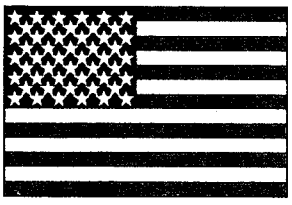
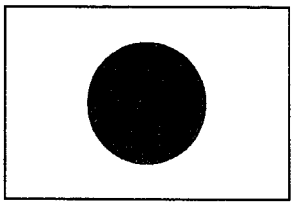
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PROCEEDINGS OF THE FIRST U.S.-JAPAN WORKSHOP ON SEISMIC INFORMATION SYSTEMS







November 15-17, 1999
Public Works Research Institute, Tsukuba, Japan

PUBLIC WORKS RESEARCH INSTITUTE
MINISTRY OF CONSTRUCTION

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PROCEEDINGS OF
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Synopsis:

These proceedings document the results of the First U.S.-Japan Workshop on Seismic Information Systems that was held at the Public Works Research Institute, Tsukuba, Japan during November 15-17, 1999 under the auspices of the UJNR Panel on Wind and Seismic Effects. The Task Committee G "Seismic Information Systems" of the Panel organized the workshop under co-chairmanships of Dr. William Roper (U.S. Army TEC), Dr. Stuart Nishenko (FEMA), Mr. Kazuo Okayama (NLA) and Dr. Hideki Sugita (PWRI).

Key words: Earthquake Disaster Prevention, Information System, Risk Assessment, Urgent Response, GIS, GPS, UJNR

FOREWORD

The following proceedings document the results of the First U.S.-Japan Workshop on Seismic Information System that was held at the Public Works Research Institute, Tsukuba, Japan during November 15-17, 1999 under the auspices of the UJNR Panel on Wind and Seismic Effects. The Task Committee G "Seismic Information System" organized the workshop under the co-chairmanships of Dr. William Roper (U.S. Army Topographical Engineering Center), Dr. Stuart Nishenko (Federal Emergency Management Agency), Mr. Kazuo Okayama (National Land Agency) and Dr. Hideki Sugita (Public Works Research Institute).

The establishment of the Task Committee G was approved on the 30th UJNR Joint Panel Meeting on Wind and Seismic Effects. The objectives of the Task Committee G include;

1) Technically assist the earthquake policy cooperation under the U.S.-Japan Framework for New Economic Partnership (Common Agenda)
2) Improve understanding of earthquakes and social impacts through development of seismic information systems
3) Review the principals, objectives, structures and methodologies of existing seismic information systems, and facilitate practical application in both countries

Recognizing the importance of the technical assistance to the U.S.-Japan High-Level Earthquake Policy Cooperation Forum under the Common Agenda, the workshop focused on the research activities in the areas below;

1) Technologies for the post-earthquake warning, notification and damage assessment
2) Technologies for the post-earthquake urgent response and restoration works
3) Technologies for the pre-earthquake loss estimation works
4) System issues and advanced technologies

Thirty-eight experts representing the government, academia, industry and private practice participated in the workshop. Sixteen papers from Japan and eight papers from the U.S. were presented in the technical sessions. In addition, lessons learned from recent 1999 Kocaeli, Turkey Earthquake and the 1999 Chi Chi, Taiwan Earthquake were presented in a special session.

The workshop also included a technical site visit to observe disaster prevention facilities at the National Land Agency, the Tokyo Fire Department and the Center for Disaster Management and Supply Control of Tokyo Gas Co. ltd..

The materials in the proceedings are presented as follows: 1) technical papers in their order of presentation, 2) workshop resolutions, and 3) appendices include the workshop program, list of participants, and photographs.

In concluding the foreword, the workshop organizers would like to express our sincere appreciation to all participants for contributing the workshop by active discussions. And we extend our grateful thanks to Mr.

Yutaka Nagahisa of the Tokyo Fire Department and Dr. Yoshihisa Shimizu of the Tokyo Gas Co. ltd. for their generous cooperation during the technical site visits. Special appreciation also goes to the assisting staff members, Messrs Y. Yamanaka, T. Kadowaki, N. Kasai, T. Nozaki and Y. Ohtani for the smooth progress of the schedule.

May, 2000

Kazuo Okayama, National Land Agency
Hideki Sugita, Public Works Research Institute
William Roper, National Institute of Standards and Technology
Stuart Nishenko, Federal Emergency Management Agency

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EARLY ESTIMATION SYSTEM FOR TSUNAMI HAZARD

KIRIYAMA Takaharu[1], OKAYAMA Kazuo[2]

ABSTRACT

The National Land Agency has created Tsunami Hazard Maps of the entire coast of Japan for the purpose of having a prior estimate of the tsunami inundation range and has developed an "Early Estimation System for Tsunami Hazard" with the ability to use the Tsunami Inudation Forecasting Database(created from the results of the calculations used to create the Tsunami Hazard Maps) to estimate the tsunami inundation range. The system searches the Tsunami Inundation Forecasting Database to find relevant locations based on the forecasting zones announced in the new tsunami forecasts of the Meteorological Agency and the specific tsunami heights expected. It then displays these locations on the screen to provide a picture of the tsunami inundation area and a rough estimate of the number of buildings and population contained there immediately after an earthquake.

KEY WORDS: Tsunami, Hazard Map, Database, Tsunami Forecasting, Early Estimation.

1. INTRODUCTION

Japan is surrounded by water and has suffered severe damage from the tsunami generated by earthquakes, making measures to counteract tsunami damage is an important issue for coastal areas. One effective means of implementing tsunami countermeasures is to envision the tsunami that are likely to occur in a given region and create a "Tsunami Hazard Map" that indicates, on a map, the areas where tsunami inundation is expected.

Like earthquakes, when tsunami strike it is vital to have a rough estimate of the damage as quickly as possible. The tsunami that accompanied the Hokkaido Southwest Offshore Earthquake of July 12, 1993 occurred at 22:17 but virtually nothing was known about the extent of the damage until the next morning because of the fact that it occurred on the remote island of Okushiri and because of the lateness of the hour.

Since fiscal 1996, the National Land Agency has been operating an "Early Estimation System for an Earthquake" that provides a seismic intensities distribution map, building damage estimate, and human damage estimate immediately after an earthquake. Tsunami estimation functions were recently added to this.

This paper describes the creation of Tsunami Hazard Maps of the entire coast of Japan for the purpose of having a prior estimate of the tsunami inundation range, and the development of the "Early Estimation System for Tsunami Hazard" with its ability to use a database (created from the results of the calculations used to create the Tsunami Hazard Maps) to estimate the tsunami inundation range.

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[2] Director, Earthquake Disaster Countermeasures Division, Disaster Prevention Bureau, National Land Agency

2. CREATION OF TSUNAMI HAZARD MAPS

2-1 OUTLINE

Tsunami Hazard Maps are maps that show the area that is expected to be inundated in the event of a tsunami attack. The map forms the basis for studies of tsunami countermeasures in the area. Figure 1 is an example of Tsunami Hazard Map created by the National Land Agency. It shows at 1/25,000 scale the inundation area and inundation depth for each meter when a tsunami of a certain height attacks a certain stretch of coast.

The map can be consulted to find the extent of the tsunami inundation area, its depth, and the streets, government institutions, public facilities, roadways, transportation facilities, factories and the like located therein. This provides a clear picture of the tsunami disaster prevention tasks to be addressed in the area.

2-2 METHOD OF CREATION

In the past, the creation of Tsunami Hazard Maps was to a large extent a matter of inference based on past tsunami experiences. However, experience may be inadequate for tsunami of relatively low frequency.

The National Land Agency, in cooperation with the Meteorological Agency and Fire and Disaster Management Agency, has therefore created a "Tsunami Damage Forecasting Manual" that draws on recent research into tsunami and recent advances in computer technology to formulate Tsunami Hazard Map creation methods based on seismic fault models and tsunami behavior simulations. The Tsunami Hazard Map creation method of the National Land Agency follows the method described in the Tsunami Damage Forecasting Manual. An outline is provided in Figure 2.

(1) Set calculation range

The first step is to set the range of the initial calculation. We used rectangular areas of 30-50 kilometers per side for our ranges. These ranges were adjusted to conform with the forecasting points used in the new tsunami forecasts of the Meteorological Agency (described below). We set a total of 412 ranges covering the entire coastline of Japan, including remote, populated islands.

We also set a seismic fault model that would generate the largest conceivable tsunami for the range.

(2) Study past tsunami

We gathered information on local inundation depths and seismic fault models etc. for representative tsunami of the past in order to verify the validity of the calculation results.

(3) Set calculation grid

We set the calculation grid at 100 meters. This grid was chosen as a means of balancing precision and costs.

(4) Digitalize topography

We digitalized topographic features using topographical maps and ocean floor topographical maps. For this, we considered only river areas of 200 meters or more in width and lakes with 200 meters or more contact with the ocean. We did not take into account the effect of levees or flood gates.

(5) Set tsunami waveform

We set tsunami waveforms to produce tsunami heights of 2, 4, 6, 8, and 10 meters in each area. However, for areas with a maximum tsunami height of less than 10 meters in the seismic fault model, we did not consider tsunami heights above the maximum.

(6) Set calculation conditions

We set the friction coefficient (ocean floor and land), calculation time interval, and other conditions.

(7) Run numerical calculations

We ran numerical calculations using the methods described in the Tsunami Damage Forecasting Manual.

(8) Analyze results

We analyzed results to determine if the inundation areas and depths were reasonable given the tsunami height and topography set. Where past tsunami examples were available, we compared them against calculation results to judge the validity of results.

(9) Create Tsunami Hazard Map

We expressed calculation results on a 1/25,000 map. Calculation results were in the form of data for a 100 meter grid, but we expressed them as color-coded inundation depth lines for 1 meter intervals.

(10) Create files containing calculation results

We created files containing the calculation results for use as a database.

3. EARLY ESTIMATION SYSTEM FOR TSUNAMI HAZARD

3-1 OUTLINE

The Early Estimation System for Tsunami Hazard searches the Tsunami Inundation Forecasting Database (created from the calculation results for the creation of the Tsunami Hazard Maps) to find relevant locations based on the forecasting zones announced in the new tsunami forecast of Meteorological Agency and the specific tsunami heights expected. It then displays these locations on the screen. This gives the government a picture of the tsunami inundation area and a rough estimate of the number of buildings and population contained therein immediately after an earthquake (within about 30 minutes). It is expected that this information will help to accelerate the government's initial response.

3-2 NEW TSUNAMI FORECASTS

The new tsunami forecasts were inaugurated by the Meteorological Agency in fiscal 1999 and use the forecasting zones shown in Figure 3 to display expected tsunami heights in concrete numerical terms (eight increments: 0.5 m, 1 m, 2 m, 3 m, 4 m, 6 m, 8 m, 10+ m).

The Meteorological Agency's model envisioned approximately 4,000 epicenters in ocean waters up to about 600 kilometers off the coast of Japan and created a standard seismic fault model for earthquakes occurring at these points. The Agency then ran numerical simulations of tsunami changing the magnitude and fault depth of the earthquake to create a database of results (approximately 100,000 records). When an earthquake occurs, the system searches the database of results for a corresponding epicenter and magnitude, and displays the tsunami forecasts described above.

The Meteorological Agency database has forecast points set every 20-30 kilometers along the coastline. A single forecasting zone will contain several forecast points; the tsunami height displayed for the tsunami forecast is the maximum height for the zone.

3-3 SYSTEM FUNCTIONS

When a tsunami forecast is published, the Meteorological Agency sends the National Land Agency on-line data on the tsunami height for each forecasting zone (in the future, this will also include tsunami heights for each forecast point). The Early Estimation System for Tsunami Hazard uses this data to search for corresponding locations in the Tsunami Inundation Forecasting Database and display them on-screen.

The original Tsunami Inundation Forecasting Database utilizes a 100 meter grid, but the system converts this to 250 meter mesh data (using the maximum value for inundation depth in the mesh). This is done to simplify expression of wide-range estimates. Expressing detailed information on specific areas is not the purpose of this system.

Below is a description of the information displayed by the system.

(1) Wide-range estimates (Figure 4)

These displays are used to provide rough pictures of wide-areas of 300 kilometers or more. This shows prefectural boundaries and the maximum inundation depth on the coastline for municipal units. The points and figures in the ocean areas indicate the forecasting point and the corresponding tsunami height.

(2) Middle-range estimates (Figure 5)

These displays are used to provide rough pictures medium-range areas of 100-300 kilometers. They also display information in prefectural units. This shows municipal boundaries and the maximum inundation depth on the coastline for municipal units.

(3) Narrow-range estimates (Figure 6, Figure 7)

These displays show local conditions for areas of 100 kilometers or less, roughly in municipal units. The map indicates municipal boundaries and inundation depths at a 250 meter mesh.

(4) Record displays (Table 1)

The system displays lists of potential inundation areas in individual municipalities (inundation depth of 2 meters or greater, and less than 2 meters), and of the number of buildings and population included in these areas. The building and population data is based on the three-dimensional mesh of the National Land Numerical Data (approximately 1 kilometer square), split up by number of land-area meshes and converted to a 250 mesh.

The examples showing in Figures 4-7 and in Table 1 are models of the Tonankai Earthquake that occurred on December 7, 1944. We have estimated figures for forecast points from past inundation records, and then input those figures to search the Tsunami Inundation Forecasting Database.

4. FUTURE TASKS

The Meteorological Agency began its new tsunami forecasts in fiscal 1999. Luckily, Japan has yet to experience a tsunami that would result in the publication of tsunami forecasts, and therefore the system has no track record. Nonetheless, the fact that this system can be used to ascertain tsunami inundation levels directly after an earthquake will have a significant impact in accelerating initial government response efforts.

Currently, the Meteorological Agency provides data only on tsunami heights for forecasting zones. It would be desirable in the near future to be given tsunami heights for individual forecast points in order to increase the precision of estimates. It would also be desirable to add functions to estimate the building destruction and outflow, human damage, and other specific damage from the tsunami.

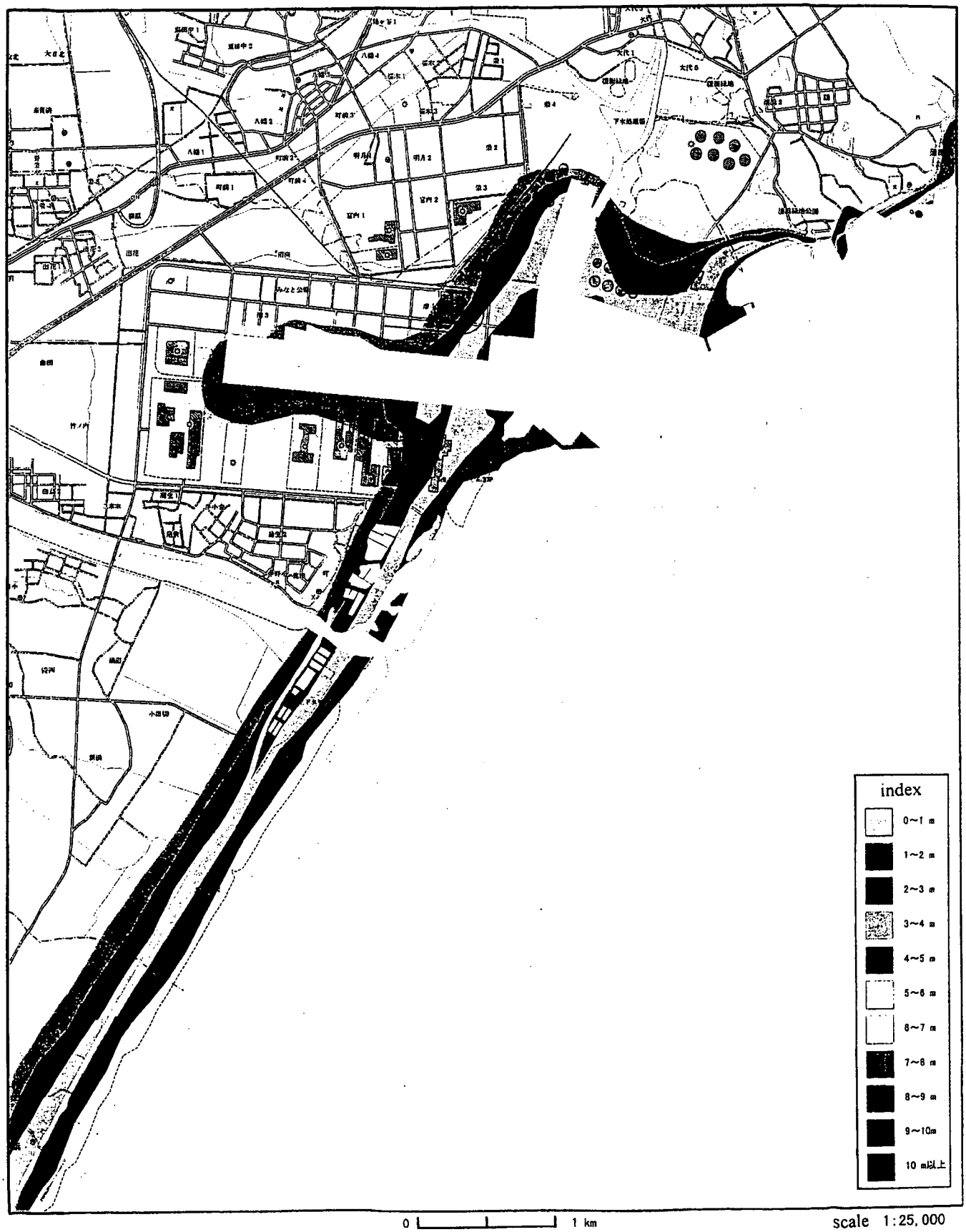
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Figure 1 Tsunami Hazard Map (tsunami height:10m)



