Development of Real-time Seismic Information System for M.O.C.

by

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ABSTRACT

This paper presents a research and development of "Real-time Seismic Information Systems for Ministry of Construction (MOC)" to support the emergency responses for civil infrastructure immediately after an earthquake. Emphases are placed on information systems for earthquake ground motion detection, structural damage and ground hazard estimation, structural damage detection and high-speed data communication using seismograph network and innovative multi-media technologies.

Key Words: Earthquake Disaster,
Real-time Information System,
Seismograph Network,
Damage Estimation,
Damage Detection

1. INTRODUCTION

Damage on civil infrastructures such as highways and river facilities due to an earthquake does not only reduce their functions but also affects the socio-economic activities in and around the damaged area[1]. Therefore, besides improving seismic performance of the civil infrastructures, pre-earthquake risk management to evaluate and mitigate their damage and post-earthquake emergency responses to reduce the effects caused by the destruction must be jointly promoted.

The MOC promoted a five-year comprehensive research project to develop disaster information systems from 1987, and compiled a "Guideline for Disaster Information Systems (Draft)[2]" which supports sectors responsible for the civil infrastructure respond emergency situations in terms of the disaster information. Taking possible techniques of information communication and processing into account, and based on the experiences of several past large natural disasters, the guideline deals with frameworks of the disaster information systems useful for acquisition, communication and analysis of the disaster information. Although seismic information systems at MOC have been developed based on the guideline, they are required to be more sophisticated in consideration of the experiences of serious disaster caused by 1995 Hyogo-ken Nanbu earthquake, progress of information oriented lifestyle and of recent technology innovation, such as remote sensing and multi-media technologies.

1995 Hyogo-ken Nanbu earthquake was the first destructive earthquake occurred right under a highly integrated urban area in Japan. Based on the experiences, the following information systems are pointed out to be urgently required for the real-time emergency activities immediately after an earthquake.

1) Real-time earthquake detection system to

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know the earthquake scale

2) Real-time estimation system to give an outline of civil infrastructure damage
3) Earthquake disaster detection system to grasp civil infrastructure damage which spreads over wide area.
4) Multi-media communication systems to transmit various kinds and a large amount of disaster information to sections and organizations concerned.

This paper introduces current state of seismic information systems at MOC, and the required real-time seismic information system for earthquake detection, damage estimation, damage detection and high-speed data communication for the emergency responses on civil infrastructure.

2. CURRENT STATE OF SEISMIC INFORMATION SYSTEMS

2.1 Communication Network for Disaster Prevention at MOC

Based on the experiences of repeated typhoons in 1940s, MOC recognized the importance to secure the communication network during a disaster, and has developed its exclusive communication network for disaster prevention. Since Niigata earthquake in 1964 in Japan when the efficiency of the exclusive communication network for disaster prevention, development of the communication network has been promoted all the more. MOC has now its nationwide communication network with 1,300 stations and 600 million channel-km of communication lines, which is the next largest network to that of Nippon Telephone and Telegram (NTT).

The communication network for disaster prevention is one of the essential parts of the earthquake disaster prevention framework at MOC. It is now being sophisticated based on the experiences of 1995 Hyogo-ken Nanbu earthquake and the revision of the National Disaster Prevention Plan (issued by the National Disaster Prevention Board, January 1996). The efforts includes revising the communication network from analogue to digital and linking it to the seismograph network and the disaster image transmission system.

Besides the communication network for disaster prevention, the optical communication network is under construction utilizing the public space such as highways and rivers. Focusing on the multi-media oriented lifestyle in coming 21 century, it is planned to complete 300 thousands kilometers of the optical communication line until 2010. As it focuses not only on the management of public facilities in usual time but also on the use for regional disaster countermeasures, it will be an essential data communication infrastructure to develop the real-time seismic information system.

2.2 Seismic Information Systems at other Organizations

At national and regional public bodies whose emergency response organizations are designated by laws, various information systems are applied to support the response actions. After Hyogo-ken Nanbu earthquake, "real-time earthquake disaster prevention" to cope with emergency response without conflicts is discussed actively, and information systems to

Table 1 Real-time Information Systems at Other Organizations

ORGANIZATIONS	EQ DETECTION (SEISMOGRAPH etc.)	DAMAGE ESTIMATION
CUBE	ABOUT IN CALIFORNIA	- ALARM
JR (UrEDAS)	EACH 20-80km ALONG MAJOR RAILWAY	- ALARM - EMERGENCY STOP
TOKYO GAS (SIGNAL)	ABOUT 300 IN KANTO AREA	- LIQUEFACTION RISK - DAMAGE DISTRIBUTION
TOKYO	ABOUT 50	- CASUALTY, FIRE SPREAD - DAMAGE DISTRIBUTION
KAWASAKI CITY	ABOUT	- DITTO
YOKOHAMA CITY	ABOUT 150	- DITTO

provide the prompt estimates of the damage on the residents and the facilities are being developed and applied. Table 1 shows examples of the real-time information systems at several organizations.

