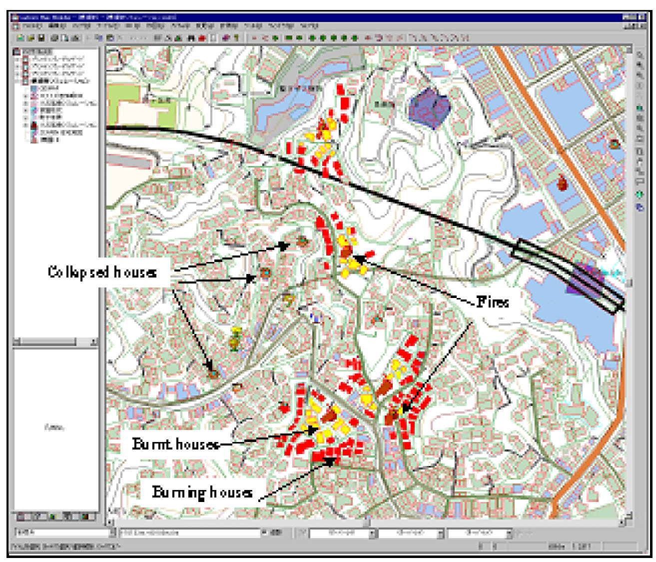

Fig. 7 Example of visualization of fire spreading simulation result and integrated disaster information by GIS

Optimal operation of fire brigades

Fire brigades must response for fire-fighting against simultaneous multiple fires in urban areas following a disastrous earthquake with limited existing resources such as personnel, fire engines, water supply and so on. For this purpose, we are developing a real time simulation system as the useful tool for decision-making in setup of strategy of emergency response at the headquarters of fire departments. This system produces such information for supporting fire-fighting activities as prompt prediction of fire spread at a certain future period, required fire engines and water supply for controlling fires, and also an optimum fire-fighting operation with existing resources based on the data of real time simulation of fire spread and fire brigades' operation.

Other Functions of Host Computer

The host computer at a fire department has the following functions:

(1) Creating base map

It can generate the image data of maps in three different scales and transmit them to terminals.

(2) Saving and editing disaster information

It can register and edit the disaster information based on the requests from terminals.

(3) Simulation server

It can transmit the simulation results in the database to terminals based on the request.

(4) Transmitting disaster information

It can transmit integrated damage data in the area designated by terminals.

(5) Conducting earthquake damage estimation, simulating fire-spreading and visualizing the results (Fig. 7)

(6) Integrating and visualizing the disaster information by GIS (Fig. 7)

(7) Dissemination of disaster information to Fire-D net

EVALUATION OF SYSTEM PERFORMANCE

The prototype system is composed of several units as described above. In the future, other components will be added to the system to be adaptive to various situations. Here, we evaluate the performance of the present system as a whole, because the performance of each unit has already been examined, respectively. The system performance was evaluated as follows using the apparatus shown in Fig. 8.

(1) Input disaster information including fire information using the information gathering terminals.

(2) Transmit the information to the host computer through FiReCos.

(3) Integrate and visualize the disaster information in the database using GIS.

(4) Carry out the fire-spreading simulation based on the fire information in the database.

(5) Visualize the result of fire-spreading simulation in three hours and transmit the data on the burnt area to the terminals.

(6) Confirm the result by the terminals.

The time required for transmitting fire information, calculating fire spreading, visualizing the result, and transmitting information to a terminal is about three minutes for three fires. Most of the processing time is taken for visualizing the simulation result by GIS.