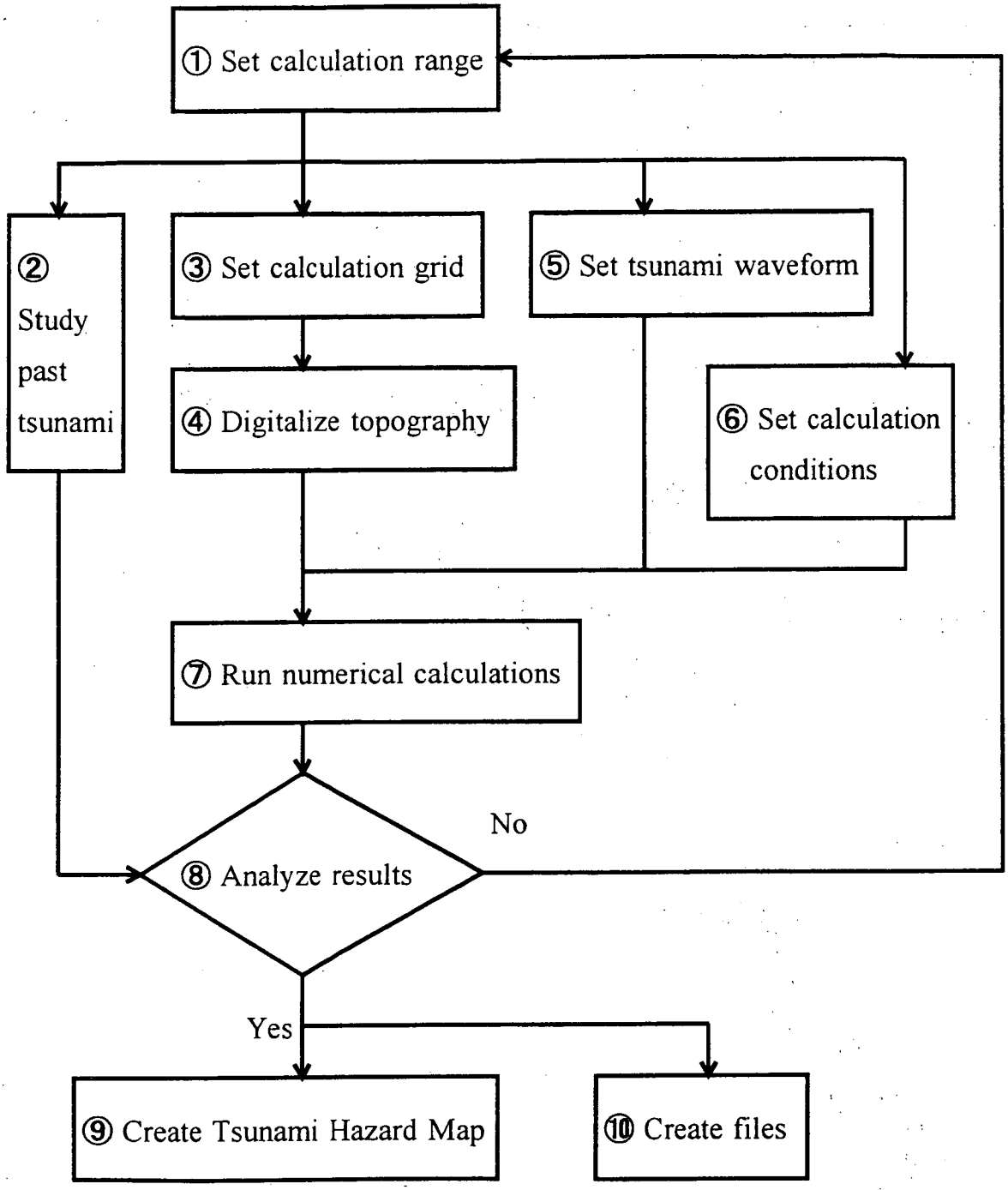


Figure 2 An outline of creating Tsunami Hazard Map

Figure 3 Tsunami Forecasting Zones

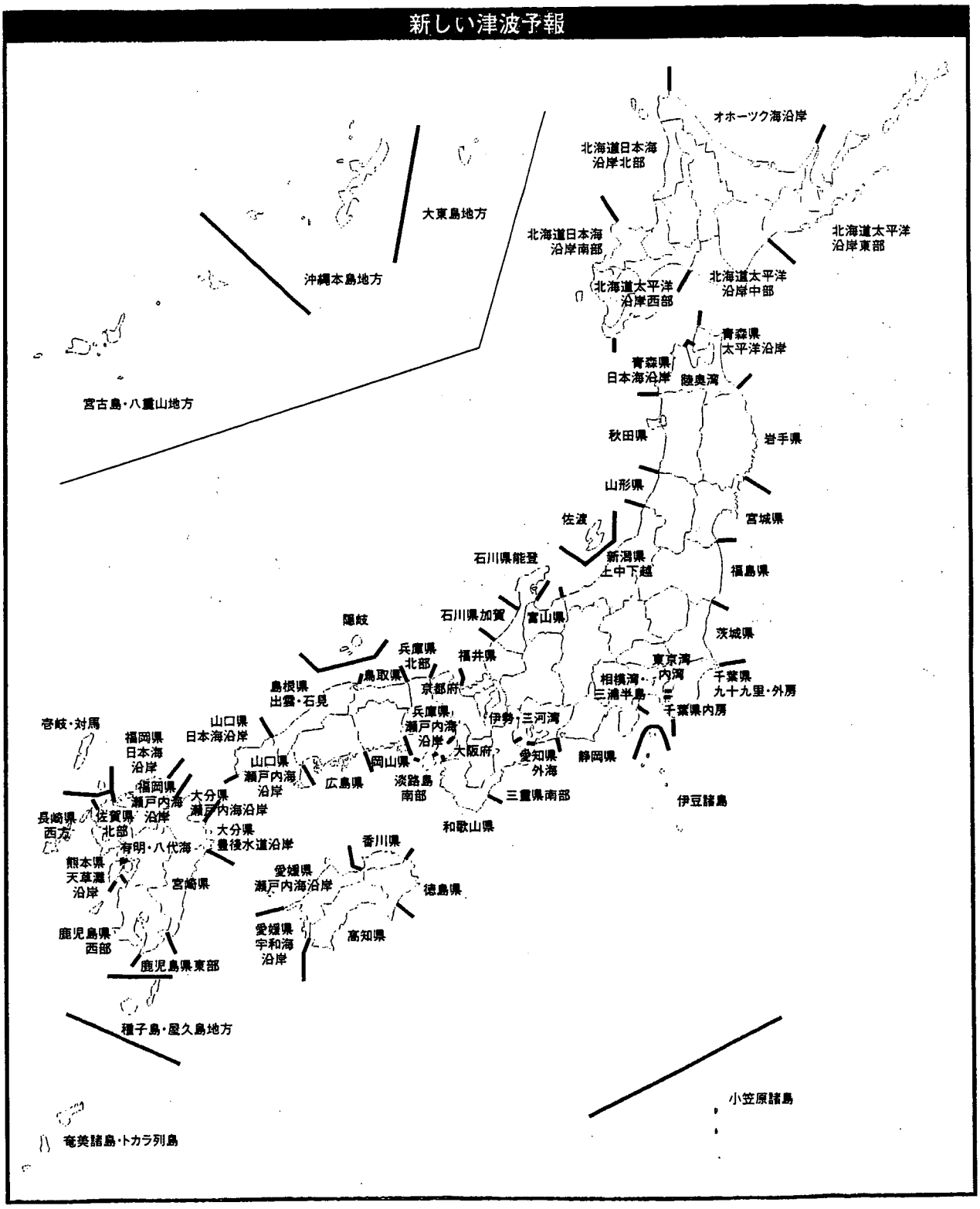


Figure 4 Wide-range Estimates

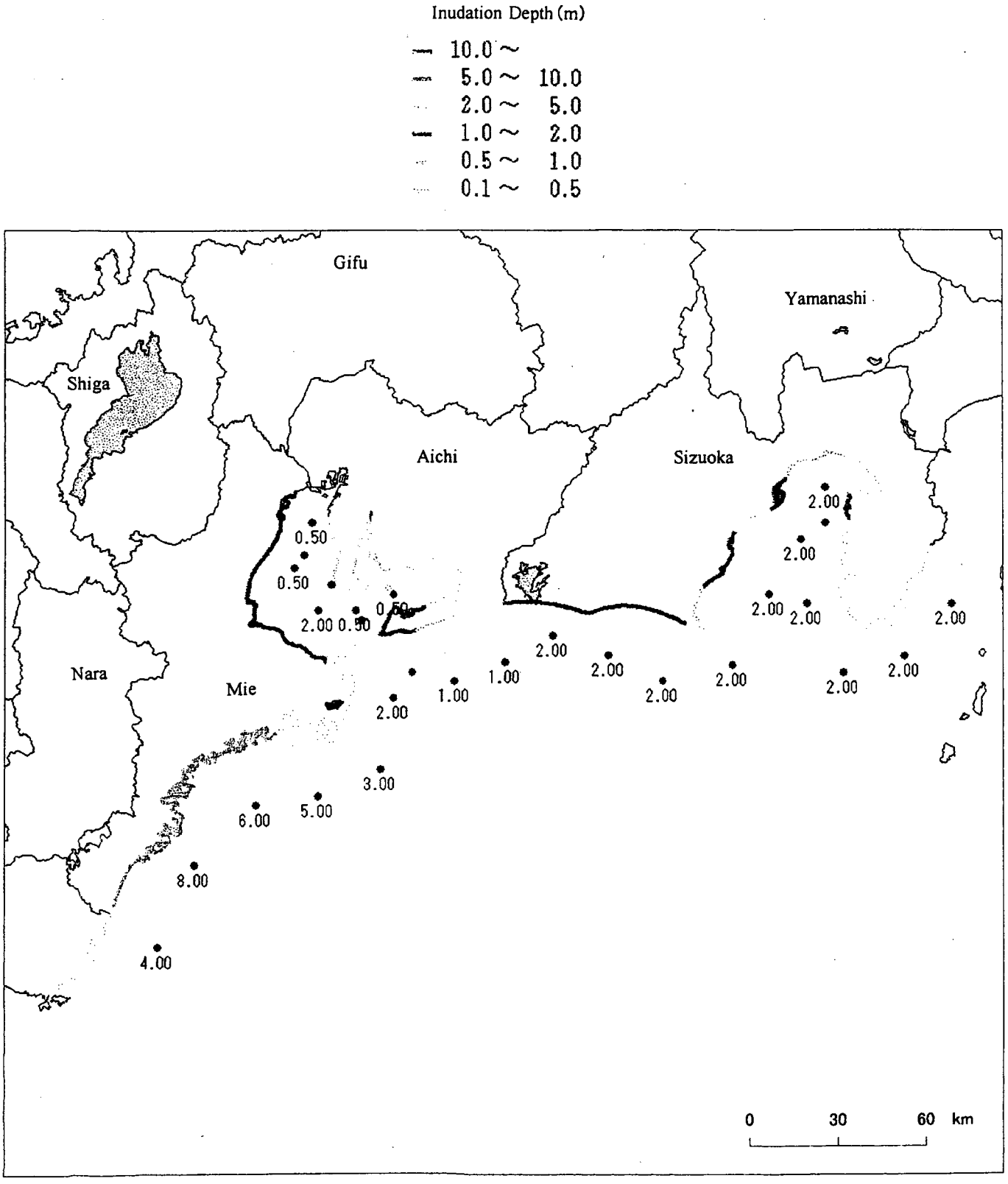


Figure 5 Middle-range Estimates

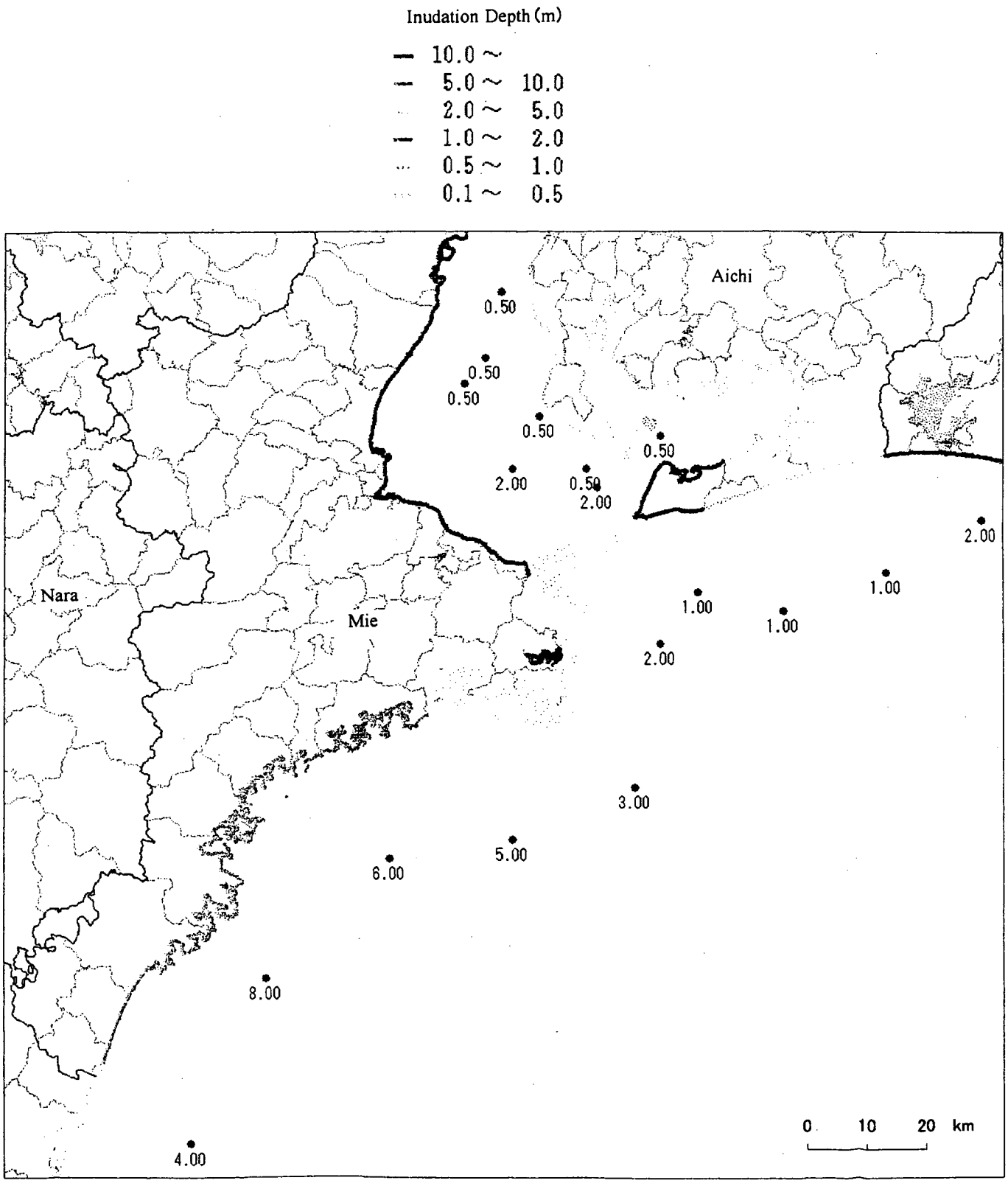


Figure 6 Narrow-range Estimates (1)

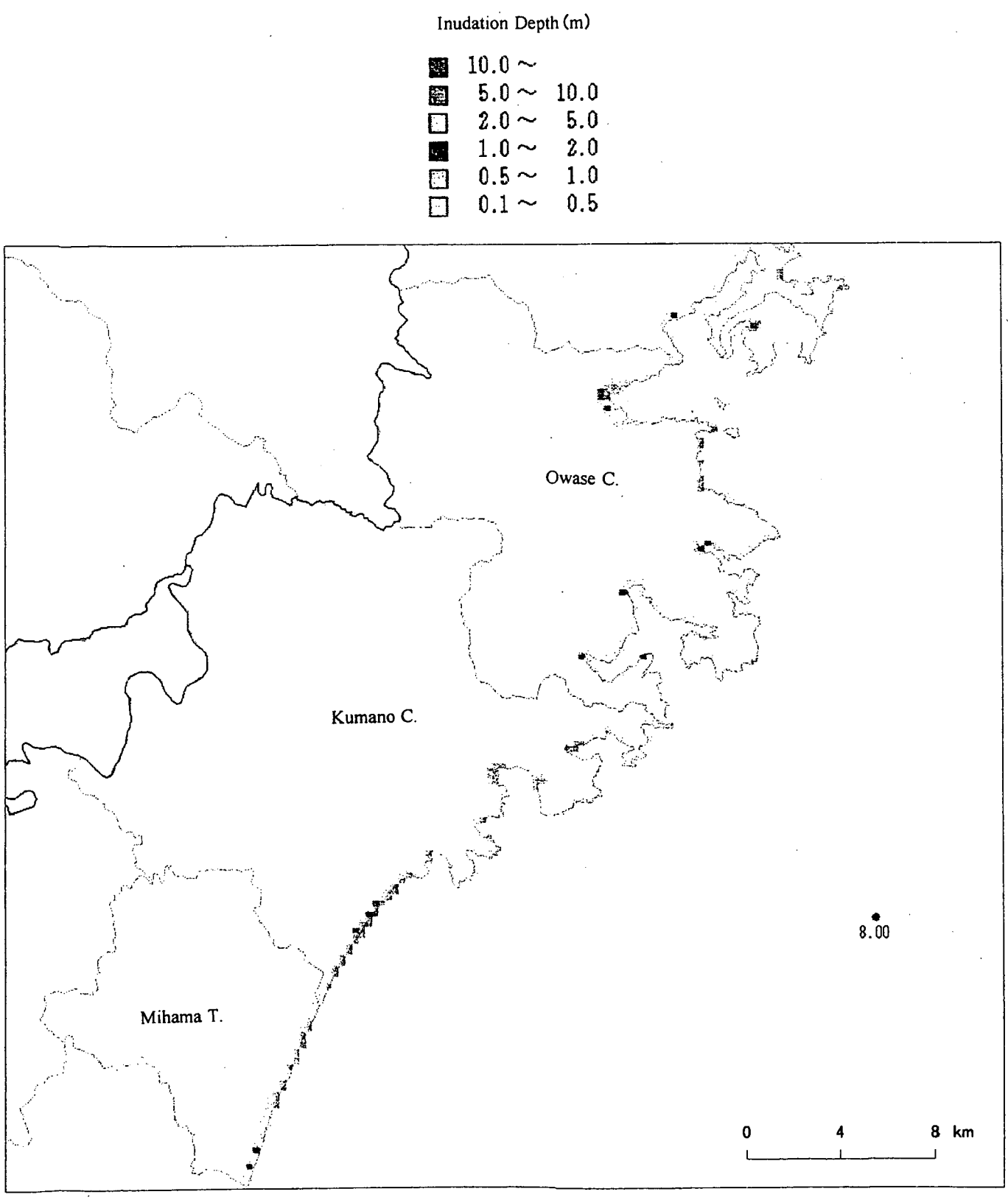


Figure 7 Narrow-range Estimates (2)

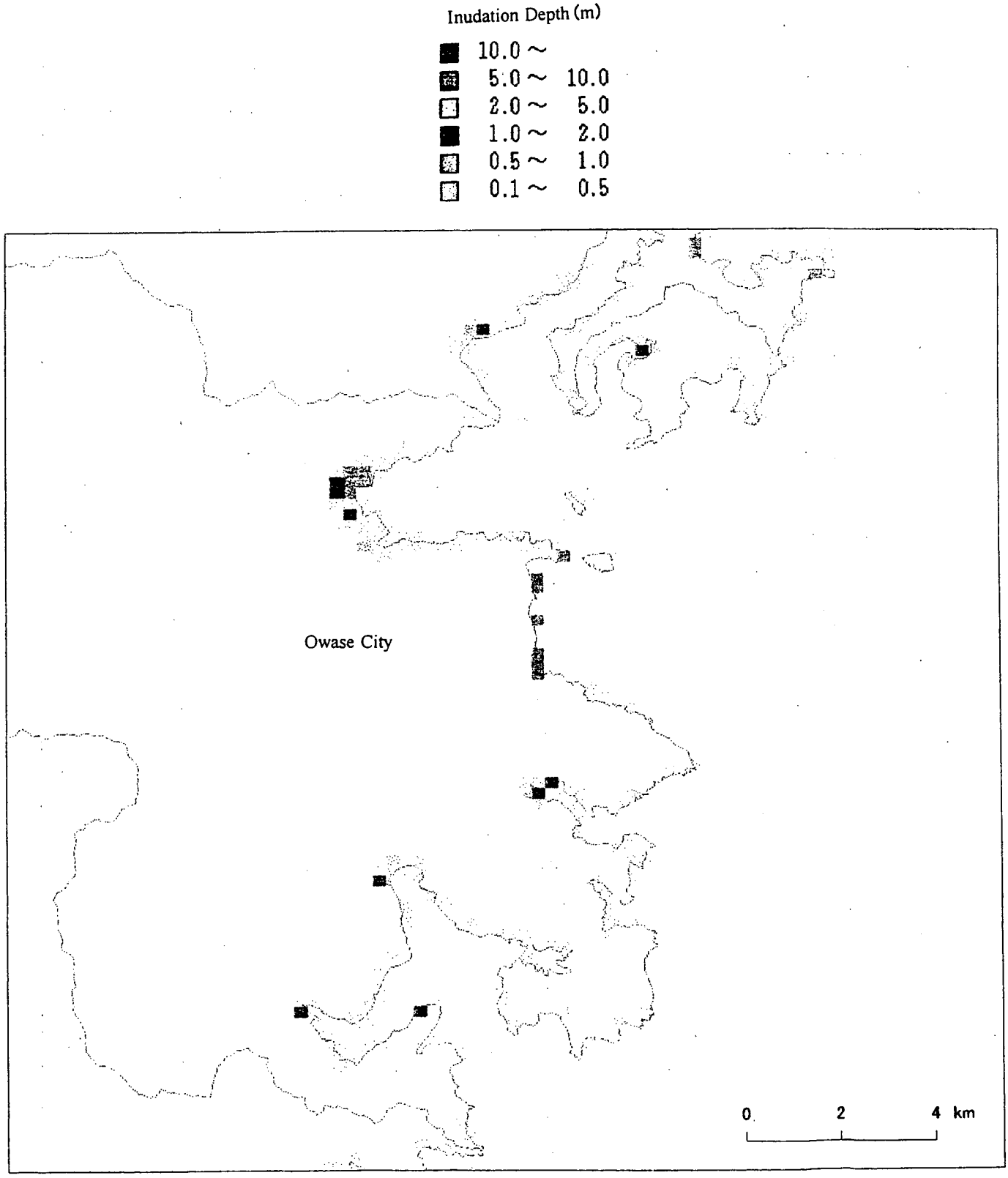


Table 1 Results of forecasting Tsunami damage

Prefecture	Municipal	Inudation Area (2m ~)	Inudation Area (0 ~ 2m)	Inudated Buildings	Inudated Population
All Japan		124.3km^2	381.8km^2	111,904	297,156
Mie		93.9km^2	162.4km^2	45,554	123,917
	Tsu C.	0.0km^2	6.8km^2	2,154	11,658
	Yokkaiti C.	0.0km^2	10.9km^2	2,197	15,176
	Ise C.	0.0km^2	8.0km^2	2,355	5,701
	Matsuzaka C.	0.0km^2	12.1km^2	2,081	6,159
	Suzuka C.	0.0km^2	6.7km^2	5,242	11,738
	Owase C.	19.6km^2	8.8km^2	3,074	8,269
	Toba C.	0.6km^2	21.9km^2	2,170	8,342
	Kumano C.	10.5km^2	4.6km^2	2,198	4,998

U.S. GEOLOGICAL SURVEY

AN ASSESSMENT OF SEISMIC MONITORING IN THE UNITED STATES: REQUIREMENT FOR AN –

Advanced National Seismic System

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EXECUTIVE SUMMARY

This report is an assessment of the status, needs, and associated costs of seismic monitoring in the United States. It submitted in compliance with a directive of Public Law 105-47. It sets down the requirement for an effective, national seismic monitoring strategy and an advanced system linking national, regional, and urban monitoring networks. A broad spectrum of opinion was sought in developing this report.

Seismic monitoring is vital to meet the Nation's needs for timely and accurate information used in reducing the loss of life and property from earthquakes, tsunamis, and volcanic eruptions. An **Advanced National Seismic System** is needed to organize, modernize, standardize, and stabilize seismic monitoring in the United States

Modernized seismic monitoring can provide: (1) alerts within a few seconds of imminent strong earthquake shaking, (2) rapid assessments of the distribution and severity of earthquake shaking (for use in emergency response), (3) warnings of a possible tsunami from an off-shore earthquake, (4) warnings of volcanic eruptions, (5) information for correctly characterizing earthquake hazards and for improving building codes, and (6) critically needed data on the response of buildings and structures during earthquakes for safe, cost-effective design, engineering, and construction practices in earthquake-prone regions.

Today, various institutions engaged in seismic monitoring in the United States face many persistent problems and challenges. Outdated, inadequate equipment and the lack of stable, long-term support are the most serious issues. Monitoring coverage is based on an uneven patchwork of networks loosely coordinated on a volunteer basis. Network operators must worry more about survival than enhancing services and products. Modernization of equipment is slow and piecemeal at best. Valuable opportunities are being lost to issue earthquake alerts, to expedite and focus emergency response, and to collect the data needed over the long-term to develop improved hazard assessments and engineering practices.

An Advanced National Seismic System is required to organize and manage data collection and distribution, and to provide new products and services. Engineering, emergency response, and seismological interests will be served by this new approach. Increased financial support is necessary to modernize the seismic monitoring infrastructure and to provide for stable, long-term operations. The cost of the modernization effort is estimated at $170 million, with $47 million needed annually for operations.

Inevitably, a catastrophic earthquake in the United States will result in a system based on the actions described and the justifications given in this report. Thus, the question is not "what to do?" or "why do it?" but "when?". Every earthquake is a chance to protect and to learn; however, these opportunities and lessons are lost without modern, effective seismic monitoring.