3. REAL-TIME INFORMATION SYSTEM FLAMEWORK

3.1 Information required for the emergency responses on civil infrastructure

Emergency response activities that is necessary for the management of the civil infrastructures vary depending on the time period after an earthquake. Therefore, it is important to treat necessary information with

Table 2 Fundamental Policies of Restoration Stages

RESTORATION STAGES	TIME PERIOD	FUNDAMENTAL POLICIES
1ST STAGE	EQ OCCURRENCE ~ 1 HOUR	- GRASPING OUTLINE OF DISASTER - EMERGENCY ACTION
2ND STAGE	~ 1 DAY	- GRASPING TOTAL DAMAGE STATUS - TEMPORARY REPAIR
3RD STAGE	~ 1 WEEK	- GRASPING DETAILED DAMAGE STATUS - PERMANENT REPAIR

appropriate accuracy according to the response activities. The response activities can be classified into three restoration stages and the fundamental policies in each stage can be shown in Table 2[3]. The information required in each restoration stage are summarized as follows.

1) In the first stage, the bi-value information if the areas are seriously affected and if the facilities have serious damage that may cause secondary disaster
2) In the second stage, the damaged parts and their damage seriousness to judge the necessity of the restoration.
3) In the third stage, the detailed information of the facilities for the complete restoration accounting the future plans of the region.

3.2 Configuration of Real-time Seismic Information System

The entire image of the real-time seismic information system is shown in Fig. 1. The system consists of four subsystems: i.e., an earthquake detection system, a damage estimation system, a damage detection system and a high-speed communication system. Function and configuration of each subsystems are as follows.

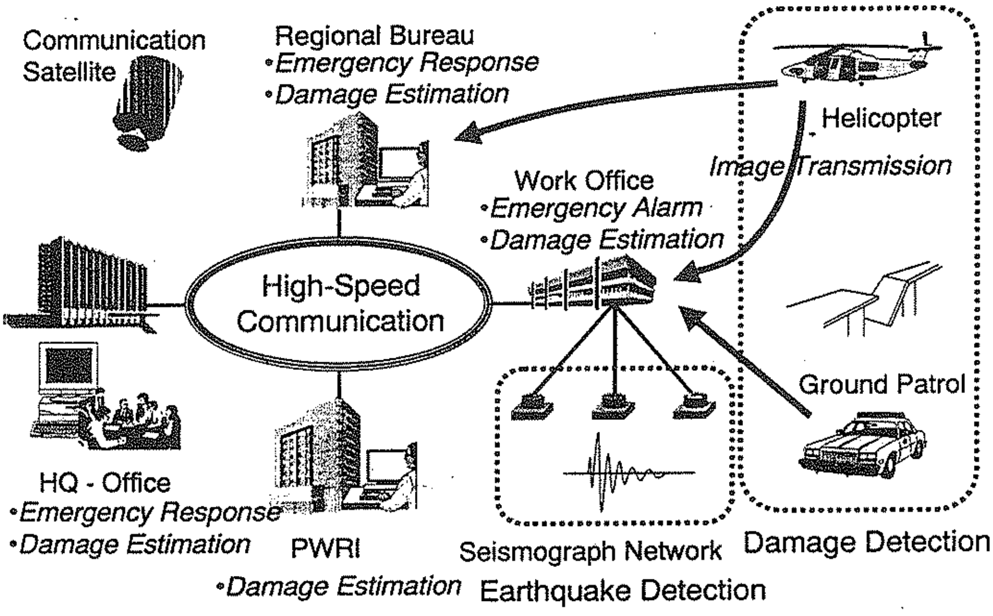

Fig.1 Real-time Seismic Information System

1) The earthquake detection system supports activating the emergency activities of the sectors in charge of the facilities by detecting the ground motion characteristics. The system mainly consists of the seismograph network.
2) The damage estimation system improves the emergency activities by roughly estimating the ground hazard and structural damage on facilities. The seismograph network and information processing devices are combined in this system.
3) The damage detection system improves the understanding of damage by combining images from a helicopter, images and data from the ground patrol.
4) The high-speed communication system transmits the data inside/ outside the organization by combining a optical communication network and innovative multi-media communication devices.

4. EARTHQUAKE DETECTION SYSTEM

It is of great importance to measure the seismic intensity at the facilities by densely placed seismographs for understanding the scale of an earthquake and possible damage on facilities. Also, the initial activities of the sectors concerned can be improved in terms of its quickness if the seismic information can be aggregated to them instantly.