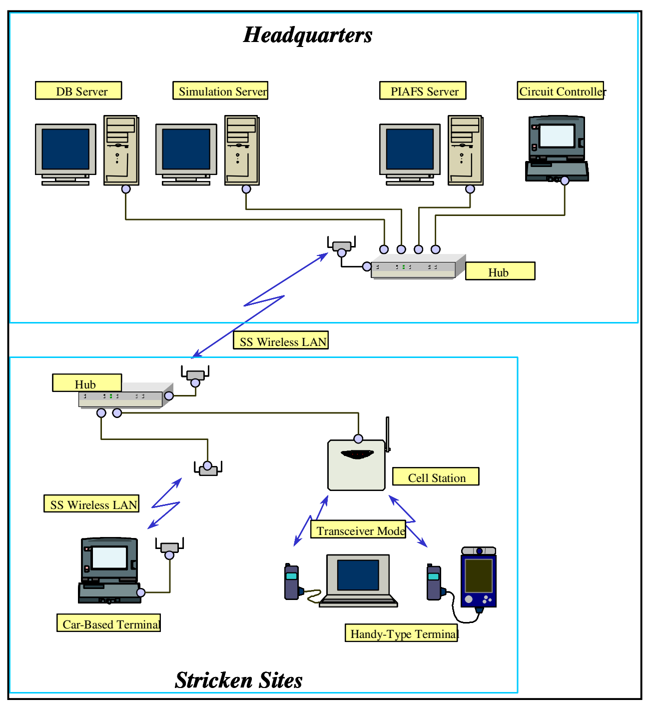

Fig. 8 Apparatuses for evaluating the system performance
SS Wireless LAN links the cell stations in the stricken sites with the LAN in the headquarters.

After that, we conducted the preliminary field experiment at Yokosuka City in order to clear up problems in operating the system prior to

the large-scale experiment at Tokorozawa City. The following items were evaluated in the Yokosuka experiment.
(1) Communication area of FireCos and wireless LAN
(2) Identification of in-situ location on map, visibility, and operationality by the terminal
(3) Data communication by means of the terminal
(4) Time needed for collecting disaster information
(5) Information literacy for the fire spreading prediction results and for integrated disaster information by means of the terminal
According to firefighters' evaluation, the system is valid for planning of fire-fighting strategy. However, improvement of the terminal is required concerning the way of input, displaying, and transmission of disaster information by the terminal.

After dealing with these problems, we performed large-scale experiments on simulating disaster information collection and transmission. The experiments were conducted in five areas of the Tokorozawa city, where is located north of Tokyo, employing twenty terminals, three days and forty people per a day. We found that the most appropriate way to survey damage is to input the damage information to handy-type terminals at disaster sites when communications between terminals and host systems in headquarters were established almost anywhere. The 'disaster clearinghouse' connected to headquarters by robust communication lines will be useful not only in collecting surely urgent damage information but also in residents' asking aid with telephones interrupted. We also found that the total number of buildings and houses is appropriate to estimate the time required for damage information collection.

SHARE AND EXPLOITATION OF EARTHQUAKE DAMAGE INFORMATION

It is very important to obtain precise disaster information more quickly and easily, and also to share the information with disaster-related organizations in a seamless manner for rational emergence responses just after a large earthquake. From this point of view, Fire and Disaster Management Agency (FDMA) has constructed the network through which most of fire departments and prefectural divisions responsible for disaster can share disaster information. This network is, therefore, expected to reinforce wide-area assistance, but it is useful only when disaster information is entered by the fire department close to actual disaster sites. As mentioned above, we have been developing the portable information terminal that can easily enter disaster information and transmit them to a fire department from disaster sites. However, this is a part of a closed system in a municipality. Then, we tried to link the system and FDMA's network in order to share seamlessly disaster information entered at disaster sites. Furthermore, we linked fire-spreading prediction system with the network at FDMA. This is useful even for not earthquake. Exchange of information between different systems was accomplished by preparing and monitoring a common file. When the file is updated, corresponding command will be executed. Thus, organizations connecting to the network will be able to obtain immediately disaster information and simulation results of fire spreading and to make rapid and precise arrangements for wide-area assistance.

CONCLUDING REMARKS

We have developed a prototype system that supports effective initial response activities just after an earthquake, in order to put the lessons to good use from the 1995 Kobe earthquake. The system is composed of several subsystems, that is, earthquake damage estimation system, disaster information collection terminal, communication network system, real-time fire spreading simulation system, optimal operation system of fire brigades and so on. Furthermore, we have conducted the field experiment to verify the validity of the system in operation for the practical use, and could get knowledge about large-scale, long distance and large volumetric information collection and transmission. Although the system is a pilot one as a total system, the subsystems and technologies used in the system have been provided with the disaster-related organizations such as FDMA and fire departments for rapid initial response, disaster prevention training, and so on.

Furthermore, in order to build useful system, the followings should be considered, that is, a distributed system against obsolescence of components of a system, standardization of information structure such as item, attribute, format, accuracy and so on, in order to share various data, common key technology for transmission and storage of large amount of information, availability for daily job, cooperation with another systems, and so on.

ACKNOWLEDGEMENTS

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