PREFACE

In fulfillment of the requirements of Public Law 105-47,[1] the United States Geological Survey (USGS) submits this report of an assessment of seismic monitoring in the United States. This report includes statements of the Nation's needs for seismic monitoring and recommendations for meeting those needs.

Rather than submit a report based on the views of a single Government agency, the USGS involved a broad cross-section of the seismic monitoring community in developing this document. Approximately 50 participants[2] attended a 3-day workshop near Denver, Colorado, in June 1998. Attendees included those with expertise and experience in emergency response management, seismic monitoring for engineering design, and seismic monitoring on national and regional scales. The participants provided the views and concepts that form the basis of this report.

1. INTRODUCTION

Earthquakes and volcanic eruptions cannot be avoided and pose a national problem.

Earthquakes and volcanic eruptions are natural hazards that cannot be controlled or reasonably avoided. Future losses of life and property due to earthquakes and volcanic activity in the United States and its territories are certain to occur.

- Thirty-nine States are exposed to significant earthquake risk.
- Six Western States are also exposed to significant volcanic hazards.
- Seventy-five million people, including 46 million outside California, live in metropolitan areas in the United States at moderate to high earthquake risk.
- According to new estimates by the Federal Emergency Management Agency (FEMA), the average annualized loss to the Nation's general building stock and essential facilities from earthquakes nationwide is approximately $4.4 billion.

The history of large earthquakes in the United States includes several whose repeat occurrence today would cause catastrophic losses. These historic earthquakes include violent shocks in southeastern Missouri in 1811 and 1812; southern California in 1857; the Island of Hawaii in 1868; Charleston, South Carolina, in 1886; southern Alaska in 1899; and northern California in 1906.

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[1] See appendix 7.1.
[2] See appendix 7.2.

Forceful reminders of the economic losses from earthquakes are illustrated by recent damaging urban earthquakes, such as Loma Prieta (1989) $6 billion; Northridge (1994) $40 billion; and Kobe (1995) $100 billion.

Seismic monitoring is the foundation upon which all earthquake mitigation practices are built.

Although the future occurrence of earthquakes and volcanic eruptions is inevitable, catastrophic losses are not. Proper mitigation practices and informed emergency response procedures can greatly reduce the impacts of these events. The implementation of effective mitigation practices involves long and complex processes. These processes require (1) quantitative assessment of the consequences of the hazard, (2) the development of proper building designs, practices, and codes, (3) effective land use planning, and (4) acceptance and implementation of mitigation practices by governments at all levels. Seismic monitoring provides the necessary foundation of basic data on which the first three of these elements are based, and without which they could not be developed, let alone acted upon.

More specifically, direct applications of seismic monitoring include the following:

- **Earthquake Emergency Response.** Seismic monitoring can provide, within a few minutes, timely information on the location and size of an earthquake and on the geographic distribution and severity of ground shaking. This information is becoming increasingly critical for effective response by emergency management officials and crisis managers, especially in urban areas with growing populations and complex and costly infrastructures.

Seismic monitoring also is necessary for hazard warning, assessment, and research.

- **Warning of Volcanic Eruptions.** Because most volcanic eruptions are preceded by seismic activity, seismic monitoring of active and potentially active volcanic centers is important. For example, seismic activity beginning in March of that year preceded the May 1980 eruption of Mt. St. Helens. Seismic monitoring of volcanoes is necessary to provide warning of eruptions.

- **Warning of Tsunamis.** The first warning that an offshore earthquake may have generated a tsunami (tidal wave) comes from seismic monitoring. Coastal areas of Alaska, California, Hawaii, Oregon, Puerto Rico, and Washington are all vulnerable to disastrous tsunamis.

- **Seismic Hazard Assessment.** Information on the likely level and character of ground shaking that can be expected at any site from future earthquakes is completely dependent on data from seismic monitoring. This information, in turn, is the basic foundation for setting guidelines in building codes for earthquake-resistant design and construction.

- **Earthquake Engineering.** Recordings of strong ground motions in structures and on the ground near the source of large earthquakes are essential for safe, cost-effective design and construction practices for every type of structure in earthquake-prone regions, including homes, buildings, bridges, highways, utility grids, dams, oil pipelines, and other critical facilities.

- **Scientific Research.** Data from seismic monitoring networks are fundamental to a better understanding of earthquake occurrence and effects and of the processes that cause volcanic eruptions and tsunamis. These data contribute greatly both to basic science and to practical research, such as the study of the influence of source effects, wave propagation effects, and local site-response effects on destructive ground shaking.

- **Public Information.** Any earthquake or other seismic disturbance that humans sense or feel creates alarm and immediately raises the questions, "What happened? Where? How bad?" The general public and news media turn to seismologists operating monitoring networks for the answers.

- **Education.** Seismic monitoring centers serve as focal points for educating the public about earthquake and volcano hazards and safety. The centers also serve as training grounds for students pursuing careers in earth sciences and engineering, and they provide special expertise to assist public policymakers, design professionals, and planners in the implementation of mitigation practices.

This report stresses the need for an Advanced National Seismic System.

Given the importance of seismic monitoring, the central theme of this report is the requirement for and the timeliness of creating the physical and informational infrastructure of an Advanced National Seismic System. Section 2 gives a detailed assessment of existing seismic monitoring networks in the United States. Section 3 presents an overview of the planned Advanced National Seismic System, together with a strategic plan for achieving it. Following sections then describe three essential aspects of the proposed system: section 4, infrastructure required; section 5, information products and services; and section 6, estimated costs and action items for achieving the advanced system.

2. ASSESSMENT OF EXISTING SYSTEMS AND NETWORKS

An assessment of seismic monitoring networks in the United States requires definition of some basic terms,[3] documentation of the inadequacies in our national and regional infrastructure for seismic monitoring, a comparison of the slow progress toward modernization being made in U.S. national monitoring with more rapid progress in other countries, and a summary of a problem that demands our national attention.

2.1 BASIC CONCEPTS IN SEISMIC MONITORING

Seismic monitoring systems consist of sensors, recorders and data analysis centers.

Seismic monitoring systems record any disturbances that generate seismic (elastic) waves, which propagate through the Earth and produce vibration or shaking of the ground at the Earth's surface. The general term "seismic event" is used to indicate any such disturbance. In addition to earthquakes, other seismic disturbances that can be dangerous or disruptive include volcanic eruptions, quarry blasts, sonic booms, mine collapses, meteorite impacts, and underground nuclear explosions.

In simple terms, seismic monitoring requires (1) a sensor (seismometer) that converts vibratory ground motion into an electric signal, (2) a local recorder or a communication network that transmits this signal to a data center, and (3) analysis at this center that combines the signals from many seismometers to determine a location, magnitude peak acceleration, and other parameters that characterize the source and nature of the event. Existing seismic monitoring systems are of two conventional types, weak and strong motion.

Most of the existing systems monitor either weak seismic motions or strong ground shaking.

Weak-motion monitoring systems use very sensitive sensors that can record weak vibrations in narrow frequency ranges both from small local earthquakes and from distant moderate to large earthquakes. These sensitive monitoring systems are essential for continuous surveillance and for characterizing many important details of earthquake occurrence throughout the United States and the world. These systems represent the traditional approach to seismic monitoring. Because they are "designed" for the study of small earthquakes, in most cases they cannot record large, nearby earthquakes with high fidelity. One of the primary products of these systems is a list, or bulletin, giving the location and magnitude of seismic events in the region covered by the sensor network over a given period of time.

Strong-motion monitoring systems use sensors with low sensitivity (called accelerometers) that can record strong, potentially damaging, shaking of either the ground or of manmade structures. Strong motion is generally associated with earthquakes greater than about magnitude 4 or 5. Strong-motion recordings provide fundamental data for engineering

[3] See appendix 7.3 for list of acronyms used in this report.

design and construction practices and for seismic design criteria for building codes. The primary data and results from these systems are records of strong shaking and empirical relationships showing the attenuation of strong ground shaking with increasing distance from the source.

Historical differences in instrumentation and interests have divided seismic monitoring efforts

These two distinct systems developed due to differences in monitoring interests and instrumentation. The engineering community was interested in recording only the very strong shaking of the ground and structures, and the instruments needed for this purpose were incapable of recording small or distant earthquakes. Seismologists were interested in detecting and locating as many events as possible for defining the seismicity associated with active tectonic and volcanic structures. The instruments used for these purposes were driven off scale by the strong shaking from nearby events.

Today's modern seismographs can serve multiple needs.

Traditionally, a seismograph consists of a seismometer and a recording system. The amplitude, or dynamic range, and resolution are measures of the ability of the instrument and recorder to faithfully record both very weak and very strong vibrations. The frequency range, or bandwidth, is a measure of the ability of the instrument to record a wide band of frequencies of seismic motion. The ideal seismograph has high dynamic range and resolution and broad-band recording capability.

For the purposes of this report, a modern seismograph records seismic data in digital format over a broad range of frequencies and amplitudes extending from the background Earth noise to as high as two times Earth's gravitational acceleration.

Seismographs developed after the mid-1980's are capable of capturing the full range of frequencies and amplitudes that convey the rich details of information embedded in seismic waves. To use a simple analogy, an earthquake can be compared to a symphonic orchestra playing a passage that involves all of the instruments; however, outdated, weak-motion listening devices miss the high and low ranges of the music and produce distorted sound when the volume increases. Outdated, analog strong-motion devices will record only the last of the crescendo. A modern seismic monitoring system should capture both weak and strong motion to provide the full range and spectrum of seismic information available and, through combined analysis, provide practical results that greatly exceed those previously realized in independent operations.

2.2 Survey of Seismic Monitoring Networks in the United States

In the summer of 1998, a survey was taken of all weak-motion and the major strong-motion networks operating in the United States and its territories (summary given in appendix 7.4). Forty-one individual networks were surveyed. These range from small networks of three or four stations operated by a single individual at a small college to

networks of hundreds of seismographs with a relatively large staff to maintain the recording and processing infrastructure. Two semi-amateur networks (Public Seismic Network and Princeton Earth Physics Project) are operated by private individuals or school groups with little or no external operational support other than perhaps some startup equipment and advice from professionals. Some network operations are mission-specific, such as the Hawaii Volcano Observatory of the USGS or the National Oceanic and Atmospheric Administration (NOAA), Pacific and Alaska Tsunami Warning Centers; others such as the Southern California Seismic Network have multiple missions, supporting agencies, and clients. Some networks are financed entirely by the USGS, some by other Federal or State agencies, some by private corporations, and many by a mix of all of these.

Seismic monitoring networks in the United States are operating with outdated equipment

The variety of sizes and operating institutions for these networks is evident in the summary table of appendix 7.4. Note that, under the instrument types, for most networks, modern broad-band instruments (Type "BB") make up only a small or nonexistent part of their seismograph stations. Only 6 percent of currently operating seismographs in the United States can accurately record both very small and fairly large earthquakes on-scale. Similarly, far fewer than half of the strong-motion instruments (Type "SM") currently operating have digital recording capability, which is needed to record on scale both moderate earthquakes and rare, very large events, and to provide rapid access to the data.

This inventory of regional seismic monitoring networks in the United States shows that most were installed in the 1960's and 1970's chiefly as research networks designed to provide relatively fine-scale information on the spatial distribution and characteristics of small to moderate-sized earthquakes. Their original equipment served this mission well but became outdated in the 1980's as digital instrumentation, improved sensors, and an expanded mission evolved. Similarly, most of the strong-motion networks in the United States predate digital technology and, while still useful, do not meet the current needs of engineers and emergency management officials.

2.3 REGIONAL AND NATIONAL MONITORING CENTERS

Regional monitoring centers perform the important function of analyzing and distributing seismic data and information on earthquakes in seismically active areas. Regional centers also provide local expertise on earthquake hazards information for the local engineering and emergency management communities and for the general public, and they provide training for undergraduates and graduated students pursuing careers in seismology and related fields. Regional centers have developed on an *ad hoc* basis over the last 30 years. They have received funding from various sources for various purposes, with limited sustained support and central direction.

The National Earthquake Information Center (NEIC) is operated by the USGS and provides uniform coverage for seismic events above about magnitude 3.5 over most of the United States and for damaging earthquakes worldwide. The NEIC provides coverage in areas outside those covered by regional networks and provides important, independent reporting of earthquakes within areas of regional coverage. The NEIC contributes critical

data and information for NOAA's tsunami warning operations, the National Warning Center, the Federal Emergency Management Agency, the Office of Foreign Disaster Assistance, the Red Cross, and to all State emergency management offices. The NEIC also provides other information and educational products, such as definitive earthquake catalogues, seismicity maps, and publications on the earthquake history of the United States.

2.4 THE USGS ROLE IN SEISMIC MONITORING

The USGS has the assigned Federal responsibility to "monitor seismic activity" in the United States.[4] It fulfills its role in seismic monitoring in the United States by—

- Operating the United States National Seismograph Network (USNSN), a skeletal network of 56 broad-band seismograph stations widely spaced throughout the United States.

The USGS has the responsibility for monitoring seismic activity in the United States.

- Operating the National Earthquake Information Center, which reports on all earthquakes in the United States large enough to be felt by humans, and all major earthquakes worldwide.
- Operating the United States National Strong Motion Program, a network of approximately 600 instruments specifically designed to record strong ground shaking.
- Contributing funding, and sometimes staff, to the operation of 16 regional seismic networks in many, but not all, seismically active areas of the United States. A list of regional monitoring activities supported by the USGS is given in appendix 7.5.

Most of the USGS funding for national and regional monitoring goes toward operation and maintenance of existing networks

The USGS funding available for seismic monitoring is provided annually through the Federal budget cycle. Funding for seismic monitoring must compete with other priorities and programs within the USGS, the Department of the Interior, and the Federal Government as a whole. In FY 1999, this funding is $14 million for domestic monitoring and $3.8 million for global monitoring. (See section 2.5 for comparison with other countries.) The USGS provides its support to regional network operations through 3-year cooperative agreements.

Most of the USGS funding is applied to the operation and maintenance of seismic networks, the routine analysis of data, and the dissemination of results. Current funding available to the USGS, given its other responsibilities under the National Earthquake Hazards Reduction Program (NEHRP), is not adequate for a comprehensive modernization of the seismic networks it supports.

[4] Public Law 101-614.

2.5 PROGRESS IN MODERNIZATION OF SEISMIC NETWORKS

Limited progress has been made over the past two decades in modernizing seismic networks. Most of this progress has been due to supplemental funding provided by other agencies or interests to networks supported by the USGS.

- **The United States National Seismograph Network (USNSN).** The USNSN was founded by the USGS in the late 1980's with funding from the Nuclear Regulatory Commission (NRC). The USNSN and the Global Seismograph Network (GSN) are the primary sources of data for the NEIC. Previously, NEIC had relied on data from selected stations in regional networks. The data were very limited in frequency bandwidth and dynamic range, and they were transmitted to NEIC over expensive and unreliable conventional telephone circuits. The NRC funding allowed the USGS to install more than 50 modern stations nationwide with dedicated satellite communication links to NEIC.

Limited modernization of USGS-supported networks has been possible only with funding from other sources.

- **Southern California.** Following the 1994 Northridge earthquake, a 5-year, $20 million project named TriNet, funded largely by FEMA and involving the collaboration of the USGS, California Institute of Technology, and the California Division of Mines and Geology, was formed in southern California. TriNet has integrated weak- and strong-motion monitoring to improve regional earthquake monitoring for a broad array of earthquake and engineering research and to provide rapid earthquake information for emergency response and recovery in damaging earthquakes.

- **Pacific Northwest Tsunami Warning.** NOAA, USGS, and the States of Alaska, California, Hawaii, Oregon, and Washington are upgrading some of their existing seismic stations for improved tsunami monitoring and public warning. These efforts are a significant first step in addressing the needed modernization of a few specific regions and missions; however, they do not address broad, national needs.

- **Global Seismograph Network.** The Incorporated Research Institutions for Seismology (IRIS) in collaboration with the USGS and the University of California, San Diego, developed the GSN for collection of data at worldwide sites. Designed primarily for research and monitoring of specific areas, the GSN was initially funded by the National Science Foundation (NSF) and the Department of Defense. The extraordinary effort required to develop the GSN and to provide easy access to its data gave rise to the development of the IRIS Data Management Center, a pioneering resource for the distribution of seismological data and information.

In all of these cases, funding for improvements has come from other agencies with specific goals and needs. Consequently, these individual developments have not been well coordinated, resulting in uneven and ad hoc progress toward addressing the Nation's seismic monitoring needs. However, these developments demonstrate that the seismology community has the technical expertise and experience needed to develop an Advanced National Seismic System.

2.6 INTERNATIONAL COMPARISONS

Japan and Taiwan are way ahead of the United States.

Like the United States, Japan and Taiwan have had similar problems with outdated seismic networks, but, unlike the United States, they have acted in recent years to replace outmoded equipment with new digital seismic monitoring systems on local, regional, and national scales. Japan is in the process of upgrading its national infrastructure for monitoring seismic events. After the 1995 Kobe earthquake, Japan doubled its annual federal earthquake research and monitoring budget to $144 million, not including salaries, which would approximately double this figure. In comparison, the USGS spends $15 million annually on all of its domestic seismic monitoring operations, including salaries. While the USGS budget for seismic monitoring does not represent the total Federal dollars spent on earthquake and volcano monitoring activities, it does represent the majority of funding.

The Japanese and Taiwanese have appropriated large budgets to modernize their strong-motion networks as well—about $300 million in Japan and about $40 million in Taiwan for implementing modern digital equipment. By contrast, almost all of the strong-motion equipment in the United States is part of an old analog system, and the budget for the United States National Strong Motion Program (funded by the USGS) is $2.8 million in FY 1999.

2.7 SUMMARY OF THE PROBLEM

Seismic monitoring in the United States is patchwork, modernization is piecemeal, and funding for operations is too little and unstable.

Seismic monitoring in the United States faces many problems and challenges, the most notable of which are—

- Outdated, inadequate instrumentation.
- Separation of functions between strong- and weak-motion monitoring systems.
- Lack of uniform geographic coverage in areas at risk.
- Lack of uniform operational standards.
- A structure that, at best, is an uneven patchwork of loosely confederated networks with different equipment, operations, products, and funding sources.
- Lack of a stated Federal commitment to provide long-term support, oversight, and modernization for seismic monitoring throughout the Nation.

3. OVERVIEW OF AN ADVANCED NATIONAL SEISMIC SYSTEM

3.1 STEPS TOWARD AN ADVANCED NATIONAL SEISMIC SYSTEM

The seed of a National Seismic System was planted in the 1980's.

The concept of a National Seismic System originally emerged in the 1980's as a desirable way to unify seismic monitoring in the United States. The motivation was and still is to create a framework for modernizing instrumentation and revolutionizing the data available for research, engineering, and public-safety. A 1989 report published by the USGS entitled "National Seismic System Science Plan" articulated the great scientific and practical value such a system would have. The 1989 report drew from reports by the National Research Council in 1980 and 1983, which addressed seismic monitoring needs in the United States.

A report by the National Research Council in 1990 entitled "Assessing the Nation's Earthquakes, The Health and Future of Regional Seismograph Networks" strongly supported the creation of a National Seismic System. As a matter of great practical importance, the report underscored the need for the Federal Government to "establish a more rational, coordinated, and stable means of support for the seismic networks of the United States." The future of seismic monitoring in the United States still hinges on this issue.

A volunteer, grass roots effort started in 1993, with no funding for implementation.

A first-generation National Seismic System was established in 1993 through the formation of the Council of the National Seismic System (CNSS). The CNSS is a national consortium of seismic network operators, now including 30 institutions and agencies throughout the United States, involved in the permanent operation of seismic networks. What exists today as a National Seismic System was formed, in effect, through coordination and limited data exchange between regional seismic networks and the USNSN. One of the fundamental shortcomings of this system, among others already described in section 2, is the lack of integration between weak- and strong-motion networks.

An action plan for the improved acquisition and dissemination of strong-motion data was put forward in 1997 in a NSF report entitled "Vision 2005: An Action Plan for Strong Motion Programs to Mitigate Earthquake Losses in Urban Areas." The aim of the plan is to advance earthquake engineering, emergency response and recovery, and earthquake design practice. The need to expand the gathering of strong-motion data in the United States had been persistently identified in earlier reports by the National Research Council in 1982, 1985, 1987, and 1989.

Strong-motion networks begin a national system approach.

In 1998 the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) was formed, fulfilling a primary need identified in the 1997 NSF Vision 2005 report. A first-order goal of the COSMOS is to provide a continuing strong link between the users of strong-motion data and the organizations that operate strong-motion networks. The engineering community recognizes that traditional instrumentation and strategies for monitoring earthquakes no longer provide adequate data and information for mitigating earthquake hazards in buildings and structures.

3.2 Vision and Mission of an Advanced System

At a workshop on this report, the concept of a combined, advanced system emerges.

The vision of a next-generation National Seismic System crystallized in preparing this report to Congress. The process of writing this report brought together, in an unprecedented way, seismologists from the CNSS and earthquake engineers from COSMOS and resulted in a plan that combines integrated seismographic monitoring on all scales with strong-motion recording and structural-response monitoring focused on urban areas at risk.

The mission of the Advanced National Seismic System is to provide accurate and timely data and information on seismic events and their effects on buildings and structures by using modern monitoring methods and technologies.

3.3 Fundamental Goals

The national workshop participants who were brought together in June 1998 to shape the core message of this report (see Preface) reached a consensus on four fundamental goals for an Advanced National Seismic System:

Four goals require equipment modernization, new monitoring concepts, and rapid information dissemination.

- Establish and maintain an advanced infrastructure for seismic monitoring throughout the United States that operates with high performance standards, gathers critical technical data, and effectively provides information products and services to meet the Nation's needs. An Advanced National Seismic System should consist of modern seismographs, communication networks, data processing centers, and well-trained personnel to constantly record and analyze seismic data and provide timely and reliable information on earthquakes and other seismic disturbances.