From the above point of view, MOC has started constructing a Seismograph Network in 1995. In the Seismograph Network, about 800 strong-motion seismographs are placed with the interval of 20 to 40km along highways and rivers, and their data are sent to the sectors responsible for the facilities through the communication network for disaster prevention.

Fig. 2 shows the structure of the Seismograph Network. Ground motion characteristics detected at each station is aggregated at each regional construction office, and the data array are sent to the headquarters office and also to PWRI. In order to perform rapid data transmission through the present communication lines with limited capacity, small number of data representing the ground motion characteristics, such as a maximum acceleration, a seismic intensity (SI) value and the equivalent JMA seismic intensity level are to be sent.

The Seismograph Network is a fundamental system for the real-time seismic information system. In combination with a damage estimation system described later, following advantages can be derived.

1) Possible areas seriously affected can be predicted based on the quantitative data such as the maximum acceleration and SI-value.

2) The initial response activities can be more efficient with the prioritized damage seriousness of inspection sites.

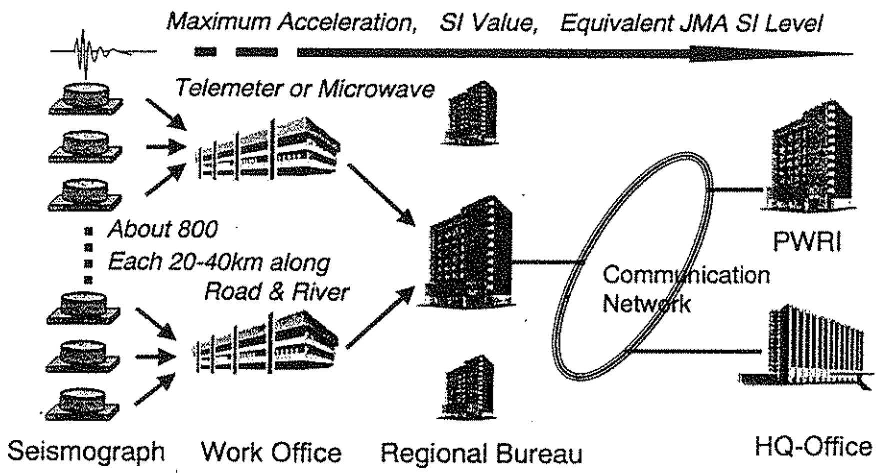

Fig.2 Structure of Seismograph Network

3) Support by the neighboring district without possible serious facility damage can be decided rapidly.

5. DAMAGE ESTIMATION SYSTEM

5.1 Structure of Damage Estimation System

The system can estimate possible ground hazard and possible structural damage on facilities by analyzing a large quantity of information regarding ground motion characteristics, ground conditions and structural conditions. This system will contribute to rationalize the initial response activities, i.e. understanding the outline of disaster and decision making on prioritized inspection area.

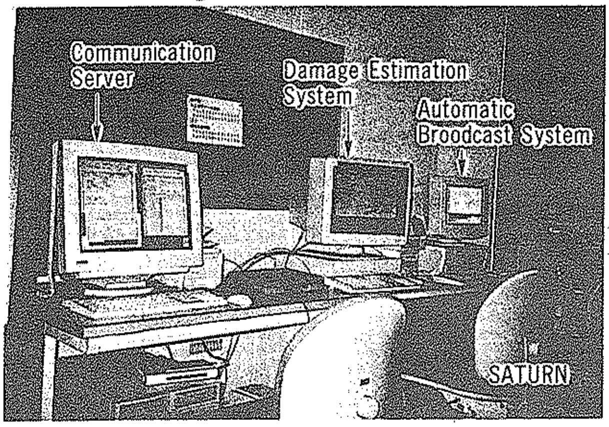

Photo.1 Prototype of Damage Estimation System:SATURN

PWRI and Kanto Regional Construction Bureau has jointly developed a prototype system (SATURN: Seismic Assessment Tool for Urgent Response and Notification) which roughly estimates the liquefaction risk and possible damage on highway bridges using the ground motion characteristics acquired by the Seismograph Network and other databases. At this time, the prototype system can perform the estimation within 15 minutes immediately after an earthquake. As shown in Photo 1, the prototype system works in cooperation with the communication server that receives and stores the seismic information in it.