- Continuously monitor earthquakes and other seismic disturbances throughout the United States, including earthquakes that may cause a tsunami or precede a volcanic eruption, with special focus on regions of moderate to high hazard and risk.

- Thoroughly measure strong earthquake shaking at ground sites and in buildings and critical structures. Focus should be in urban areas and near major active fault zones to gather greatly needed data and information for reducing earthquake impacts on buildings and structures.

- When a significant earthquake occurs, automatically broadcast information for immediate assessment of its impact. Where feasible, for sites at distance from the epicenter, broadcast an early warning seconds before strong shaking arrives. Similarly, provide capabilities for automated warning and alert for tsunamis and volcanic eruptions.

3.4 Operational Concepts

An Advanced National Seismic System, to be effective and efficient, must be based on operational concepts that are different from those under which networks have worked for the past half century.

The new system must break the mold of weak *and* strong-motion networks operated for separate and limited objectives and interests.

- The interrelated components of a National Seismic System must function in a well-organized way. The system should be designed, created, and operated using a systems engineering approach to ensure that both the whole and its parts meet the desired performance goals in a cost-effective way.

- An Advanced National Seismic System must deliver useful and timely information products and services, as well as collect technical information to meet both immediate and long-term needs of the Nation. Advances in earthquake science and engineering require the gathering of new high-quality data. At the same time, a publicly funded Advanced National Seismic System requires balanced emphasis on innovative and dedicated customer service to all users needing information and assistance.

3.5 Strategic Plan and Actions Required

To create an Advanced National Seismic System that effectively achieves the four fundamental goals, there are four basic requirements—modern instrumentation, tools for effective distribution of earthquake data and information, performance standards, and leadership. The strategic plan for building the desired system has six key elements:

The overhaul must be comprehensive and systematic.

- Integrate existing capabilities and expertise of regional seismic networks, strong-motion networks, and the U.S. National Seismograph Network, and use a systems-engineering approach to create a master plan for nationwide seismic monitoring and information flow, including performance goals, standards, and procedures.

- Modernize and expand the infrastructure necessary for monitoring earthquakes and volcanoes. These tasks will require expansion of the USNSN, complete modernization of regional networks, and integration of these with new instrumentation in urban areas at risk from damaging earthquakes.

- Install robust capabilities (hardware and software) for real-time data acquisition and processing and for the automated exchange of seismic network data among the national and regional network-recording centers that will be linked under an Advanced National Seismic System.

- Establish an effective data management scheme for the integration, archiving, and distribution of seismic data collected by all monitoring elements of the advanced system.

- Develop interagency and public-private collaboration for enhancing the infrastructure and advancing the goals of the system. (Monitoring in urban areas for earthquake safety is one notable example of potential collaboration with the private sector, where the private sector would have their interests, needs, and involvement integrated into an Advanced National Seismic System.)

- Optimize the use of real-time seismic information through training and public education as part of a responsiveness to the dynamics of the digital age and ongoing change affecting all segments of our society. (Collaboration with the Federal Emergency Management Agency in conducting drills and exercises based on real-time simulations of earthquake information is one example.)

4. AN ADVANCED NATIONAL SEISMIC SYSTEM: INFRASTRUCTURE REQUIREMENTS

To fulfill the Nation's needs for mitigating earthquake and volcano hazards, it is essential to replace the obsolete equipment that dominates most seismic monitoring networks throughout the country. This section outlines the infrastructure needed to meet the vision, goals, and requirements of an Advanced National Seismic System.

4.1 NATIONAL SEISMIC MONITORING

Expand the national monitoring network to 100 stations.

The USNSN should be expanded to 100 modern seismographs, from its present configuration of 56 stations, to provide uniform coverage in areas not covered by regional networks. The USNSN supplies the primary data used for national seismic monitoring provided by NEIC. It furnishes monitoring and reporting capabilities for the continental United States where none other exists, critical real-time data for tsunami hazards monitoring, enhanced reporting and response capabilities for regional networks in seismically active areas, and data for general scientific research. With an average spacing of about 500 km between stations, the present USNSN must be densified to fulfill its mission.

4.2 REGIONAL SEISMIC MONITORING

Modernize regional monitoring with 1,000 modern seismographs.

A total of 1,000 modern seismograph stations are needed to replace existing analog equipment within the regional seismic networks. Regional seismic networks provide finer space-time resolution of seismicity and comprehensive characterization of seismic sources and active tectonic processes in regions of moderate to high seismic hazard and risk. A comprehensive review is required to identify hazardous regions targeted for seismic monitoring on a regional to local scale. This task includes ensuring that all potentially active volcanoes in the United States are monitored by at least three seismographic stations within 20 km.

4.3 URBAN SEISMIC MONITORING

The scarcity of recordings of strong earthquake shaking in urban areas underscores the basic need for achieving economically and socially acceptable earthquake resistance of both existing and new construction. The existing instrumentation in metropolitan areas at risk to damaging earthquakes, such as San Francisco, Los Angeles, Seattle, Salt Lake City, Anchorage, Reno, Memphis, St. Louis, Charleston, S.C., Boston, and New York City, is insufficient to meet the present needs of the emergency management, engineering, and research communities. Improving strong-motion monitoring in urban areas requires significant increases in the number of instruments over existing inventory (appendix 7.4).

Install dense networks for strong-motion monitoring in urban areas.

An additional 3,000 free-field (ground-based) strong-motion seismographs should be installed in densely populated areas at risk to strong ground shaking to aid in rapid notification for emergency response and recovery following a damaging earthquake. Data will be analyzed at and results distributed from regional data centers. Measurements of strong ground shaking can now be obtained relatively inexpensively by using modern instrumentation technology. These instruments would be deployed in urban areas at risk to large, damaging earthquakes, such as San Francisco, Los Angeles, Seattle, Salt Lake City, Anchorage, Reno, Memphis, St. Louis, Charleston, S.C., Boston, and New York City. Instruments would also be placed on or at critical facilities such as bridges, freeway overpasses and exchanges, and power plants.

Install additional instruments for strong-motion monitoring in structures.

Another 3,000 strong-motion instruments should be installed in buildings and structures to resolve outstanding issues in engineering design practice. The strong-motion instruments described here are intended to provide data on critical structures, facilities, and buildings for emergency response applications and for engineering research and applications. These instruments are a subset of 10,000 instruments identified in the NSF-sponsored report entitled "Vision 2005: An Action Plan for Strong Motion Programs to Mitigate Earthquake Losses in Urban Areas" for deployment in structures. Table 3 (in Section 6.2 below) gives an assessment of the number of stations needed in various urban areas.

4.4 Regional and National Network Operation Centers

To ensure rapid and authoritative notification of potentially damaging earthquakes, national and regional seismic monitoring centers must have in place robust capabilities (hardware and software) for real-time data acquisition and processing and for the automated exchange of data and results. These tasks require modern, modular computer systems using common infrastructure (operating systems, communications protocols, and so on); robust applications software for acquisition, processing, and dissemination of data and information; and integration of all signals from ground-deformation sensors, including Global Positioning System (GPS).

Regional network centers need modernization for routine monitoring and emergency response functions

Regional network data centers need to be modernized according to uniform standards that will allow them to communicate with each other, the national center, and the public in the same language. The centers need sustained support so that development and planning can be carried out on other than a survival basis. Standard data acquisition and processing software will be used to simplify the exchange of information and data between regional centers and the national center. In large urban areas with moderate to high seismic risk, regional monitoring centers will produce maps, based on strong-motion data, showing the distribution of strong ground shaking following significant earthquakes.

NEIC will be in central leadership role of any national system.

The National Earthquake Information Center functions as the focal point for all seismic monitoring in the United States. It must strengthen its leadership in setting standards for data formats, data processing, and data exchange. It should, and has, served as a backup for all regional networks and data centers. It must be able to replicate their services should a regional center fail due to a major earthquake, power loss, or other extreme event, as it did during the Loma Prieta and Northridge earthquakes. It needs to modernize and expand its data and information products and associated dissemination procedures.

4.5 DATA MANAGEMENT AND DISTRIBUTION CENTERS

Archiving and distribution of large volumes of seismic data are necessary functions of an advanced system.

Long-term investigations earthquake and volcanic processes and effects require investment in data management facilities to organize and distribute raw seismic data for research purposes. Although NEIC is the national distribution point for parametric earthquake data, earthquake catalogs, and general earthquake information; larger, more specialized facilities are needed to archive and distribute raw seismic data. On national and regional scales, the seismological community has significant experience in archiving and distributing data through the IRIS Data Management Center and various regional centers such as the Northern California Earthquake Data Center. As part of an Advanced National Seismic System, these facilities would be expanded to accommodate the increased data, or new facilities modeled on the IRIS center and the northern California center would be established elsewhere to efficiently accommodate needs and requirements of the research community.

4.6 PORTABLE SEISMOGRAPH ARRAYS

Earthquakes may often occur in regions where instrumentation is sparse or where there are needs to resolve important earthquake hazards issues. Seismologists frequently deploy temporary networks of sensors following earthquakes to monitor aftershocks or to better understand local earthquake effects. For example, portable seismometers, if deployed quickly, can help determine the cause of concentrated or unusually severe damage. To facilitate these studies, an Advanced National Seismic System should develop two portable seismograph networks, each consisting of 25 modern seismographs, to supplement permanent network monitoring, on a temporary basis, for aftershock studies and other strategic recording, especially in areas where permanent network instrumentation is inadequate. The portable seismograph arrays and accessory equipment should be maintained and operated so that one is located in the Eastern and one in the Western parts of the United States, respectively.

5. INFORMATION PRODUCTS AND SERVICES

A new system means new products and services.

An Advanced National Seismic System will provide better data, more complete and timely information, and enhanced services to a wide range of technical and non-technical users. The many national needs for seismic monitoring information can be grouped into the following three basic categories:

Information needs for immediate public safety and emergency response when the dangers of an earthquake, tsunami, or volcanic eruption arise.

- Long-term needs for technical data to advance science, engineering, and hazard assessment so that vulnerability and losses in future earthquakes can be reduced.

- Ongoing needs for information and services, including expert assistance, in arenas such as education and awareness, public policymaking, planning and designing, and disaster preparedness and risk management.

In each of the three categories above, the flow of information and data under an Advanced National Seismic System requires a coordinated information infrastructure suitably adapted to the World Wide Web and other communication pathways of our changing information age. In emergency situations, the system must reliably deliver needed information, the information must be accurate and authoritative, and all available information from the system must be integrated for convenient access. For research purposes, effective data management will ensure standards for data recording, processing, and exchange that will lead to the timely integration and archiving of data and facilitate data retrieval. These strategies will result in comprehensive information products for general use and decision making.

5.1 TIME-CRITICAL INFORMATION FOR PUBLIC SAFETY

A National Seismic System can provide time-critical information on earthquakes, tsunamis or volcanic eruptions. In the case of damaging or disruptive earthquakes, it will provide valuable information for rapid alert, response, assessment of impact, and recovery.

An earthquake early warning can give a few seconds notice of imminent strong shaking.

Earthquake early warning is an emerging application of seismic monitoring technology that offers the automated capability (where instrumentation is in place) to recognize when an earthquake is in progress and to provide seconds to tens of seconds of warning before the onset of strong shaking at a site, depending on its distance from the epicenter. Early warnings can enable individuals in vulnerable situations to protect themselves or others. School children can take cover under desks to avoid injury from falling structural debris or nonstructural building components. Surgeons can suspend delicate operations. Businesses and industries can stop critical processes such as the handling of toxic substances and protect assets such as active data bases. Utilities and transportation lifelines can take preventive action to avoid major service disruptions.

Rapid notification can help direct allocation of emergency response resources

Broadcasting post earthquake notifications of the location, size, and distribution of strong shaking where strong-motion instruments are in place allows appropriate emergency response and recovery actions to begin. Authoritative earthquake information products for emergency response applications will provide response agencies with an immediate understanding of the scope of the event, the levels of mobilization required, and to some extent, the types of resources needed to respond effectively and to efficiently allocate what is available.

Delivering emergency response information will involve State and local emergency service agencies, which are responsible for taking actions based on earthquake notification provided by the National Seismic System and, in some cases, for delivering hazard warnings to the population. Providing rapid seismic information to any large and complex urban area—and indeed to the Nation—requires careful planning, well-considered management, and clear lines of organizational responsibility. Local and regional broadcast news media will be included in the information delivery system as partners, and partnership with other parts of the private sector will also be developed.

Training and public education to ensure effective response.

Training and public education are required for effective use of real-time seismic information—especially earthquake early warnings. An appropriate public response to an early warning will require close and careful coordination among those who generate, deliver, and use this information. Technology transfer, training, and public education will be important to ensure that new products of upgraded seismic networks, such as near-real-time ground shaking maps, are understood and used successfully in managing emergencies, promoting greater safety, and improving recovery. The Federal Emergency Management Agency has played a major role in promoting emergency management training. FEMA is in a strategic position of leadership to promote the use of new realtime technologies.

5.2 DATA AND INFORMATION FOR LONG-TERM EARTHQUAKE LOSS REDUCTION

Data from seismic networks are the foundation for all seismic hazard assessments and basic research on earthquake and volcano processes

Seismic networks are a primary source of data and information for understanding and defending against the dangers of earthquakes. Advances in earthquake science and engineering inevitably are made based on experience and data from actual earthquakes. Long-term gains in earthquake safety depend on the sustained gathering of technical data through seismic monitoring. While the seismological data collected by the National Seismic System will be of value for both basic and applied research, we emphasize their practical value for reducing earthquake losses.

A comprehensive national seismicity catalog is the foundation for evaluating earthquake potential, for wide-ranging research in earthquake science, and for reliable earthquake hazard assessments at national, regional, and local scales.

Identifying and characterizing earthquake source zones and understanding the physics of earthquakes are essential to basic earthquake hazard research. Identifying active faults, space-time patterns of occurrence, and rupture processes of earthquakes leads to improved hazard assessments.

Understanding earthquake source and propagation effects from large earthquakes is at the heart of earthquake engineering and hazards assessment. Understanding how strong shaking propagates and how the Earth responds to strong shaking influences the design and performance of structures and critical facilities.

Validating and calibrating earthquake loss-reduction tools are fundamental to modern emergency management response and recovery. Basic to this process is an understanding of the assumptions and models used in developing new microzonation maps for ground shaking and liquefaction hazards in urban areas and in developing loss estimation programs such as HAZUS, now used by FEMA nationwide for forecasting earthquake losses.

Strong-motion data are the basis for advances in earthquake-resistant design and construction practices.

An Advanced National Seismic System will provide strong-motion data needed to resolve outstanding issues in engineering design practice. Strong-motion measurements are needed (1) to define expected free-field ground motions (that is, shaking of the ground on which structures are built) for use as inputs in evaluating performance of structures and systems and (2) to improve and validate modeling and analysis procedures used in assessing seismic performance of structures. The following data and information will directly contribute to earthquake safety through improvements in seismic-resistant design of buildings, dams, bridges, industrial facilities, and lifelines:

- Measurements of site-specific ground motions and site response are needed to help predict future free-field ground motions at a specific site and, in the case of nearby damaged structures, to determine ground motions to which those structures were subjected.

- Measurements of structural response and soil-structure interactions are required to improve seismic-resistant design of all structural types.

- Ancillary measurements for selected structures enable a complete analysis of response to strong ground shaking. These measurements include constitutive properties of soils, ground displacements, transient stresses and strains in structural elements, and hydrodynamic pressures.

- Researchers and practitioners in the engineering community have specialized needs as a user group for strong-motion data. Special attention will be given to their needs for (1) standardized high-quality processing of time-history recordings of strong ground acceleration, (2) the availability of derived data from the direct recordings, such as velocity, displacement, and spectra (response and Fourier), (3) important information relevant to the original data recordings, and (4) ancillary measurements where available.

5.3 General Information and Expert Services

The third category of national needs associated with seismic monitoring is the need for information and services, including expert assistance, to individuals and groups involved in activities such as education and awareness, public policymaking, planning and designing, and preparedness and risk management. Human responsiveness, not just web sites and other internet outlets of information, must be provided.

The National Earthquake Information Center in Golden, Colorado, is a national outlet for earthquake information and information products and also is the recording center of the USNSN. Modernization of the NEIC will allow it to—

- Play a strong leadership role in the planning, development, and coordination of the products and services of the advanced system.
- Provide national and worldwide seismic monitoring with 24-hour-a-day staffing and reporting capability.
- Provide improved customer services to emergency management agencies, news media, and the public in general.

National and regional data centers serve the public as sources of earthquake safety information

Regional earthquake network centers also serve as regional information centers and provide key leadership and expertise at regional, State, and local levels in advancing earthquake safety. An important part of the plan for an Advanced National Seismic System is to provide resources to enable regional seismic network centers to—

- Create useful and important region-specific information products (for example, maps, data bases, reports, publications, Web sites) directly arising from seismic monitoring,
- Serve as local/regional information outlets and repositories of expertise, especially for expert assistance to public policymakers, safety officials, planning and regulatory agencies, local businesses, news media, and the general public, and
- Ensure the long-term availability of seismological expertise through the education and training of the Nation's professional seismologists.

5.4 SUMMARY

In summary, an Advanced National Seismic System will result in:

- improved earthquake and volcano hazard assessment by bridging the gap between observation and implementation of hazard reduction strategies, better probabilistic hazard assessment from better definition of seismically active faults and volcanoes, and compilation of a complete catalog of earthquakes for the Nation;

- timely dissemination of earthquake information for emergency management activities through better real-time warning of tsunami-producing earthquakes, authoritative earthquake and volcano early warnings and notification, predictions of the distribution of strong-ground shaking in urban areas;

- better evaluations of the damage experienced by structures in strong ground shaking through new observations of strong shaking in urban areas exposed to high earthquake hazard, and

- new data for basic research on earthquake and volcano processes, propagation and site effects due to Earth structure, and prediction of ground motions for future, large damaging earthquakes in urban areas.

6. ACTION ITEMS FOR AN ADVANCED NATIONAL SEISMIC SYSTEM

6.1 KEY STEPS FOR IMPLEMENTATION

The strategic plan for creating an Advanced National Seismic System (see section 3) calls for building upon existing regional seismic networks, strong-motion networks, and the USNSN to integrate nationwide seismic monitoring and its information flow. Major investments in hardware, software, and communications are required (section 4). Key steps for implementing the plan are the following:

Success depends on: committed participation, stable funding, standardization, partnerships, and planning.

- Secure participation commitment of all networks that will become either national, regional, or urban components of the advanced system.
- Secure funding commitment for new equipment and for stable long-term support of operations and service.
- Set standards and performance goals to ensure quality control and effective results.
- Establish and enhance partnerships to leverage and maximize all available resources.
- Develop and implement a management plan to ensure that the diverse elements of the National Seismic System are organized into a whole that will perform effectively as a true system.

Approximately $170 million is needed for equipment to modernize seismic monitoring in the United States.

6.2 FUNDING FOR AN ADVANCED NATIONAL SEISMIC SYSTEM

There are two chief funding needs beyond current support for the advanced system—modernization and stable operations.

Modernization and reconfiguration of existing networks will require the purchase and installation of new equipment and the reconfiguration of certain regional networks to meet new operational requirements, such as early earthquake notification. These costs are estimated in table 1.

Table 1. Costs for expansion and modernization for an Advanced National Seismic System.[5]

Action Item	Equipment	Cost
National monitoring: Expand the USNSN to 100 modern seismographs in areas not covered by regional networks. (Sec. 4.1)	Purchase and install 44 additional modern seismographs, including satellite communications at $62,500 each.	$2,750,000
Regional monitoring: Complete modernization of regional seismic networks. (Sec.4.2)	Purchase and install 1,000 modern seismographs, including communications systems at $31,250 each.	$31,250,000
Urban monitoring: Strong-motion monitoring at ground sites for warning and rapid damage assessment. (Sec.4.3)	Purchase and install 3,000 strong-motion recorders, including communications systems at $18,750 each.	$56,250,000
Urban monitoring: Strong-motion monitoring in structures for rapid damage assessment and earthquake engineering. (Sec. 4.3)	Purchase and install 3,000 strong-motion recorders, including communications systems at $18,750 each.	$56,250,000
Regional network centers: Modernization to manage new data and functions. (Sec. 4.4)	Modernization and standardization of hardware and software at 20 regional centers, approximately $1,000,000 each.	$20,000,000
National network center: Modernization to manage new data and functions. (Sec. 4.4)	Modernization and standardization of hardware and software at National Earthquake Information Center (NEIC)	$2,000,000
Data management and distribution centers. (Sec. 4.5)	Use existing facilities.	0
Two portable arrays for aftershock recording and special studies. (Sec.	Purchase two (with 25 stations each) at approximately $56,250 per station.	$2,812,500
Total		$171,312,500

[5] These costs include USGS overhead expenses.

These costs may come down if equipment is purchased in large orders or if technological advances reduce the cost of manufacturing. Nevertheless, a major investment of this magnitude will be needed, spread over a 5- to 10-year time period, to achieve the required modernization of seismic monitoring in the United States.

Approximately $47 million will be needed each year to maintain and operate an advanced system.

Stable operational support. Seismic networks must be operated on a stable-funding base. Estimated annual operating costs are given in table 2.

Table 2. Annual operating costs for an Advanced National Seismic System at full operation.[6]

Item	Activity	Cost
National, regional, and urban seismic monitoring. data centers.	Network operations, maintenance, and data processing plus information products and services.	$35,500,000
Communications.	Dedicated circuits for 4,050 sites @$1,500 and dial-up circuits for 3,000 sites @$1,000	$9,075,000
Data management and distribution centers.	Operations and services at two data distribution and archiving centers @ $750,000	$1,500,000
Portable arrays.	Annual maintenance, deployment, and data management	$800,000
Total		$46,875,000

Distribution of Urban Stations. A preliminary estimate of the distribution of seismic stations in various urban areas is given in Table 3. This distribution is based, in part, on the level of seismic hazard and the population at risk. In practice this distribution may change somewhat depending on the degree of development of urban seismic networks supported by state and local governments and other interests. A map showing the general distribution of the various types of stations is given in appendix 7.6

[6] These costs include USGS "overhead" expenses. Existing USGS support of domestic seismic networks, $14 million, could be applied to these costs.