5.2 Damage Estimation Methodologies

Fig. 3 illustrates the execution flow of damage estimation by the system. The execution proceeds through three steps: i.e., estimation of ground motion characteristics at facility sites, estimation of liquefaction risk, and estimation

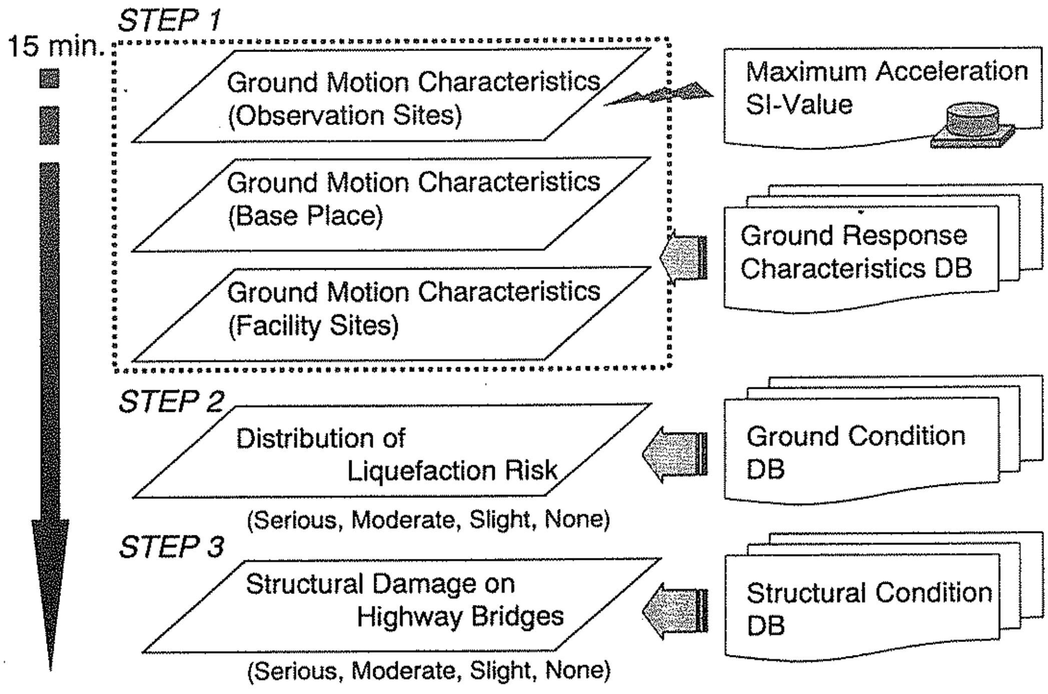

Fig.3 Flowchart of Damage Estimation

of the structural damage on highway bridges. Basic concepts of each steps are as follows.

(1) Ground Motion Characteristics at Facility Sites

Ground motion characteristics such as a maximum acceleration and a SI-value at a certain point can be estimated by interpolating them monitored at plural seismograph stations surrounding the point as shown in Fig 4. To avoid topographical influences on the estimation, ground motion characteristics are interpolated not at the ground surface but at the base place. Although the ground response characteristics must be known to estimate the ground motion characteristics at base place, immediately after an earthquake, it is quite difficult to calculate the response characteristics by the one-dimensional wave propagation method for all the points. Therefore ground response characteristics at station/ facility sites are calculated in advance and are stored in a database. It realizes the rapid information processing right after an earthquake.

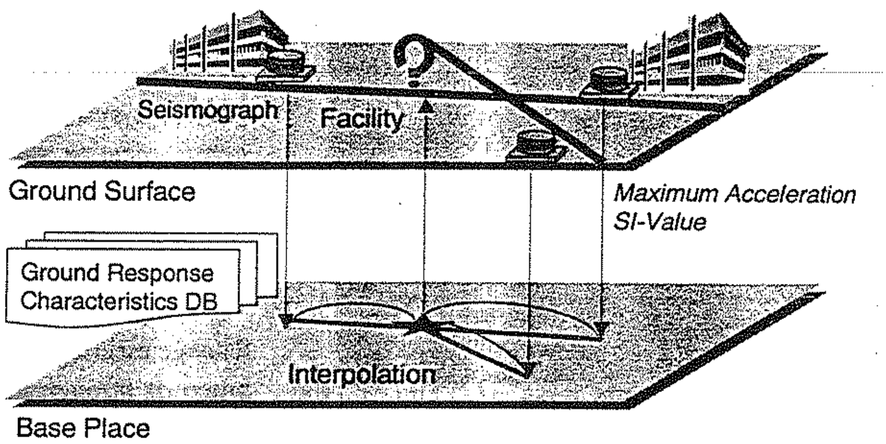

Fig.4 Estimation of Ground Motion Characteristics at Facility Site

(2) Distribution of Liquefaction Risk

The estimation of the liquefaction risk in the affected area is carried out by combining two kinds of estimation, i.e. estimation on a line along highway facilities, and estimation on areas besides highway facilities. Estimation along highway facilities can be carried out with sufficient ground condition data by calculating the "resistance values against liquefaction: F_L" and the "liquefaction index: P_L" regulated in the [Specifications for Highway Bridges] revised in 1996. Estimation on areas besides highway facilities is performed by a simplified method based on the topographical micro-zoning due to the insufficiency of ground condition data.