Table 3. This table shows, for various urban areas, the approximate number of seismic station needed. The number for each area is based, in part, on a rough estimate of seismic risk. A relative risk factor was determined by multiplying the hazard by the population. The earthquake hazard is given in terms of the severity of ground shaking (in per-cent of gravity) that has a 10% chance of being exceeded in the next 50 years. The number of stations needed may vary depending on state and local involvement in developing urban seismic networks. Only a few stations are placed in areas of low hazard with very high population.

Urban Area	Earthquake Hazard in %G	Population in Millions	Risk Factor	Number of Urban Stations
Los Angeles, CA	88	15.4	5.1221	1300
San Francisco, CA	99	6.5	2.4322	1000
Seattle, WA	34	3.3	0.4241	600
Salt Lake City, UT	29	1.2	0.1315	400
Anchorage, AK	35	0.3	0.0397	300
San Diego, CA	25	2.6	0.2457	300
Portland, OR	19	2.0	0.1436	300
Reno, NV	33	0.3	0.0374	200
Memphis, TN	14	1.1	0.0582	200
St. Louis, MO	10	2.5	0.0945	200
Santa Barbara, CA	52	0.4	0.0786	100
Salinas, CA	43	0.4	0.0650	100
San Juan, PR	30	1.0	0.1134	150
Provo- Orem, UT	19	0.3	0.0215	100
Sacramento, CA	17	1.6	0.1028	100
Las Vegas, NV	12	1.1	0.0499	100
Chattanooga - Knoxville, TN	10	1.1	0.0416	100
Stockton - Lodi, CA	18	0.5	0.0340	60
Fresno, CA	12	0.8	0.0363	60
Charleston, SC	18	0.5	0.0340	60
Albuquerque, NM	11	0.7	0.0291	50
Eugene - Springfield, OR	14	0.3	0.0159	50
Evansville, IN	11	0.3	0.0125	40
Boise, ID	7	0.4	0.0106	50
New York, NY	6	18.1	0.4105	40
Boston, MA	5	5.8	0.1096	40
Total				6000

6.3 STANDARDS AND PERFORMANCE GOALS

Standards, performance goals, and uniform procedures are critical to the success of an Advanced National Seismic System. These must govern the whole range of system operations from the installation and calibration of instruments to communication protocols to data processing to data archiving to the distribution of data and information.

The advanced system must perform as a unit according to common goals and standards.

- Standards for the collection, exchange, and archiving of seismic data, including standardized data formats and standardized operating practices, will ensure quality control and efficiencies in making data quickly and widely available.

- Performance goals for network monitoring will come from a comprehensive review of regions throughout the Nation where seismic monitoring is most needed. This review will result in specific plans to ensure such things as continuous surveillance and data gathering, the reliable delivery of time-critical information in emergency situations, and real-time responsiveness of the national system 24 hours a day, every day of every year.

- Standardized information products will ensure that both technical and non-technical users throughout the Nation receive professional high-quality, "user friendly" service.

- Standards for data collection and processing will not necessarily require seismic network operators to stop using existing hardware and software. Rather, they will prescribe guidelines that network operators and other potential participants must meet to integrate their instruments and data into the National Seismic System.

6.4 PARTNERSHIPS

Many different Federal, State, and local agencies, as well as private companies, are now involved in seismic monitoring activities in the United States. The inclusion of most of these in the listing in appendix 7.4 reflects the current substantial cooperation between operators of weak-motion seismic networks (under the CNSS consortium) and operators of strong-motion seismic networks (under the COSMOS consortium).

All interests need to brought into the management and support of the advanced system.

Because the need for seismic information spans the interests of many public and private organizations, a true National Seismic System with realtime capabilities offers unprecedented opportunities for mutually advantageous partnerships to modernize seismic monitoring. These partnerships include the following:

- Interagency partnerships relating, for example, to emergency response and recovery; the safety of dams, mines, and nuclear facilities; risk management of public assets; improved building codes and seismic design; and comprehensive test ban treaty monitoring.

- State-Federal partnerships in high-risk, densely populated regions where existing seismic monitoring is inadequate or in hazardous regions where needs for monitoring have been neglected, perhaps because of relatively low population or inadequate resources.

- Public-private partnerships in urban areas at risk where instruments are needed to measure strong ground motions in structures or in sparsely populated areas where denser instrumental coverage may be needed to enhance the safety of commercial facilities and infrastructure.

- International partnerships relating, for example, to common vulnerability to earthquake, volcano, and tsunami hazards—variously affecting regions between the United States and Canada, Mexico, the Pacific Basin, and the Caribbean Basin.

To date, coordination among existing seismic networks has not been fully achieved, chiefly because of different missions and scales of operation. An Advanced National Seismic System, however, introduces compelling advantages for participation in the system. For both publicly funded and privately funded network operators, the rapid integration of their data with those from the entire seismic community will generally provide a more complete assessment of any seismic disturbance than would be apparent from their data alone. Individual network operators will also benefit from the new technologies and streamlined procedures planned for the National Seismic System.

6.5 MANAGEMENT PLAN

The dynamics of information technology are increasingly leading institutions and organizations to become more distributed than hierarchical. The success of an Advanced National Seismic System will require a combination of (1) purposeful systems management to ensure performance of the system as a system and (2) consortium-type decision making to accommodate the multi-jurisdictional, cooperative nature of the sub-elements of the system, namely the participating seismic networks.

- The USGS should assume primary responsibility for management of an Advanced National Seismic System, based on its assigned Federal responsibility for national seismic monitoring, as well as its central role in the operation and funding of current seismic monitoring activities in the United States (section 2).

The management of the system should be based on the strong implementation and continuance of consensus based decisions.

- CNSS and COSMOS, the national consortia of institutions and agencies that coordinate operations at permanent seismic networks in the United States, will have both advisory and collaborative roles in managing the advanced system and a collaborative role in establishing standards, performance goals, and standardized procedures for the system.

- Network operators participating in the advanced system will directly operate their sub-elements of the system, in coordination with the USGS, and will participate in decision making for the system through CNSS and COSMOS.

A useful, but admittedly imperfect analogy for the Advanced National Seismic System is the air traffic system in the United States. Individual air traffic control centers (like seismic networks) have significant responsibilities in operating their parts of the system, but a systems manager in the form of the Federal Aviation Administration (like the proposed role of the USGS) is clearly needed to oversee and safeguard performance of the complex system, to enforce standards, and to ensure that the Nation's relevant needs are well served.

6.6 CHALLENGE AND OPPORTUNITY

The paramount challenge for seismic monitoring in the United States, emphasized in section 2, is the persistent lack of a stated Federal commitment to provide stable long-term support and oversight for seismic monitoring throughout the Nation. As more people and more societal infrastructure become concentrated in areas vulnerable to earthquake, volcano, and tsunami dangers, problems are growing.

Numerous national policy reports since 1980 (see section 3) have repeatedly identified the need for leadership and action by the Federal Government to modernize the Nation's infrastructure for seismic monitoring, including strong-motion instrumentation. While some progress has been made in specific regions, important nationwide needs remain unmet because current resources are simply inadequate.

Why act now? Firstly, modern seismology and information technology have dramatically increased the benefits that an Advanced National Seismic System offers today, compared to a decade ago. In our rapidly changing digital age, neglecting to modernize seismic monitoring is setting the stage for national failure on a far-reaching scale. Secondly, network seismologists and earthquake engineers, by breaking down previous disciplinary barriers, are poised in an unprecedented way to make an Advanced National Seismic System a reality.

Inevitably, a catastrophic earthquake in the United States will produce the courses of action urged in this report. Waiting to take these steps until after this event has occurred does the Nation no service. The opportunity to act and create a long overdue Advanced National Seismic System is here and now.

Real Time Provision of Earthquake Information In Japan

Keiji Doi*

ABSTRUCT

The Japan Meteorological Agency (JMA) has been providing various kinds of earthquake information on a real-time basis. Seismic Intensity Information, *inter alia,* is most useful one for the emergency operation. JMA developed a Seismic Intensity Meter which could measure seismic intensity automatically without human observation, and has been operationally using instrumental seismic intensities with the Meters. This enables for people to know seismic intensity distribution in two minutes after an earthquake occurrence. JMA has been also developing a *Nowcast Earthquake Information* system with which forecasts of an arrival time and amplitude of a principal wave caused by an earthquake are available. It gives us a new way to reduce earthquake disasters. JMA's effort for the real-time provision of earthquake information is presented in this paper.

Key Words: Earthquake Information, Seismic Intensity, Emergency Response, Early Warning

1. Introduction

Japan is situated one of the tectonically active areas in the world, where the seismic and volcanic activities are very high. As many as 80,000 earthquakes take place in a year, among which 1,000-2,000 earthquakes are felt or a few cause tsunamis. Some of them struck towns, cities, and coastal areas causing sometimes destructive disaster (see Fig.1, and Table 1). Therefore, efforts for prevention and mitigation of earthquake disaster have been continued as one of the most important national programs.

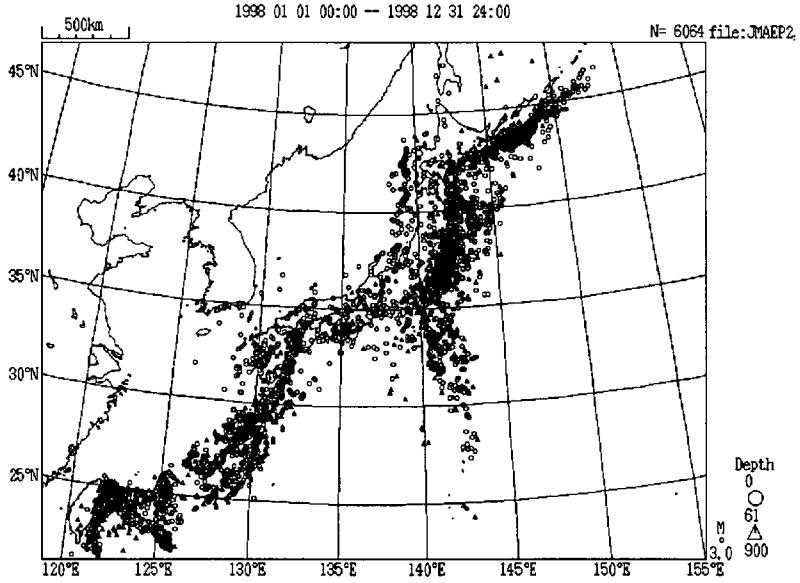


Fig.1 Seismisity in and around Japan in 1998 (M>=3.0)

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Table 1 Major earthquake and tsunami disasters in Japan

Date	Earthquake/Tsunami*	Magnitude	Killed and missed
1872 Mar. 14	Hamada Earthquake	7.1	804
1891 Oct. 28	Nobi Earthquake	8.0	7,273
1894 Oct. 22	Shounai Earthquake	7.0	726
1896 Jun. 15	Tsunami by Sanriku Earthquake	8 1/2	22,072
1896 Aug. 31	Rikuu Earthquake	7.2	209
1923 Sep. 1	Great Kanto Earthquake	7.9	142,807
1925 May. 23	Kitatagima Earthquake	6.8	428
1927 May. 7	Kitatango Earthquake	7.3	2,925
1930 Nov. 26	Kitaizu Earthquake	7.3	272
1933 Mar. 3	Tsunami by Sanriku Earthquake	8.1	3,064
1943 Sep. 10	Tottori Earthquake	7.2	1.083
1944 Dec. 7	Tonankai Earthquake	7.9	1,223
1945 Jan. 13	Mikawa Earthquake	6.8	2,306
1946 Dec. 21	Nankaido Earthquake	8.0	1,330
1948 Jun. 28	Fukui Earthquake	7.1	3,769
1960 May. 23	Tsunami by Chilean Earthquake	8 1/4~8 1/2	142
1983 May. 26	Central Sea of Japan Earthquake, 1983	7.7	104
1993 Jul. 12	Southwest off Hokkaido Earthquake, 1993	7.8	230
1995 Jan. 17	Southern Hyogo Prefecture Earthquake, 1995	7.2	6,433 (as of 1998.12.25)

The Japan Meteorological Agency (JMA) is the unique agency in the Government of Japan which is responsible for tsunami forecasts (warnings/advisories), the short-term prediction of a large-scale earthquake, and the information services on earthquakes, tsunamis and volcanic activities. Earthquake information and tsunami forecasts are issued immediately after the occurrence of earthquakes or volcanic eruptions, and are used as a trigger for emergency response taken by related organizations of the national government, polices, fire departments, and municipalities. They are also disseminated to residents through municipalities and mass media. To accomplish the above-mentioned responsibility of JMA, maintenance and operation of nation-wide seismological and observation networks as well as cooperation with related national and international organs and universities has been kept.

2. Concept of Real-time Earthquake Information

Methodology for seismic data processing on a real-time basis such as estimation of focal parameters from observed data, or information based on its results is called "Real-time Seismology" or "Real-time Earthquake Information", respectively. "Real-time" usually covers a time range within several hours after the earthquake occurrence.

For emergency responses to be taken by related organizations in the cases of an earthquake, it is most important for them to know a degree of ground motion, which may cause disasters. It is less important to inform of the location or the magnitude of the earthquake. In this regard, a seismic intensity is a convenient index to know a degree of a ground motion and to estimate a degree of the disaster caused by an earthquake. Historically, a seismic intensity used to determine with a feeling of watch standers of seismological observatories or a post-earthquake surveillance both for academic purposes and for decision of measures for recovery or rehabilitation from earthquake disasters. The evidence of the degree of earthquake disasters is not always be collected soon after an earthquake occurrence. Therefore, generally,

a few hours or a few days after an earthquake are necessary to know seismic intensity distributions. However, information of seismic intensity distribution is to be of real-time earthquake information.

3. Seismic Intensity Measurement

3. 1. History in Japan

Japanese seismic intensity scale has been developed uniquely. Because Japanese people always anticipate with an occurrence of tsunami when a tremor of an earthquake is felt. The seismic intensity is used not only for knowing a degree of a disaster caused by an earthquake, but also for a trigger of an action which may reduce a tsunami disasters such as tsunami forecasts or self-evacuations. The JMA established the tsunami forecast procedure using seismic waveform readings and seismic intensities which were measured by personnel of each of meteorological observatories and weather stations and were gathered to Regional Tsunami Warning Centers through JMA's meteorological communication circuits to determine a location and a magnitude of an earthquake. A hypocenter, a magnitude, and seismic intensities as a result of the procedure were to be announced immediately to people through municipalities as well as mass-media as earthquake information. It enabled them to judge the evacuation would be needed or not by themselves before a tsunami forecast, for which 15-30 minutes were necessary. The earthquake information, which involves seismic intensities at each of meteorological observatories and weather stations where a tremor was felt, was also used for decision making by responsible organizations for disaster management and emergency response such as local governments, polices, fire departments and so on. Seismic intensities are the most important information just after an occurrence of an earthquake because only few fact data that indicates a degree of disasters are available.

3. 2. Seismic Intensity Meters

The sooner Seismic Intensity Information is issued, the more appropriately they would be able to take measures and actions to reduce earthquake disasters. Objective measurement of seismic intensity and prompt gathering of its result were needed for immediate provision of seismic intensity information to related organizations and the public. In order to meet with this need, the JMA developed a Seismic Intensity Meter, which is capable to measure a seismic intensity objectively and automatically using seismic wave data, for the first in the world in 1991. It enables us to get seismic intensity distribution automatically and immediately after an earthquake occurrence. Measurement of seismic intensity is conducted fully automatically in 1996 by means of Seismic Intensity Meters after about 600 sets of Seismic Intensity Meters had been installed with 20km interval all over Japan by the JMA. (Fig.2)

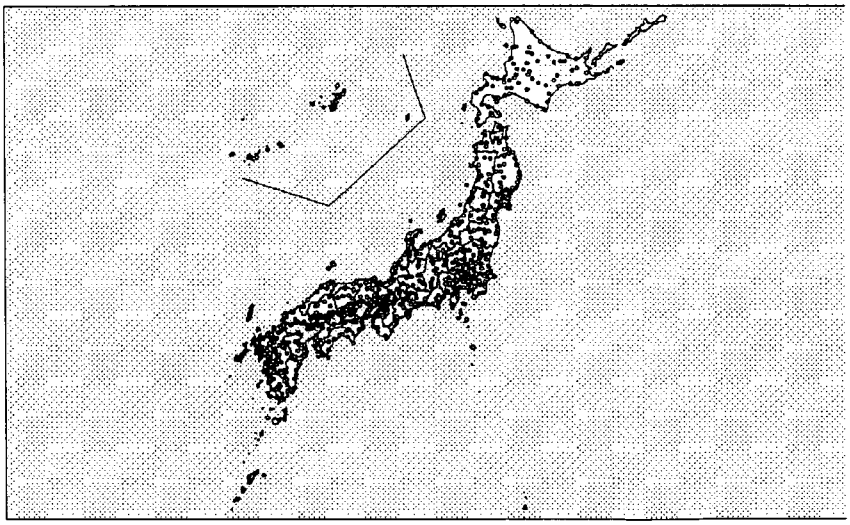


Fig.2 Seismic intensity measurement stations by JMA

Moreover, each of 47 prefectural government has also installed Seismic Intensity Meters cities, towns, and villages in it by its own. A total number of seismic intensity meters in Japan reaches nearly 4,000. JMA is planning to gather all of instrumental seismic intensities of local government's Seismic

Intensity Meters to compile them together with JMA's into earthquake information. JMA has been using about 2,300 seismic intensity measurement stations as a whole including 30 prefectures' as of November 1999.

JMA also prepared the "Explanation Table of JMA Seismic Intensity Scale." This table provides modern situation and damage caused by earthquake correspondent to instrumental seismic intensity. The intensity scale provides useful information to predict the damage. This will aid officials to take measure in emergency situation. (Table 2)

Table 2 Seismic Intensity Explanation Table (extract)

Instrumental Seismic Intensity	JMA Scale	People	Reingforced-concrete buildings	Lifelines
5.0-5.5	5+	Many people are considerably frightened and find it difficult to move.	Occasionally, large cracks are formed in walls, crossbeams and pillars of less earthquake-resistance buildings and even highly earthquake-resistant buildings have cracks in walls.	Occasionally gas pipes and/or water mains are damaged. [Occasionally gas supply and/or water supply stop in some regions.]

4. Provision of Information

4. 1. Earthquake Information Issuance Procedure

When an earthquake takes place and Seismic Intensity 3 or above is observed, a quick report including the maximum Seismic Intensity and the area names are disseminated in about two minutes after the earthquake. After the determination of the hypocenter and the magnitude of the earthquake which are processed with a nation wide observation network. (Fig.3) Tsunami warning/advisory will be issued if

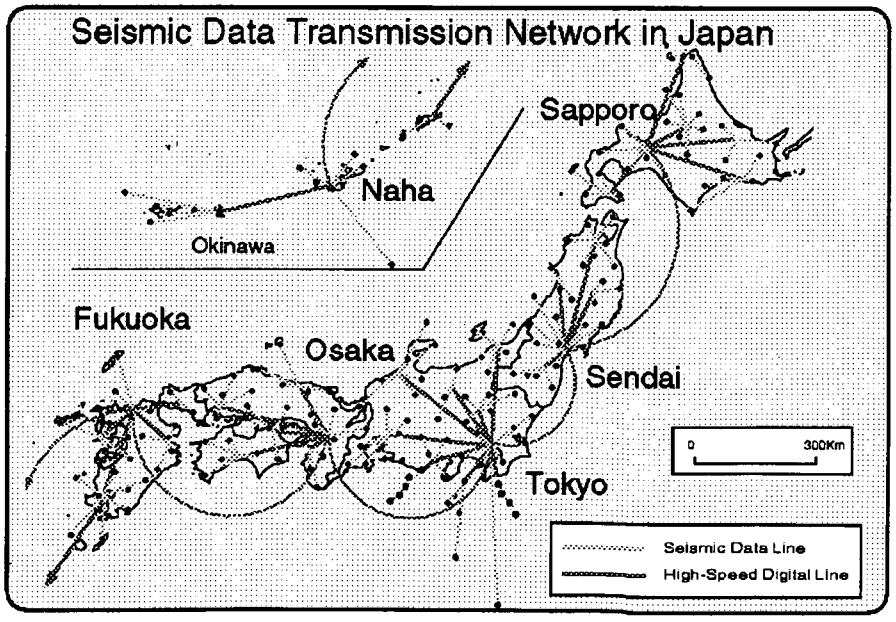


Fig.3 Seismic data transmission network

necessary. The earthquake information contains the area names with the seismic intensity 3 or above, the hypocenter and the magnitude. The "area" used in a quick report and seismic information is of 182 blocks which Japanese island is divided into. JMA will also issue the seismic intensity observed at every measurement station as earthquake information. If an earthquake with maximum intensity 2 or 1 occurs, only seismic information including a hypocenter, a magnitude, and seismic intensity of every observation stations will be issued.

Operationally, JMA successively issues earthquake information and tsunami forecasts as follows:

- About two minutes after the occurrence of the earthquake:
  Flash report of areas and their maximum seismic intensities where the seismic intensity is equal to or greater than 3;
- Three to five minutes:
  Tsunami forecasts;
- About five minutes:
  Information on the hypocenter and the magnitude of the earthquake; and
- Five to ten minutes:
  Information on the seismic intensity at each observation station.

In addition to them, information on tsunami observations, a frequency of earthquakes, and a probability of large aftershock occurrence is issued if necessary.

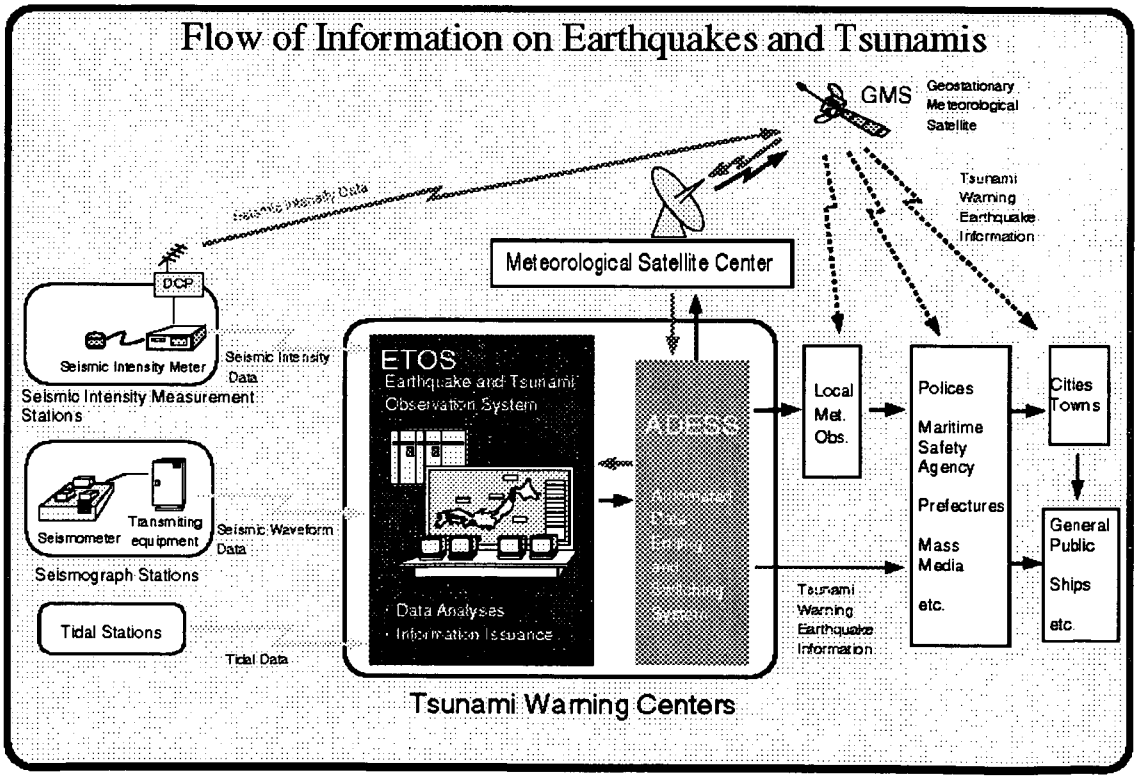


Fig. 4 Flow of information on earthquake and tsunami

4. 2. Dissemination of Earthquake Information

The information on earthquakes should be disseminated urgently and surely to the authorities and the public. In this regard, JMA has been developing and improving its systems to disseminate the information to the authorities concerned by facsimile via dedicated lines. Some of the authorities have

already introduced or are planning to introduce the computer systems, directly connecting to the JMA's system to receive and process the information from JMA through dedicated lines on a real-time basis. JMA has also been providing the urgent information to the authorities and other users through the "Satellite-based Information Dissemination Systems" using the Geostationary Meteorological Satellite (GMS) since 1993. (Fig.4) In addition, the information is broadcast to the public under the cooperation with radio and television services, by interrupting programs and/or superimposing on television screens to notify the occurrence of an earthquake.

4. 3. Example of use of seismic intensity value

Delegations from related ministries/agencies will be called to meet at the Cabinet Information Center in case of Seismic Intensity 6Lower or above in whole country or 5Upper or above in Metropolitan area.

The National Land Agency has been developing and operating "Disaster Information System" which quantitatively estimates amount of casualties within 30 minutes after an earthquake. Seismic intensity data provided by JMA is put in the system as the initial values of its estimation.

Self-Defense Force and Maritime Safety Agency will make aerial survey in case of Seismic Intensity 5Lower or above. (Fig.5)

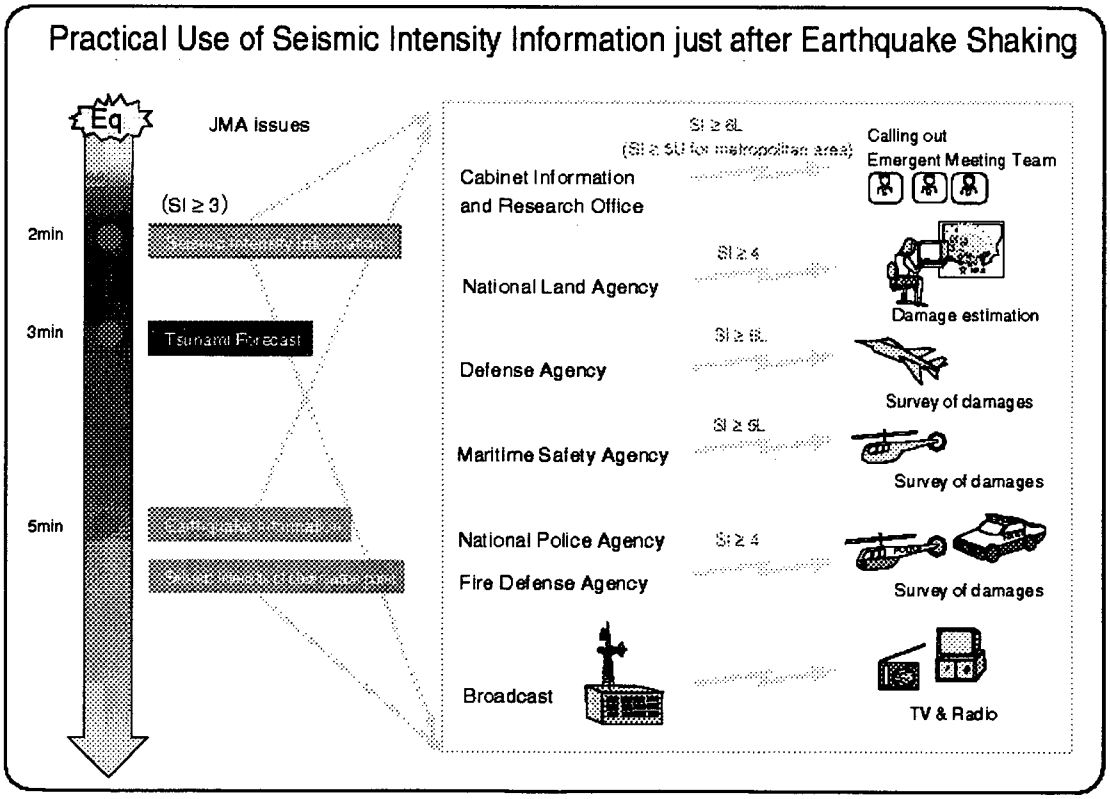


Fig. 5 Practical use of seismic intensity information just after an earthquake

5. Strategies for the Future - *Nowcast Earthquake Information*

5. 1. Outline

Seismographs, data processing techniques and the speed of telecommunication have been

improved rapidly. These developments have enabled us to estimate the focus and the magnitude of an earthquake and seismic intensities even though the data from the station are limited in number just after the occurrence of the earthquake before the principal seismic waves reach distant places from the epicenter.

JMA has been examining to develop a system for provision of information concerning the fact of the occurrence of an earthquake, and the forecast of the arrival times and amplitudes of principal motions, which may cause damage to the architecture, as early as possible. It is not called "Forecast" but "Nowcast" because it is issued at extremely short notice. It may be only several tens of seconds available to respond to the Information.

"*Nowcast Earthquake Information*" is defined as the information of the forecasts of the principal motion before its arrival to distinguish it from other "real-time" information. Practically, "Real-time Earthquake Information" is used for the responses taken after the earthquake, and "*Nowcast Earthquake Information*" is used as an earthquake early warning for the responses taken before the arrival of the principal motions.

Some kinds of equipment give alarms when they detect an earthquake that exceeds a certain threshold. In this case, however, the ground where the equipment is installed is already shaking when the alarm goes off. On the other hand, the *Nowcast Earthquake Information* enables the emergency control of various systems before the arrival of principal motions.

5. 1. 1. The classification and the timing of issuance

The *Nowcast Earthquake Information* will be issued in the sequence as shown as follows (Fig.6);

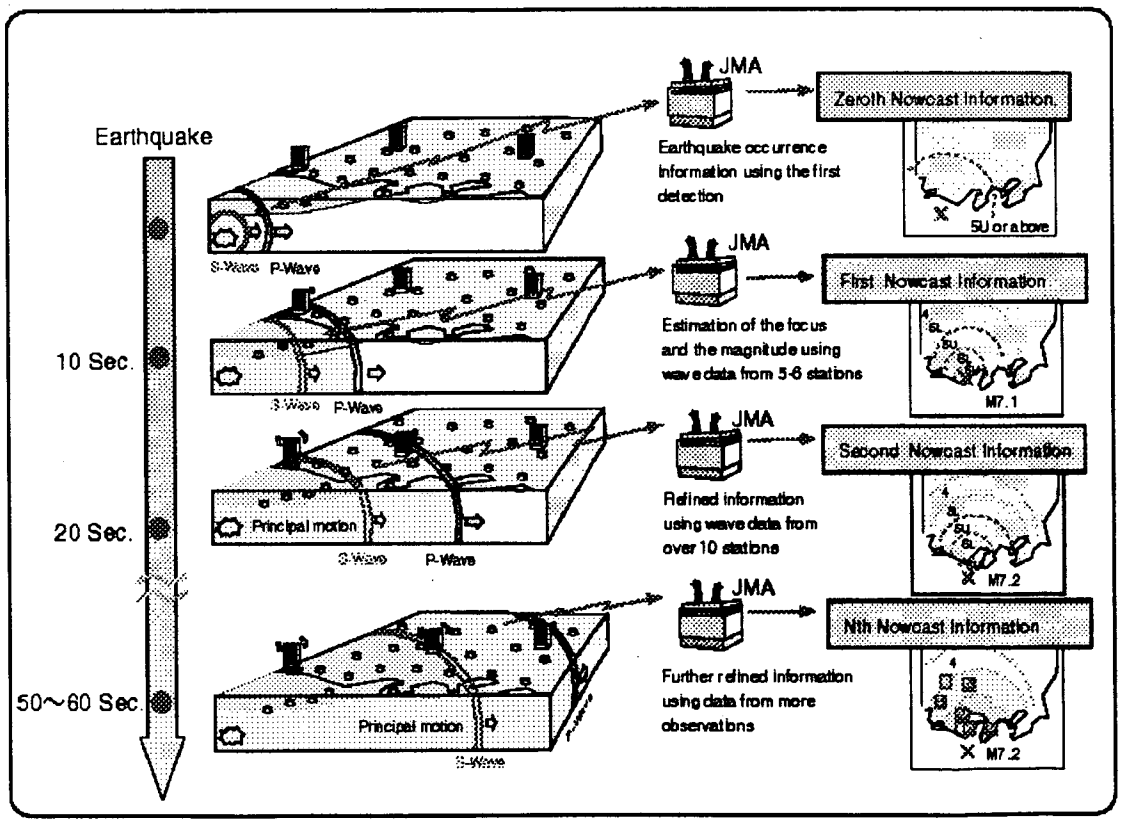


Fig.6 Conceptual Image of *Nowcast Earthquake Information*

Zeroth Information	The fact that an earthquake is detected at one station
First Information	Rough estimate on the focus, arrival times of seismic motion at specific points and observed seismic intensities at specific points with observations from three to six stations
Second Information	Estimates better than the first one with observations from around ten observations
.....	.....
N-th Information	Observation report or better estimation with observation form plenty observations from many stations

The time required to issue respective information will depend on the condition of data acquisition..

5. 1. 2. Application of Nowcast Earthquake Information

Nowcast Earthquake Information is made from the observations available at a time, before enough data are collected to calculate the precise focus and other information. The number of stations that observe and report tremor increases as seismic waves propagate after the occurrence an earthquake, and then the accuracy of the *Nowcast Earthquake Information* increases. On the other hand, time to respond before the arrival of the principal motion will become shorter at the place near the focal region where the stronger motion will strike.

The application of the *Nowcast Earthquake Information* should be examined taking into account its accuracy, the timing of issuance, and the loss estimation if applied. For example, in one extreme case that the expected damage caused by the earthquake is large and the false alarm would not cause severe losses, users would respond to the zeroth information. On the contrary, if the expected damage by the earthquake is not very large and the false alarm may cause severe losses, users would wait for more accurate information that is issued at a certain time after the earthquake.

5. 2. Towards Implementation the Nowcast Earthquake Information

5. 2. 1. Result of questionnaire survey

JMA conducted a questionnaire survey on the feasibility to utilize the *Nowcast Earthquake Information*, the needs of the information, and practical application by interviews with responsible persons of companies and local governments in the Metropolitan area, Hanshin region, and Shizuoka Prefecture. The results of the survey are summarized as follows;

- Many of potential users want to use or think beneficial to use the *Nowcast Earthquake Information*.
- Various business sectors are considered as potential users.
- "Time to respond", "accuracy", and "cost" are considered important and essential conditions to introduce the *Nowcast Earthquake Information* for potential users' emergency response.

The total cost, *inter alia*, should be examined taking into account the users' benefits of using the *Nowcast Earthquake Information*, the cost to introduce and operate the system, and the financial losses caused by false alarms.

Table 1 shows categories that the *Nowcast Earthquake Information* would be applicable based on key criteria, "time to respond", "accuracy", and "cost". Users have different demands for these conditions and more surveys are needed.

5. 2. 2. Further Consideration

In order to implement the *Nowcast Earthquake Information* practical, following issues are to be considered.

i. Awareness and Education

It is essential and important for the promotion of the Information to make potential users aware of its usefulness. In particular, they should clearly understand the relationship between the time to respond

and the accuracy of the Information. Materials to experience time to respond virtually should be developed so that not only potential users but also the general public can familiarize the Information.

ii. Application and Requirements

The feasibility of the Information should be evaluated by considering practical applications and the cost of application hardware and software as well as the benefits and losses of the Information. The requirements for the Information should be further clarified.

iii. Improvement of the Information

A number of the case studies should be carried out under various conditions of the seismic observation network, epicenter, and user's locations. Referring to the requirements for the Information, plans for its technical improvement concerning accuracy and time to issue should be developed.

iv. Public Promotion System for Introduction

It is not enough to wait until potential users could understand the effectiveness of the Information and develop their own application systems. It is one of ways to consider policies such as subsidies and/or tax remission so as to encourage potential users to introduce the system.

The Japan Meteorological Agency has plans to continue researches to apply the *Nowcast Earthquake Information* for potential users more individually and more practically and to develop systems for earthquake observations, data processing, and disseminating and receiving information.

Session II: Crisis Management- Urgent Response Works and Restoration (1)

- Disaster Management through Normal-service GIS Based on Spatial-temporal Database, *Shigeru Kakumoto*, Hiroyuki Kameda (Kyoto Univ.)*
- Gathering of Earthquake Shaking and Damage Information in California, *David J Wald,* (Presentation: *William Ellsworth* (USGS)*)
- Modeling of Phase Characteristics of Earthquake Motions in Spatial Field and Interpolation of Observed Earthquake Motions, *Tadanobu Sato* (Kyoto Univ.), Yoshitaka Murono*

Disaster Management through Normal-Service GIS based on Spatial-Temporal Database — For Realizing Risk-Adaptive Regional Management Information Systems (1)

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Abstract

A spatial database based on urban design maps has been developed as a part of our national infrastructure. Thus, GIS appears to be available for normal services offered by municipal governments. However, unless the obstacles to practical usage of systems developed under former projects can be overcome, we may fall into the same mistakes which GIS makes less efficient. To solve these problems, we propose replacing the simple spatial database with a spatial-temporal database. The obstacles preventing municipal governments from using GIS are analyzed, and methods for incorporating RARMIS (Risk-Adaptive Regional Management Information System) into the normal and emergency services are proposed.

Introduction

Following the Great Hanshin Earthquake which hit the southern part of Hyogo Prefecture, geographic information systems (GISs) began to spread as the information processing systems of choice for promptly coping with disasters and emergencies. It has been demonstrated that information requirements are an important interface between physical and social requirements in time of major urban disasters[1]. Expectations have risen for GISs as a means of understanding and analyzing spatial locations as well as temporal changes in relevant information to help deal with disasters. Many government and municipal offices are now considering the introduction of GISs.

Currently, however, car navigation systems, which are a form of GIS, remain exceptional on the whole. Some municipal governments have attempted to improve the efficiency of area management by using GISs instead of paper maps, and have actually, introduced systems. However, very few of them continue to be used. We have summarized the problems involved with municipal GISs based on our experience of developing a GIS in collaboration with Nagata Ward, Kobe City, and using the system to support restoration activities following the Great Hanshin Earthquake.

Needless to say, GISs must be cost effective in comparison with conventional work procedures. Our analysis of past projects should be a helpful in summarizing relevant issues, and thereby facilitate the development of practical GISs.

Concept of a Risk-Adaptive Regional Management Information System (RARMIS)

Based on experience in supporting information processing related to the removal of damaged buildings as well as the subsequent systematic development for the Nagata Ward Office in Kobe[2][3], we recognized the importance of developing an information system which could be used for both daily work and emergency activities. Information systems which are developed exclusively for the purpose of emergency operation are rarely used effectively however practical they are. The number of operators who can use the system may be limited or databases may not always be updated. Rather than such a system, what was used for processing information during the emergency was the system used in daily work which they were familiar with. Thus, we have come to propose the concept of RARMIS, which incorporates functions to cope with disasters into the system for daily work associating emergency activities with normal activities.

Organizations specializing in emergency activities, such as fire departments, are ready to deal with emergencies on a daily basis. However, under the assumption that their facilities are not damaged. For municipal governments, although daily administrative work may appear quite different from emergency work, target areas and data are similar and common databases can be used. The two works look different because they are different in terms of content, volume, and priority. In addition, administrative officials themselves can be sufferers in an emergency.

We propose RARMIS from this viewpoint. Figure 1 shows the concept as designed for a municipality. The three basic features are listed below.

Coordination between Normal and Emergency Functions. It is important that emergency functions are incorporated into a system used under normal conditions. This can be achieved by making the base common to normal and emergency activities available for use at all times, then limiting the use of certain functions of the system or shifting priorities during an emergency.

Time Management of a Spatial Database. Conventionally, municipal governments have managed most of their administrative data mainly names and addresses in text format. Although this format is sufficient for information management under normal conditions, it is not effective in an emergency when it is difficult to locate a place based on address information and when the situation is ever changing. Therefore, it is necessary to manage relevant administrative data as spatial and temporal information with reference to a digital map.

Cross-data Reference among Administrative Departments. Cross-data reference among administrative departments is required in an emergency, but may have to be restricted to protect privacy under normal conditions. To meet this requirement, when information integration is necessary, data must be managed on the same spatial-temporal axis.

Problems Concerning Data Management by Municipalities and Realization of the RARMIS Concept

Time Management of Spatial Objects

Municipal governments keep track of the latest status of an area by writing updated information on paper maps when new roads or buildings are built. Many GISs have updating functions but in reality the local government staffs cannot update the databases within their daily work. In addition, most systems cannot restore previous data once they are updated. For these reasons, the current status or changing situations in an area cannot be followed on a GIS, making it necessary to go back to working on paper maps. Over time, unregistered new information increases and the system will become obsolete. Periodic database updates are merely spending expenses for digitizing changing data registered on paper maps.

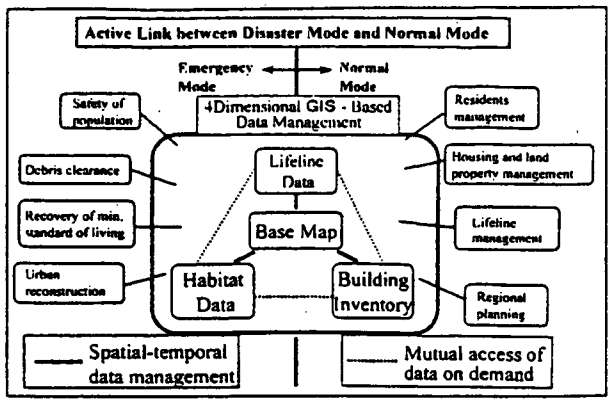


Figure 1.

To solve this problem, time management should be put into practice using objects such as buildings as units. In other words, an object which is represented by $\Sigma(X, Y, Z) + A(\text{Attributs})$ is managed together with time information. Time information includes the generation, extinction, and transitional status of an object. Thus, an object can be described as follows:

$$\Sigma(X, Y, Z) + \Sigma(T) + A$$

Here, topological relations among objects, which have been described as data in many conventional systems, change over time. Thus, by employing a system in which implicit descriptions are used rather than explicit descriptions and in which calculations are made as the need arises, requirements for the description of dynamic changes and topological information are met.

Attribute Data Management

Municipal governments have conventionally managed building and land data as list data which are information based on addresses. In GISs, graphic data written on a map are also linked to address data. Building and land data have been managed as attribute data of the corresponding addresses. Efficiency is an issue and there are also cases when matching proves difficult unless a common address is attached to different pieces of information. After the earthquake in Kobe, before demolishing collapsed houses, attempts were made to locate such houses based on address information. However, it was often difficult to locate such houses because door plates and address boards were missing. In addition, it is confusing when land at a certain address is divided into lots or when several houses are built at the same address.

All attribute data can be managed by matching the data to a spatial-temporal location $(X, Y, Z, \Sigma(T))$. If an address is managed as a piece of attribute data, a new address can be added whenever there is a change.

Cross-Data Reference

Many GISs use closed database structures that are different from one system to another. For this reason, it is necessary to convert data into a public format to allow the exchange of data between different GISs. This means that the same information must be registered redundantly when multiple GISs are employed. It is neither efficient nor practical to share processed data after converting them for different systems. This situation is shown in Figure 2-1. Even if direct reference to other systems is possible, it is difficult to ensure appropriate updating and temporal data management.