Fig. 5 shows a example of the distribution

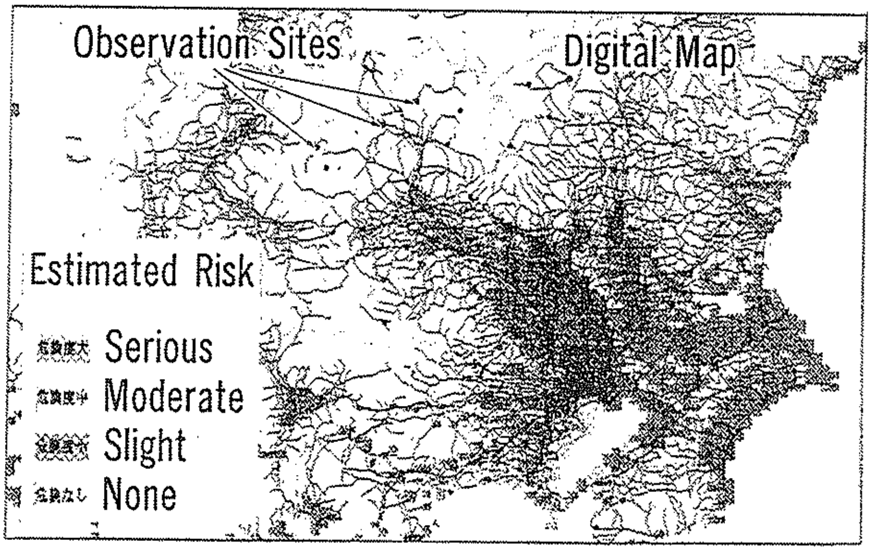

Fig.5 Estimated Liquefaction Risk distribution

of liquefaction risk. The liquefaction risk is displayed in four simplified categories of "serious, moderate, slight and no risk" as it is referred in an emergency situation immediately after the earthquake.

(3) Structural Damage on Highway Bridges

It is general to apply the response analysis methodology with mathematical models to know the behavior of highway bridges during an earthquake. However, it is difficult to complete the calculation by the general methodology urgently after an earthquake. Also at present, the information of the structure condition is not sufficiently prepared for the computation.

From the emergency response's point of view, the most important task is to know if each bridge is passable or not. Therefore, rough estimation on serious damage of bridges gives a effective information to decide the emergency inspection strategies. Fig. 6 shows an example of estimated structural damage in the affected area. Estimated damage is displayed in four simplified categories of "serious, moderate, slight and no damage".

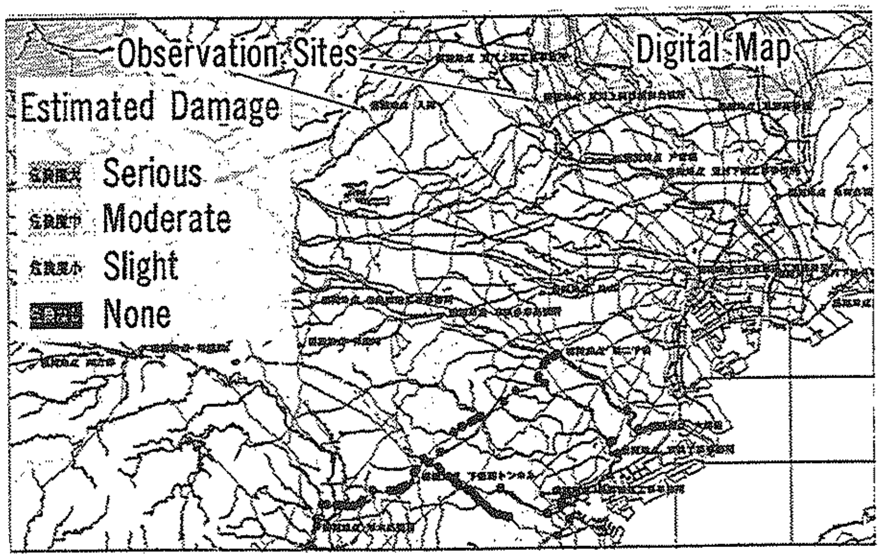

Fig.6 Estimated Structural Damage on Highway Bridges

The structural damage possibility of bridges is estimated by combining damage possibilities of bridge parts, such as columns, foundations and bearings. Damage possibilities of bridge parts are estimated by comparing their strength and ground motion characteristics such as maximum acceleration and SI-value. Here, the relationship between ground motion characteristics and occurrence of damage must be statistically studied in advance based on damage cases due to past