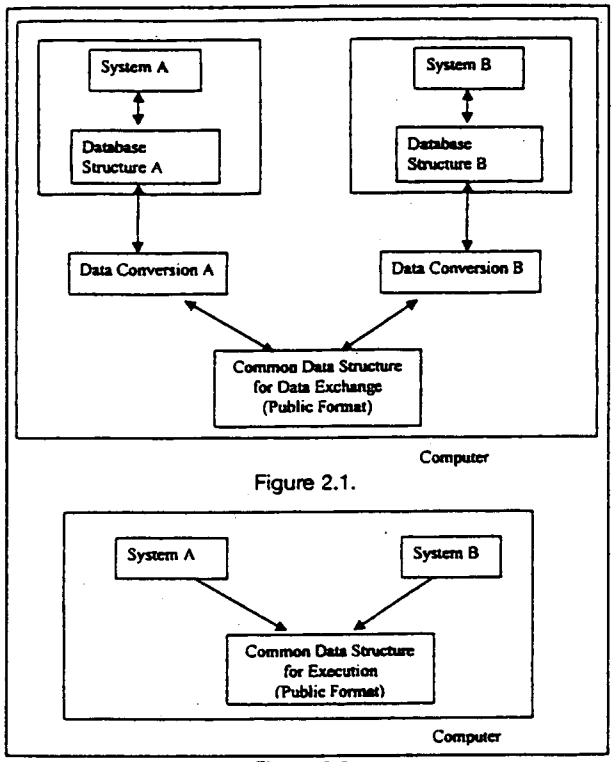


Figure 2.1.

Figure 2.2.

On the other hand, this problem can be solved if data structure ready for practical use is made public as shown in Figure 2-2. Direct reference to common data is assured by ensuring that a new system is compatible with precedent data structures.

Constructing an Integrated Database

Map databases are often created by digitizing conventional paper maps. If different paper maps are used, the representation of the same buildings and lands may also be different. Even if the same scales are used, the same buildings and lands are often described differently on paper maps. If databases are developed in different scales to be used for different purposes, data integration is not possible. As a result, data management becomes complicated and inconsistent. The effectiveness of the database never improves while maintenance costs keep on increasing.

Redundant descriptions of the same object can be avoided by collecting the most precise information from all kinds of map data about the object, for example, a building or a road. This leads to data integration. In this process, topological relations among different objects need to be corrected to eliminate inconsistency.

Integrated map data allows freedom to choose display items and magnification rates in map displays and plotter outputs. Thus, even if the data is described with differing topological precision, a purpose-specific map can be made freely by integrating the data as long as the required precision is ensured for each object.

Realizing Spatial-Temporal Processing and Constructing Municipal GISs

Under the RARMIS concept, it is important that systems used during normal times be seamlessly available as anti-disaster systems in an emergency.

To analyze changing situations in emergency situations as well as processing transfer notifications during normal times, an integrated database is necessary in which spatial-temporal data processing and descriptions of changing objects are unified so that changes in information are better managed.

Here, as temporal information, each object's generation and extinction time spans are described as shown in Figure 3. In addition, the start and completion of the generation and extinction time spans are specified. Accordingly, four kinds of time information are assigned to each object, which can be represented as $\Sigma(T)$.

Implicit topological descriptions are used for calculating required topological information as the need arises. Here, each polygon is described as a combination of an outline with a designated line type and representative points in the polygon. If the coordinates of a point at which outlines intersect is calculated in advance, the calculation amount for the polygon can be reduced. The effect of quantum errors regarding the intersection point can also be avoided. In addition, since topological information is calculated when required, there is no need to store a large volume of topological information.

Future Directions

It is necessary to facilitate the development of normal-time systems and spatial databases that can be used on a full-scale basis in an emergency by municipalities. Ideally municipal governments should publish their spatial databases together with public data formats for practical use, as well as data updated subsequently for internal use. The ISO/TC 204 promotes the standardization of practical data formats among map database

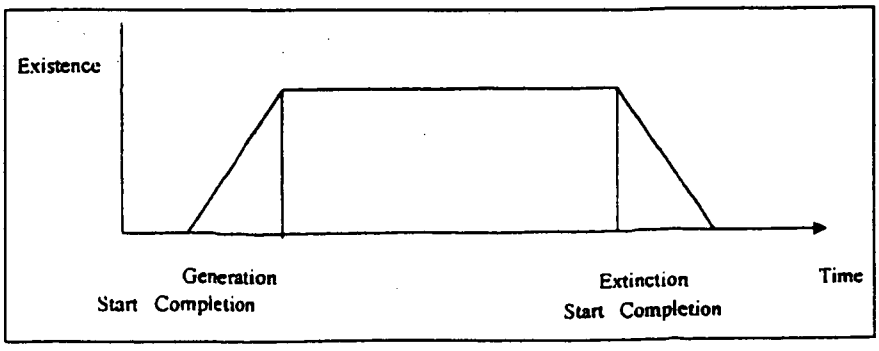


Figure 3.

providers and car navigation manufacturers. Since specifications for this attempt have been developed, certain results can be expected. If data are to be provided in the forms of plotted charts and electronic media at relatively low prices, local residents are willing to use them. As the number of users increase, data errors will be pointed out, which will lead to improvement in data quality. If resellers are also allowed to sell data by paying a fee, the development of value-added data will be facilitated. Moreover, common data sources will be used, which ensures data consistency.

By sharing what is virtually a common spatial database, anti-disaster systems can be established to cope with unexpected events.

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Biographies

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Michinori Hatayama was born in Osaka, Japan on 18 September 1968. He is a reserch fellow of the Japan Society for the Promotion of Science and belong the Department of Computational Intelligence and Systems Science, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology. His current research interests lie in robotics, rescue support systems in fire and disaster, and geographic information systems. Mr. Hatayama is a member of the Robotic Society of Japan, the Information Processing Society of Japan, and the GISA among other organizations.

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Development of Rescue Support System and its Application to Disaster Drill in Nagata Ward, Kobe City For Realizing Risk-Adaptive Regional Management Spatial Information System (2)

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Abstract

Through the experience with disaster and recovery support activities obtained as a result of the Great Hanshin Earthquake, the information systems to be used in times of disaster must have the following three features: 1) continuity between normal times and times of emergency, 2) decentralized independence, and 3) integration of space and time information. To achieve these capabilities, we have proposed, as a concept, the Risk-Adaptive Regional Management Information System (RARMIS). Then, to actualize this concept, we have developed DiMSIS-EX, a software component based on multi-dimensional spatial temporal information system. Here we will report on effective information processing in emergencies using a case study for the disaster drill in Nagata ward, Kobe city.

Introduction

The Great Hanshin Earthquake that rocked southern Hyogo Prefecture on January 17, 1995, left enormous scars throughout the stricken area. This compound urban disaster brought into clear relief the vital importance of information issues (in addition to the physical and social issues) in any disaster prevention program [1]. Thus, the earthquake focused considerable attention on disaster prevention and disaster response support systems utilizing the Geographic Information System (GIS). However, nearly all of these systems are specifically emergency systems with little or no relationship to the information systems used in normal times. Therefore, they would be difficult to utilize fully in an emergency.

In this article, we will report on the disaster response support system developed

through experience with disaster and recovery support activities obtained as a result of the Great Hanshin Earthquake. We will describe the basic RARMIS concept, a system that allows practical utilization immediately after any disaster. We will report on effective information processing in emergencies using a case study for the disaster drill in Nagata ward, Kobe city.

The Risk-Adaptive Regional Management Information System

None of the information in emergencies described has meaning in and of itself. All such information takes on value only through correspondence to a given place (location). Therefore, the ideal disaster prevention or disaster response support system must be built on a foundation of geographical information system, and it must be able to correlate all information to specific locations.

Requirements of a Rescue Support System

The disaster recovery support activities that took place after the Hanshin Earthquake demonstrated that, to be practical and helpful in the chaos and initial operation stages, the system must satisfy the following five requirements[2].

- It must be portable.
- It must not require an expert.
- It must be a system that is also used in normal times.
- It must allow the integration of information in multiple systems.
- It must allow the building and updating of an area database.

Approach to Building a Rescue Support System

The rescue support system for processing information in the chaos and initial operation stages of a disaster must have GIS information at its foundation and must meet the five requirements described in 2.1 above. To meet those requirements, we have proposed a system with the following three features[3].

Continuity between emergency and routine use (an operability issue). The system used in emergencies and the system used in normal times should not be considered different systems. Some of the functions and data in the routine system should be used to do effective information processing in times of emergency.

Independence and decentralization (a technical issue). All the information should be stored in portable notebook computers. Thus, each computer becomes an independent system that can be operated alone, as opposed to a client-server system which is highly vulnerable to large-scale disasters. The system also must allow decentralized processing and trading of information between systems to keep up with changes.

Integrated space and time information (a technical issue). The system should be easy to update every day, and should always have the latest geographical data. Time axis information should be integrated into the space information, thus leaving a record of events and making it easy to reproduce moment by moment changes.

A system with these three features is more than a system for managing only disaster response support activities, and these features are available in the system we call RARMIS (Risk-Adaptive Regional Management Information System). This system is positioned as a disaster response support system for use in times of emergency. It comprises a rescue activity support component, which summarizes and manages information mainly during the initial operation stage, and a recovery management component used during the recovery stages (Fig. 1).

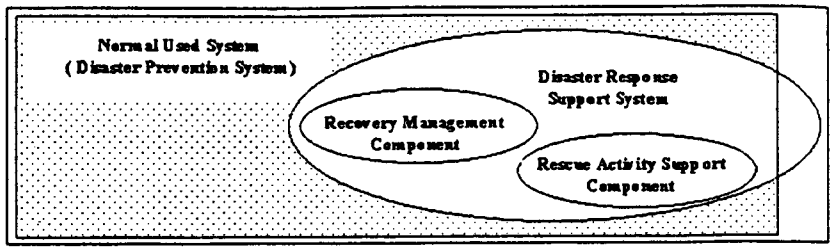


Figure 1.

Processing Information Immediately after a Disaster

Information required immediately after a disaster is collected at anti-disaster headquarters (including the headquarters on the site), the disaster-stricken site and evacuation centers (including hospitals). By exchanging the gathered information among these places without accumulating it at one site, its value is multiplied (Fig. 2). Information processing technology can be used effectively in the following operations.

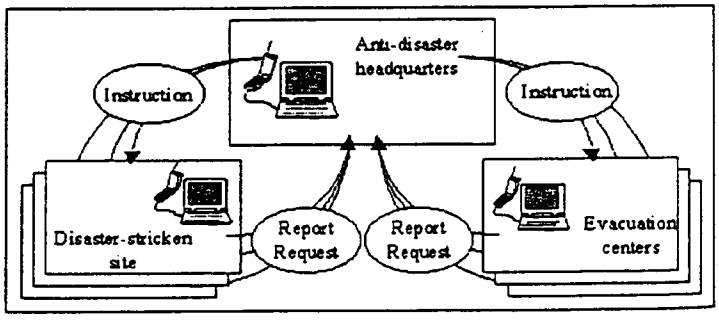


Figure 2.

Disaster-Stricken Site

- Monitor the disaster and report the results to anti-disaster headquarters.
- Establish working sites and report the location of the sites to anti-disaster headquarters.
- Secure workers and make a request for equipment required for work.
- Identify residents who are not yet verified.

Evacuation Centers

- Take a roll call of evacuees and report it to anti-disaster headquarters.
- Notify evacuees of the conditions of the disaster-stricken site.
- Check the other refugee centers' condition.
- Make a request for necessary goods.

Anti-Disaster Headquarters

- Acquire the updated geographical data.
- Establish the danger zone and notify it.

- Instruct the disaster-stricken site on the arrangement of workers (fire fighting, police, etc.).
- Select evacuation routes and evacuation centers, and notify it.
- Instruct workers on the work carried out in the disaster-stricken site.
- Totalize and analyze the disaster's magnitude and transmit the information to outside organizations.
- Totalize information on evacuees and transmit it to outside organizations.
- Analyze the data supplied by outside organizations (as required).
- Respond to inquiries from the outside.

Outline of System Development

Software, which can process the operations described in 3, was created by using a four dimensional (space + time) GIS component DiMSIS-Ex that has been developed since immediately after the disaster in order to realize the RARMIS concept. This application operates on Windows 95, and its structure is

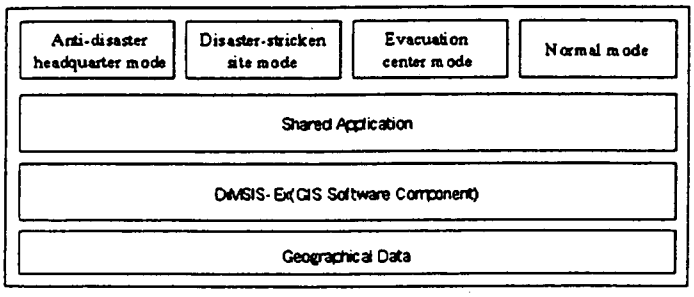


Figure 3.

shown in Fig. 3. This figure shows that GIS component DiMSIS-Ex deals with map information such as vector search and plotting. The shared part of the application, such as setting conditions for plotting/search and map enlargement/reduction, is commonly used by all applications.

Data can be exchanged between each systems by cutting out, transmitting, and receiving the changes in information using communication and electronic mediums. This enables the developed system to be a perfectly autonomous distributed system.

Application to the Comprehensive Emergency Drill in Nagata-Ward

Outline of the emergency drill

Date: 10:00-11:00, Wednesday, June 4, 1998

Assumed disaster: A seasonal rain front stagnates all over western Japan. In the southeast part of Hyogo-prefecture, it has been raining since June 1, and the amount of the total rainfall reached more than 300mm. A local downpour started from around 5:00 A.M. on June 4 in Kobe area, and rainfall of 150mm in city area and 200mm in mountain areas were recorded. As severe damages such as collapse of houses and damages to roads were anticipated due to landslides, the head of Nagata-ward established the anti-disaster headquarter at 10:00 A.M..

Details of the drill:

- Initial stage management drill
- Evacuation/rescue drill
- Rescue operation/relief activities
- Life line temporary repair drill
- Fire-fighting drill

Positioning of the experiment: The developed application was applied to the initial stage of management, evacuation and rescue drills.

Created data

Risk-management type system is created on the condition that the information accumulated in the normal state is used as effectively as possible at the time of a disaster. In this experiment, the following data was used as attribute information.

- Designated evacuation center within Nagata-ward (all centers)
- Areas facing the danger of flooding within Nagata-ward (all areas)
- Information on the resident living around the selected danger area
- Normal state in the vicinity of the selected area (static/dynamic image)

Experiment and study

(1) Configuration of hardware and workers for the experiment. For the experiment, notebook-sized personal computers with the system installed and portable telephones used for data communication were prepared at the anti-disaster headquarters and evacuation centers (two locations), and the disaster-stricken site (two locations). It is based on the assumption that desktop computers may not be available in the case of a large-scale disaster, considering damages to equipment and a problem in securing power source. Portable telephone was selected in assumption that wire communication may not be possible. Systems of the anti-disaster headquarter and the disaster-stricken site were operated by three government employees of Nagata-ward, and evacuation center by two local residents.

(2) *Details of applicable experiment.* The following experiments were performed according to the drills.

Anti-disaster headquarters.

- Sort out the results of danger zone patrol.
- Refer to the normal state of evacuation advice area.
- Refer to and receive the condition of the disaster-stricken site.

Establish evacuation routes.

- Refer to and receive information on evacuees.
- Prepare disaster status report (HTML).

Disaster-stricken site

- Correspond the pictures of the site with the position and transmit the data to the anti-disaster headquarter.

Evacuation center

- Verify evacuees and Transmit the data to the anti-disaster headquarter.

(3) *Experimental results and problems.* The developed system demonstrated its effectiveness in rescue operations immediately after the disaster. However, it became obvious that various problems would occur in practical use. The following items should be studied in the future.

Establishment of rules regarding information collection and

delivery. Information is collected in various places at the time of a disaster. Work efficiency can be improved in each place by efficient collection and delivery of information.

Multiplicity of evacuation center/disaster-stricken site. It is easy to see that, as the scale of disaster becomes greater, the number of evacuation centers and stricken areas will be increased.

Improvement of user interface. It is important to build the user interface which can be used without reading manuals, as human resources are limited at the time of an actual disaster.

Conclusion

This experiment made it clear that the most important point in building the status management system used immediately after a disaster is to realize distributed processing.

It is still fresh in our memories that wire communication was unusable at all for over several days after Hanshin-Awaji Great Earthquake. It is obvious that, under these circumstances, how fast the most effective information can be exchanged among headquarters, disaster-stricken site and evacuation center influences the efficiency of rescue operations and relief activities.

In addition, how to secure power source and work environment in rainy weather remain as physical problems. Although Nagata-ward actually suffered from heavy rain brought by a typhoon after this emergency drill, the system was not available despite of the issuance of emergency warning. To solve these problems is another challenge in developing a rescue operation support system.

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Biographies

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Development of Disaster Management Spatial Information System (DiMSIS)

Based on 3-dimensional spatial temporal Geographic Information System (GIS), and its Application to Administrative Database of Local Government (From Experiences in the Hanshin-Awaji Earthquake)

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Abstract

An examination was made on the characteristics of disaster information by organizing the data of the disaster of the Hanshin-Awaji Earthquake with the use of the Geographic Information System (GIS). It was revealed that disaster information need to be controlled as special positional information because, in the confusion of the disaster-stricken area, it was difficult to ensure addresses. It was also revealed that continuity is important between the system used at normal times and that of emergency, and that, in order to put it into practice, time management of data is effective. A regional geographic database can always maintain the latest data through the renewals incorporated in the normal duties and can immediately respond in case of emergency. It also saves expenses greatly by dispensing with costly periodic renewals.

Introduction

The Hanshin-Awaji Earthquake victimized more than 6,300 people as well as causing damage to a large number of buildings. There was also great confusion in gathering, transmitting and organizing the information of the disaster. From the experiences of the disaster this time, a need was pointed out to efficiently deal with a huge amount of disaster data so as to be promptly prepared in the initial stage in case of a tremendous urban catastrophe. Great expectations are therefore placed on the GIS which, as a possibility, is capable of coping with this need.

After nearly two years since the great earthquake, local governments are examining the introduction of a disaster prevention system on the basis of the GIS.

This paper examines the system that is capable of responding to the actual requirements such as inquiries after person's safety, classification of damaged state, and utilization of stored data for disaster prevention. At first, an experiment was made to expand the DiMSIS, which has been developed to support the classification of disaster data and the application for the removal of collapsed houses, so that it may be applied to the task of a local government both at normal times and in emergency. Actually, the system was used in a disaster prevention drill and proved to be effective and practical.

On the basis of the experience in Nagata Ward, Kobe City, this paper presents the ideal way of an administrative database and a system as it ought to be prepared at normal times.

Characteristic of Disaster Information and Need of Computerization:

In the disaster this time, the gathering of information was relied mainly on paper and

pencil. Evacuees wrote their names in a book; and memos were used in the survey of stricken facilities. As a means of communication to the victims, posted bills and bulletins played an active part. Inevitably, the sorting and processing of information was done through transcript from paper to paper.

It was far from the processing utilizing latest computers and communication means, making little difference from the situation in the Great Kanto Earthquake of 1923.

The necessity of computerization depends on the density of population and the extent of damage in the disaster-stricken area. In a densely populated giant city, disaster information is complicated and numerous with the readjustment hardly dependable on people's memory and paper. Especially, the number of urgent cases inquiring after persons' safety will be enormous, which also spread spatially in a wide area. Extracting the missing will require computing in a short time the safety information of residents evacuated in plural shelters.

After that, with the removal of dangerous objects, collapsed houses, etc., grasping of daily situation will be indispensable. Issuing various certificates will also require the processing of information in a large number of cases.

A disaster prevention system is often regarded as a system exclusively used for that purpose. However, it can not be expected that a system unused at normal times is comfortably used in case of emergency. Moreover, there is no guarantee that a special disaster prevention system is free from breaking down or accessible when needed. Therefore, it is required that the computers used at normal times are also used as they are in emergency as well. Such computers are desirably those personal computers that can be commonly operated by a great number of people.

GIS for Disaster Management as it Should Be

In applying the GIS to disaster management, contents for processing may change as time elapses after a disaster. The information system to control regional information can be classified into the following five phases based on the purpose in the lapse of time after the disaster. The flow is shown in Fig. 1.

1) Confusion stage (a few days immediately after disaster): Inquiry after safety, rescue support, allocation of shelter, etc., are required. The disaster information is transmitted outside the stricken area through a narrow communication network.

2) Initial stage (several weeks after the confusion stage):

Classification of damaged condition in houses, roads and life lines, and removal of dangerous objects are required.

3) First half period of restoration (several months after the initial stage):

Classification of damage information, support for forming restoration plans, etc., are required.

4) Latter half period of restoration (several years after the first half period): Disaster analyses and support for drafting redevelopment plans are required.

5) Normal times (after completion of restoration): Support in grasping movement of residents, supervision over fixed properties such as houses and lands, maintenance of roads and public facilities, etc., are required. By analyzing the regional situation, city planning is made for constructing a safe town with the basic data stored for disaster prevention.

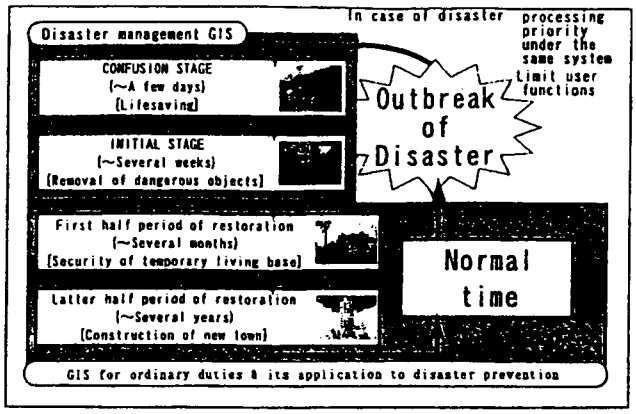


Figure 1. Flow of recovering process after disaster and role of GIS.