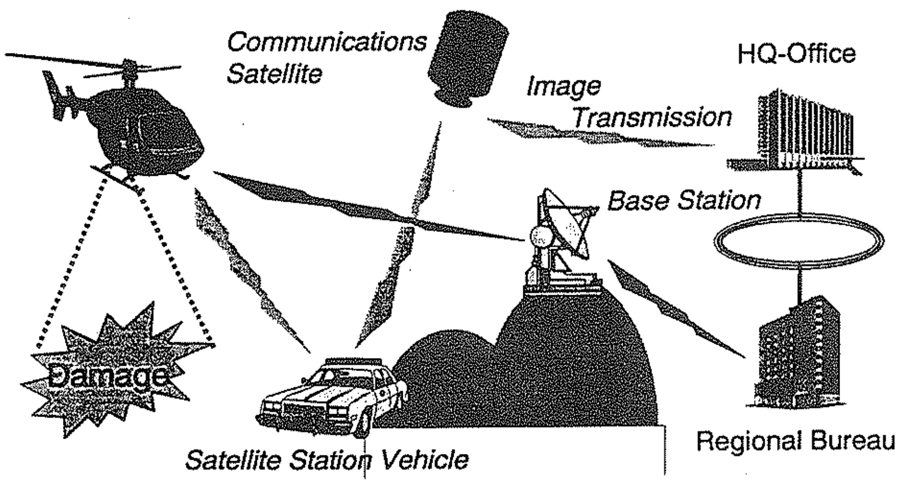

Fig.7 Helicopter Image Transmission System

earthquakes.

6. DAMAGE DETECTION SYSTEM

6.1 Remote Sensing by Image from Helicopter

Inspection by a helicopter from the air is quite efficient in terms of the damage detection after an earthquake[4] because it is not affected by the damage on the road or traffic congestion, and because it can collect the information of wide area in a short time. Also, visual images such as those taken by a video camera can provide desirable information in a short time. The structure of the helicopter image transmission system is shown in Fig. 7.

There are three helicopters administrated by MOC which are disposed at Tokyo, Osaka and Fukuoka. Among them, two of them are introduced after the 1995 Hyogo-ken Nanbu earthquake. They are equipped with various sophisticated information devices. Those include a video camera, a thermal image sensor, a GPS device to determine the position of the helicopter and other communication devices. Also the relay stations and the relay lines for the digital signals from helicopters are being improved.

It should be noted that the proper combination of flight rules of a helicopter and rules of taking images are important. For instance, overall images of the affected area and distribution of seriously damaged facilities, which are required on the first stage of restoration, are inspected by taking the images of panoramic view with much height in the sky. On the second stage, information for the emergency restoration such as damage on columns and cracks on embankments can be obtained by flying along the facilities with large magnification. An example image of a highway bridge taken from a helicopter is shown in Photo. 2.

6.2 Damage Detection by Ground Patrol

Although it takes time to reach the damaged site, the ground patrol can collect more detailed damage information than that by from the air. An efficient way of information collection is to combine the inspection from the

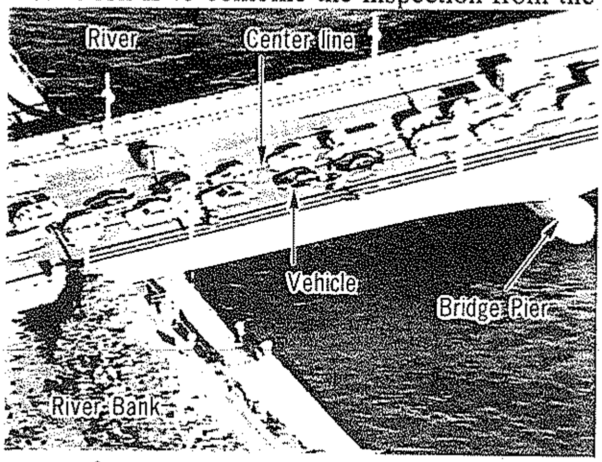

Photo. 2 Image of Highway Bridge Taken From Helicopter

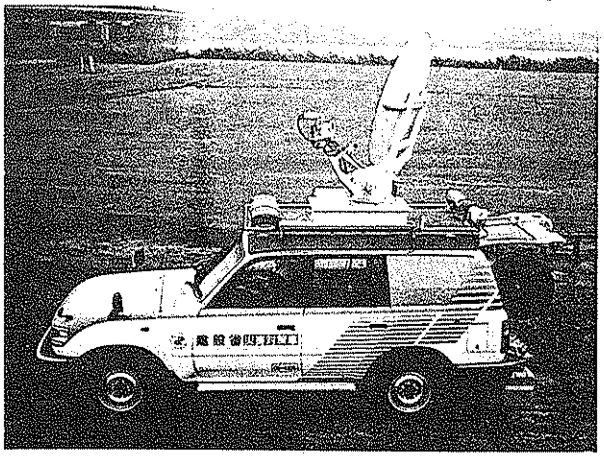

Photo.3 Satellite Communication Vehicle

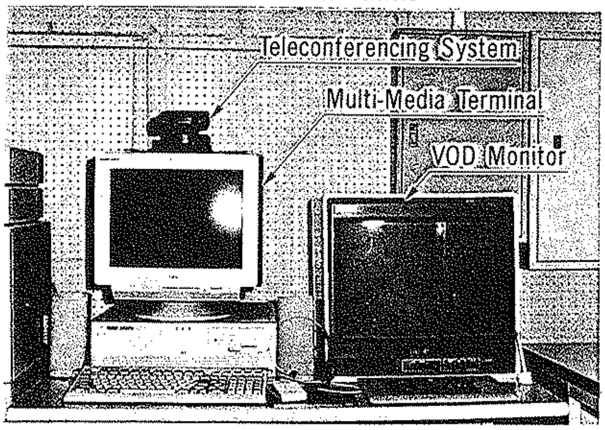

Photo.4 Prototype System for Damage Analysis based on Visual Image

air and that by the ground patrol. For instance, after grasping damage distribution from the air, detailed damage conditions can be inspected smoothly by the ground patrol.

The detected information can be transmitted through a communications satellite by dispatching a satellite communications vehicle or by assembling the small relay station at the site. The transmitted image can be referred at plural sectors and it is easy to hold the information in common among the sectors. In addition, the cellular system exclusive for MOC (K-COSMOS) is being constructed to transmit the information of a handy computer terminal and a digital camera

6.3 Damage Analysis Based on Visual Images

Visual images collected in a damaged area are aggregated at the headquarters office through the communication network for disaster prevention. In the headquarters, therefore, an information system which enables to classify and store a large amount of data systematically and enables to analyze damage conditions promptly is essential. Photo. 4 shows a prototype system for damage analysis based on visual images. Using the system, adding up of damage and remote judging of damage seriousness can be carried out based on visual images.

(1) Adding up of Damage based on Helicopter Images

Based on the transmitted image shown in a VOD monitor, discerning and adding up damage conditions can be carried out by operating engineering workstation. Procedures are as follows.

1) Discerning damage conditions- posing, rewinding and slowly playing of image are available using VOD (video on demand) function of the system.

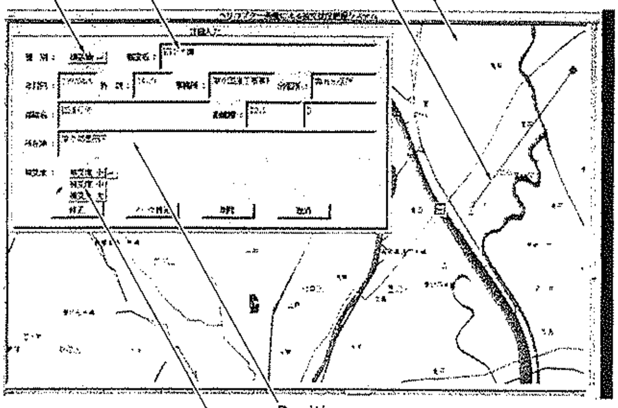

Fig.8 Adding Up Damage Conditions

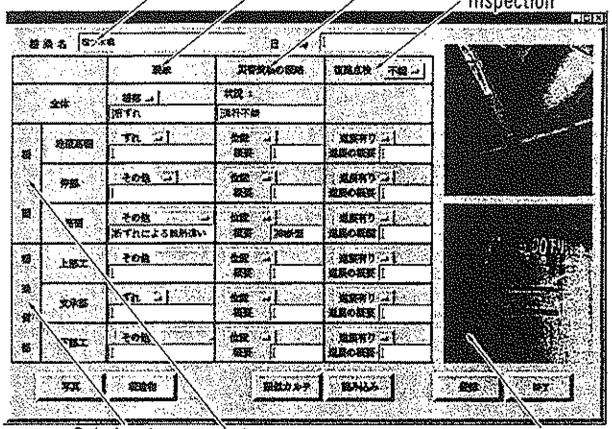

Fig.9 Remote Judging of Detailed Damage Conditions of a Highway Bridge

2) Marking damaged sites on a digital map- this operation is possible by referring the position of the helicopter displayed on the map automatically.

3) Typing structure type, structure name and damage seriousness in a worksheet on the display- attributes of the facility from the database is displayed on the worksheet automatically by cricking the proper position.

4) After completing the inputs of damage information, a damage record map and a table of the damaged sites are created and stored automatically by the system; the created data can be commonly referred by the sectors concerned.

Fig. 8 shows an image to adding up damage conditions using the system.

(2) Remote Judging of Damage Seriousness based on Visual Image from Surface

Detailed damage records can be created by experts for each facility based on the detected information such as digital camera images and video images by the ground patrol. Based on the detailed damage information which can be referred commonly by the work office, PWRI and other supporting sectors through the disaster prevention communication network, the detailed damage record is created by plural sectors jointly through the TV conference. Fig 9 shows an example of the detailed damage record of a highway bridge.

To judge the damage seriousness of remote sites efficiently, it is desirable to apply the information regarding the ground condition and the structure condition by constructing their database during the usual situation and by linking them to the image data in the emergency situation.

7. HIGH-SPEED COMMUNICATION NETWORK USING MULTI-MEDIA TECHNOLOGIES

7.1 Fundamental Requirements for High-Speed Communication Network

As a major part of the real-time seismic information system, communication network for the disaster prevention is required to be sophisticated by applying innovative multi-media technologies. For activating above described information systems on earthquake detection, damage estimation and damage detection, issues to be required are as follows.

1) Transmission Capability- transmission of various media (numerical data, character data, voice data, still and animating image data) with required preciseness and speed
2) Common Utility- cooperative work (processing, exchanging and reference of data) by several sectors connected to the network
3) Seismic Safety- communication lines, devices and network redundancy

7.2 Experimental Study on High-speed Communication Network

As a high-speed communication network which satisfy several issues described above, communication system with Asynchronous Transfer Mode (ATM) was selected. And its possibility to the emergency response activities was studied through experiments. The structure of the high-speed communication network for the experiment is shown in Fig 10.

PWRI, Tokyo National Highway Work Office and Japan Construction Information Center (JACIC) were connected each other by the optical fiber cable. These three organizations were designated respectively as a supporting sector at remote site, a sector responsible for restoration activities and a headquarters office responsible for decision making. Different kinds of information devices were located in these three organizations corresponding to their roles. Devices are the VOD server to store and provide images, the database server to provide mapping/ structural data and the application server for the damage detection/ analyzing system.

Regarding the efficiency of high-speed communication network to the damage detection, following points were derived.

1) Helicopter images can be transmitted instantly to the HQ Office and the supporting sector. The most recent digital image compressing technology reduces the fail of the quality and enables discerning and aggregating damage information.
2) Judging damage seriousness at remote site can be realized with sufficient preciseness. However, the data transmission speed from

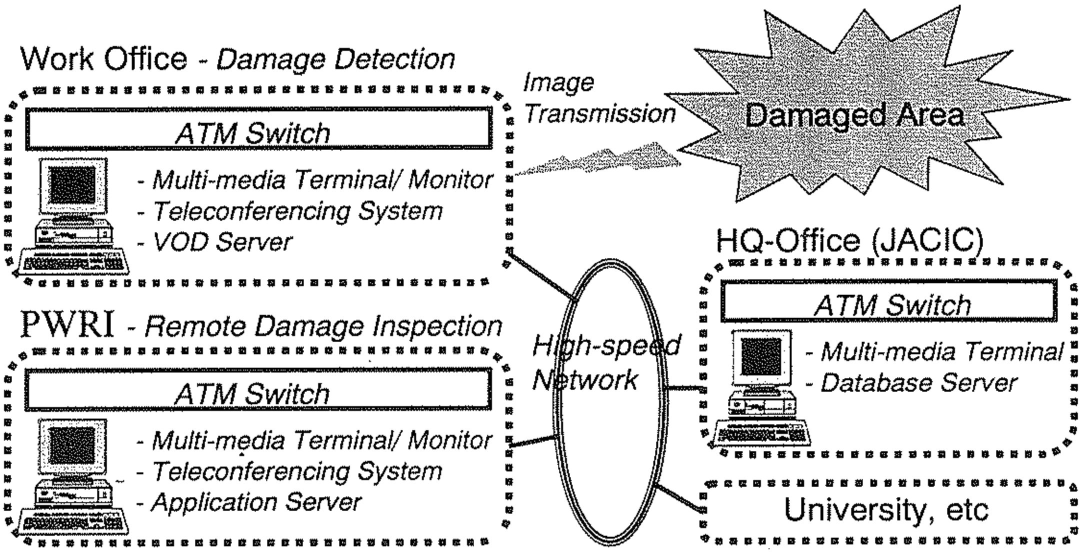

Fig.10 Experimental High-speed Communication Network

database servers and the workability of application shall be improved for smooth execution of cooperative works such as creating the detailed damage records.

8. CONCLUSIONS

Research and development of "Real-time Seismic Information System" was introduced focusing on a earthquake detection, damage estimation, damage detection and high-speed communication. By improving emergency response activities for civil infrastructures immediately after an earthquake, earthquake effects in and around the damaged area caused by structural destruction is anticipated to be much reduced.

For minimizing earthquake effects, pre-earthquake risk management and post-earthquake emergency response must be jointly promoted. Therefore, further study on "Comprehensive Seismic Information System" is required to be made for the pre-earthquake risk management including earthquake loss estimation methodologies and loss reduction strategies.

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