If information management by addresses and names is performed at normal times of the phase 5, the GIS with special specifications will be needed in the Phase 1 and 2, namely, GIS for disaster management.

In order to use an information system in case of disaster, it is essential that the system is the one used commonly between ordinary duties at normal times and emergency duties at the time of disaster. At the time of disaster, efficient operations are expected for the functions necessary for taking counter measures; any other extra functions only reduce the operation efficiency. Accordingly, on the basis of temporal and spatial information management, a integrated system is expected to be built, which is capable of handling disaster information, by employing a system structure that contains the addresses and names of the residents, and by making such responses in emergency as partially limiting the normally used functions.

As shown in Fig. 2, even if a costly exclusive system is built as a disaster prevention system, "unexpected situations" take place in most cases, preventing the demonstration of the functions originally assumed. A large-scale disaster may destroy disaster prevention systems as well as making victims out of the operators in charge. Under such circumstances especially, a fully functioning disaster prevention system is necessary. In addition to the problems of hardware for the system, an examination is essential on the software, deciding the way that a method of managing regional information should be. A processing method is sought after in which disaster data processing is grasped as a continuity to ordinary duties with emphasis placed on cost effectiveness. It seems to be the answer to take the disaster as spatial information. With computers used, it is possible to build an information system that is provided with a three-dimensional space containing names and addresses and that is also capable of time description. The requirements for this system may be summarized as follows:

1) Mobile information system: It need to be workable even under an unexpected unstable operating environment. Additionally, it should be capable of interlocking with stationary systems if situation permits.

2) System operable by non-specialists: Human resources being limited in a stricken area, a system is desirable that is easy to operate by anyone having experience in using a calculator.

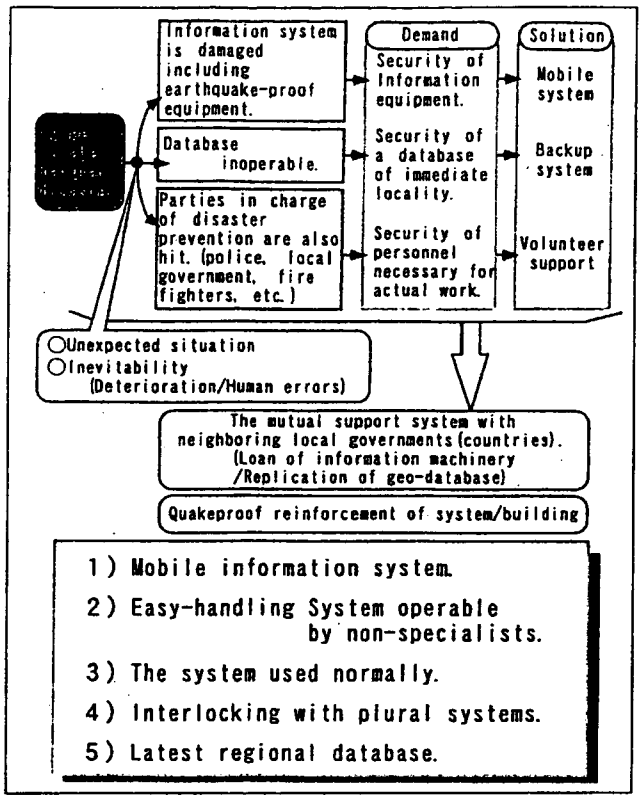


Figure 2. Requirements for disaster mangement GIS.

3) System used in normal times: A system unusable for ordinary duties is economically inefficient and is limited in the adaptation to circumstances and the conformity to ready use.

4) Interlocking with plural systems: A system is desired that is self-contained distributed type and usable for coordinated operation.

5) Latest area database:An area database is required that is controlled by each local government. The storage of backup data may be carried out jointly with other local governments. For example, such an idea seems to be effective as database is mutually maintained between local governments with sister-city affiliation and mutually supported in case of emergency.

These requirements can be satisfied with a system whose basis is personal computers used in ordinary duties. Personal computers are such that a mobile system in series has been marketed and that a number of people have experiences in using it. In municipal offices for example, the introduction of personal computers has been well under way so that the continuity may be advantageously maintained between normal situation and emergency.

GIS for Three-Dimensionally Spatial and Temporal Management

The purpose of the geographic information processing is to grasp the situation of the stricken area and to enable proper judgment. For that purpose, a conception of information processing is necessary that is beyond a map premised on a planar description.

In Fig. 3, the conception of a system is shown which is free from the descriptive restrictions of a map and which is capable of utilizing computers. The characteristic of this method is the structuring of a model of the actual area (area model) in a computer. In other words, the method is to express the area condition with numerical data that can be processed by a computer. The actual world is spread in the three-dimensional space and variable in time. Therefore, street margins or the positions of houses for example are recorded on their three-dimensional loci, while their numerical values are expressed as survey data with required precision regardless of the reduced scale of the map.

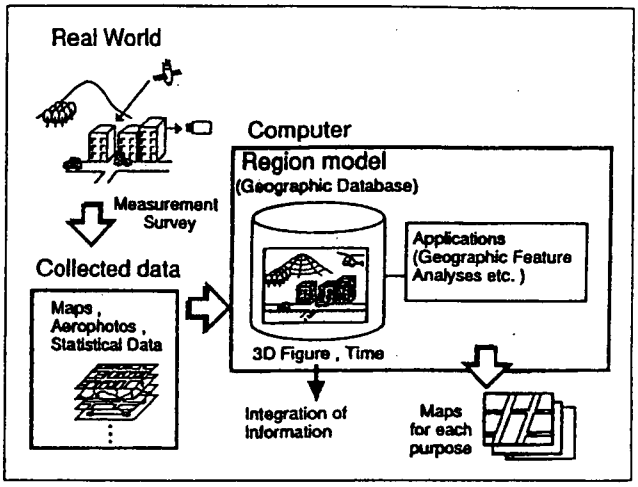


Figure 3. Conception of Threee-dimensional spatial temporal GIS.

In order to build this area model, the map prepared by surveying the subject area can be used as a good design drawing. In addition, various statistical data, survey data, land registers, etc., are also integrated as the information descriptive of the model. Under such integrated information processing, the following added values may be anticipated:

1) Since this model is provided with the subject area numerically described, it is possible to output a map separately by purpose through a virtual graphic, to analyze or express the topography three-dimensionally, and so on. Further, comprehensive management and comparison are possible concerning the underground public facilities or the condition of the stricken area, etc.

2) Through the integrated management of the information which is conventionally overlapped in multiples, the mutual utilization of the information is made possible, enabling the elimination of data discrepancies, or reducing the amount of information to be managed. As a result, an efficient processing is possible with a small hardware.

3) It used to be necessary to renew the database in an expensive way through the duplication of each original drawing. In the new system, the duplicating renewal work is eliminated, greatly reducing the man-hour of the work.

4) The model of each area is described in consideration of a rotary ellipsoid (spherical body) for the specified area; therefore, consistency is feasible with a measured data such as satellite photographs.

Time Management for Spatial Database

The maintenance control of the spatial data describing the areas can be realized through the time management for each object. If each object is under the time management, the data can be renewed as a change takes place perpetually.

At the time of confirming a construction, a person in charge in a local government can easily input the subject housing data. Renewal in real time is possible unlike the conventional paper map base in which periodic renewal was indispensable manually by specialists. Moreover, as a map required at a point in time can be outputted at the scene of service in a local government, the maintenance of paper maps is no longer necessary. Input errors by a field worker can be easily corrected by reversing the time for a little while back and confirming it. If need be, only the changed portions may be matched to the aerial photograph so as to assure the positional accuracy.

The initial database can be prepared with more accuracy correlatively by inputting the conventional survey data integrally. Furthermore, it is expected that objects written on the paper map in a number of duplications can be replaced with one only inputting, greatly saving manpower. The positional accuracy may be increased with each integration of data. It is necessary to have a "growing database" with history efficiently maintained both in positional accuracy and contents.

If the database is such as renewed through daily duties, it will be provided with a description immediately before the outbreak of emergency. In addition, the exchange of information is easily realized by recording rapid changes and by mutually comparing various data, simultaneously eliminating the duplication of data input.

Development of DiMSIS

DiMSIS has been developed for the purpose of organizing disaster data and demonstrated its effect for example on accepting applications for demolition and/or removal of collapsed houses. This system had prospects of being applied to house information management at normal times. Accordingly, the system was expanded so as to be capable of coping with emergency. An "emergency mode" was provided in the functions at normal times controlling fixed properties like houses and lands. The emergency mode is made ready by giving an instruction through icons normally selectable. It is so structured that, with the emergency mode actuated, ordinary requirements is processed by operating in accordance with the guidance for the operation environment.

In general, the purpose of the system is different depending on where it is used.

1) Headquarters for countermeasures: It is required to judge the overall situation and to give instructions to the field. The judgment of the situation must be made in reference to the changing situation and on the basis of the data gathered at normal times including the characteristics and dangers of the places.

2) Shelters: In the shelters, it is necessary to call over the names of the evacuees and to extract the vacant zones with no evacuees. For that purpose, it is effective to mark on the map automatically the houses confirmed by the names or the locations and to make a list.

3) Actual field: In the stricken field, gathering of information and report to the headquarters are required. In order to gather the changing information, it is effective to utilize a graphic data related to positions. Accordingly, positions for photographing are inputted in the map. Since instantaneousness is more emphasized than the picture quality, a digital camera is effective.

The effectiveness of this processing has been proved in the disaster prevention training (June 12, 1996) in Nagata Ward, Kobe City.

Conclusion:

The GIS is desired which takes the disaster information processing as continuity to normal duties and which attaches great importance to cost effectiveness.

The answer conceivably is to deal with disaster as spatial information. The area management by the names and addresses is a rational system based on the know-how for many years. In the information management premised on the use of electronic information equipment in addition to paper, it is possible to build a temporal and spatial information system incorporating the above conventional information system.

Problems have been pointed out such as the method and cost of preparing geographic data. The basic problem is that the conventional information processing by the map is on the assumption that the database is periodically renewed so as to reconstruct the information stored until that point. This problem can be solved by pointing to the structuring of the GIS which is capable of storing area information as the temporal and spatial information through normal duties. The prospects are bright that this next generation type GIS can be fully operated by inexpensive personal computers with the preparation of spatial data realized through the integration of information without a great deal of special cost.

It is essential to recognize that the information processed as disaster information is equivalent to that of normal times. Inquiry after the safety of people corresponds to the move management of the residents; removal of collapsed houses corresponds to the control of industrial waste and the management of fixed properties; disaster prevention plan corresponds to city planning, etc. Thus, the processing of disaster information is possible that is directly connected to the normal duties and ordinary use of a local government.

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Gathering of Earthquake Shaking and Damage Information in California

David J. Wald [1)]

ABSTRACT

We report on several systems now in place in California for rapid gathering and transmission of earthquake shaking and damage information, and report on recent results from the magnitude 7.1 1999 Hector Mine earthquake in southern California.

KEY WORDS: ShakeMap, Community Internet Intensity Map, Earthquake Damage, Shaking

1. TriNet "ShakeMap"

The U.S. Geological Survey, Caltech, and the California Division of Mines and Geology has been running and is further deploying TriNet, a new generation seismographic network in southern California. TriNet is a multipurpose network to record and analyze earthquake ground motions, to distribute that information quickly, to improve our understanding of earthquakes and their effects, to contribute to improving building codes and structural design, and to facilitate emergency response in cooperation with other agencies.

As of October, 1999, there were 120 USGS-Caltech real-time stations online and nearly 130 CDMG dialup stations; in all there will be approximately 670 TriNet strong-motion stations in the next 3 years (see Mori *et al.*, 1997). Within the first minute following the shaking, ground-motion parameters are available from the USGS-Caltech component of the network and within several minutes most of the important near-source CDMG stations contribute. A more complete CDMG contribution is available approximately within the first half hour. Initial maps are made with just the real-time component of TriNet, but they are updated automatically as more data are acquired. Parametric data from the stations include peak ground acceleration (PGA), peak ground velocity (PGV), and peak response spectral amplitudes (at 0.3 sec, 1 sec, and 3 sec).

One critical product of TriNet is "ShakeMap". Rapid (3-5 minutes) generation of maps of instrumental ground-motion and shaking intensity is accomplished through advances in real-time seismographic data acquisition combined with newly developed relationships between recorded ground-motion parameters and expected shaking intensity values (Wald *et al.*, 1999a). Estimation of shaking over the entire regional extent of southern California is obtained by the spatial interpolation of the measured ground motions with geologically based frequency and amplitude-dependent site corrections. Production of the maps is automatic, triggered by any significant earthquake in southern California (see Wald *et al.*, 1999b, for more details).

Maps are now made available within several minutes of the earthquake for public and scientific consumption via the World Wide Web. We are also working with the state of California Office of Emergency Services (OES) to develop and test dedicated communications for emergency response agencies and critical ShakeMap users. The OES will distribute ShakeMap via the Response Information Management System (RIMS), a Lotus Notes based system. In addition, the distribution of ground motions on the ShakeMap grid will be sent to OES as input for loss estimation using established tools (HAZUS and EPEDAT). TriNet is also testing dedicated distribution of ShakeMap data files for use by utilities for examining effects on critical facilities and coordinating post-earthquake response efforts.

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The TriNet system was very recently tested by the October 16, 1999, magnitude 7.1 Hector Mine earthquake. Fortunately, the earthquake occurred in a remote area of the Mojave Desert, so little damage and few injuries were reported. However, it was a good opportunity to evaluate the network. Since the event occurred in a sparsely populated region, the spacing of seismic stations in the near-fault region was sparse. Effectively, this allowed us to evaluate the performance of ShakeMap under conditions that might be expected for a more urban earthquake for which near-fault stations might not immediately report due to power or communications failures.

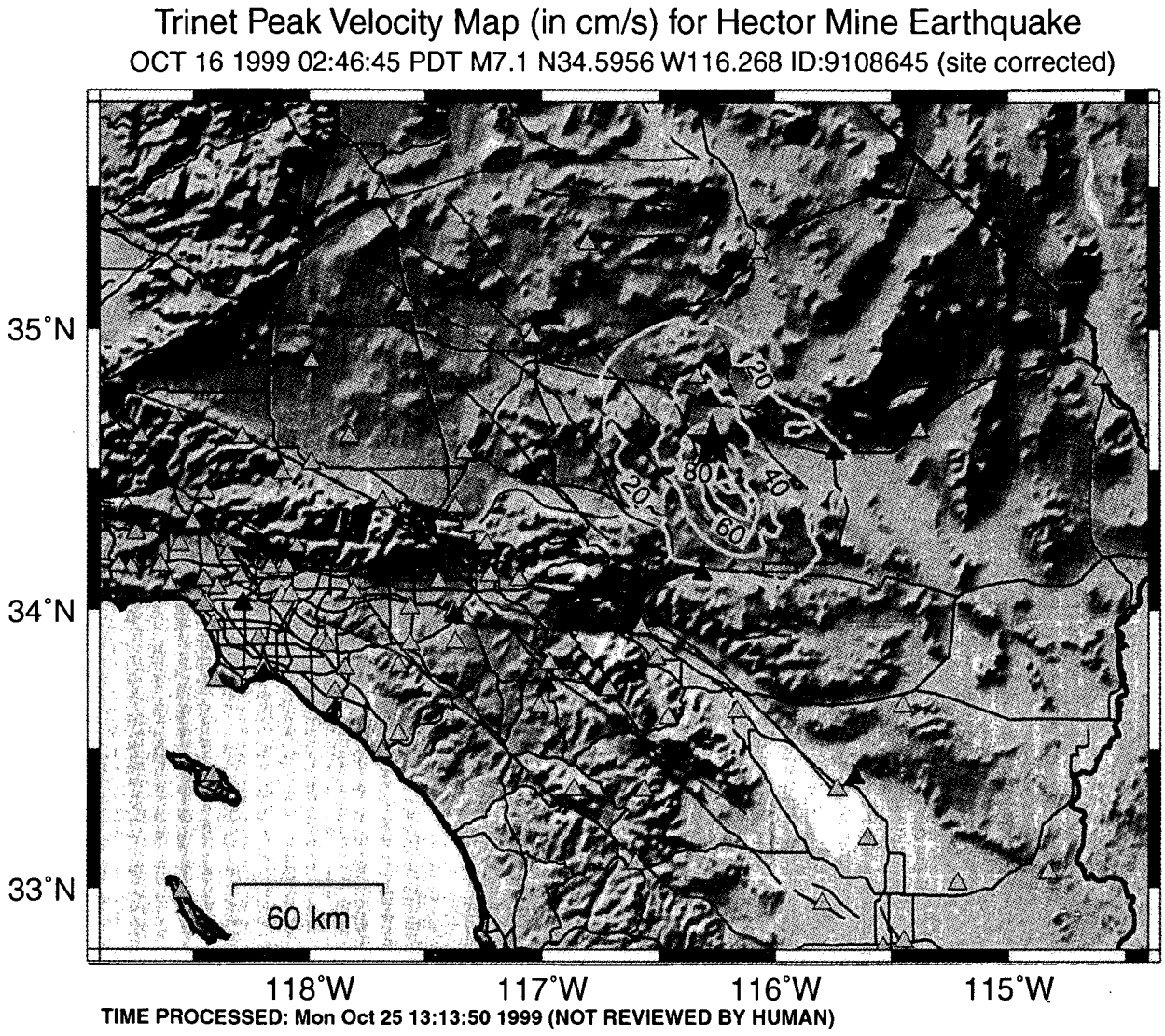
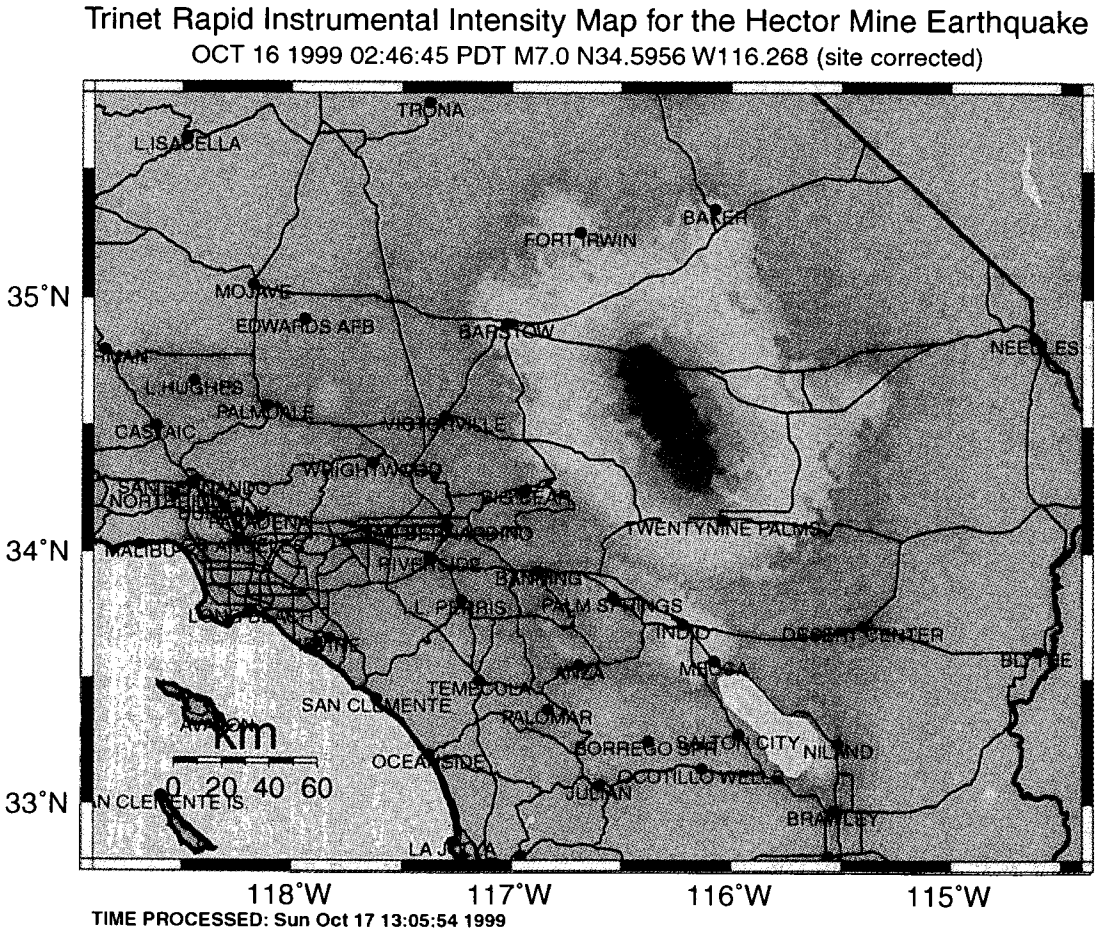


Figure 1. TriNet ShakeMap for the 1999 Hector Mine, California, Earthquake. Triangles show station locations; the epicenter is show with a star, and contours show peak ground velocity in cm/sec. Red lines depict faults; black lines indicate highways.

The TriNet real-time system determined a magnitude (Energy magnitude) of 7.0 within 1 minute of the event, and ShakeMap was successfully produced and distributed within 4 minutes (see Figures 1 and 2). Initially, ShakeMap ground motions in the near-source region were estimated using ground motion

regression from a point location at the epicenter. Later, as information about fault dimensions became available (in the form of aftershocks, source rupture models, and observed surface slip), the fault location and dimensions served as the basis for ground motion estimation in the near source region.

Several utilities, including Southern California Edison, and Caltrans made use of the maps for post-earthquake resource allocation, and although web access to the ShakeMap site was extremely heavy, the server remained operational with only limited interruptions. Careful evaluation of the system and communication load and performance is still underway.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII			

Figure 2. TriNet Rapid Instrumental Intensity of the 1999 Hector Mine, California Earthquake.

2. Community Internet Intensity Maps ("Did You Feel it?")

The U.S. Geological Survey is also experimenting with a new system of Internet-based post-earthquake information gathering, which focuses on shaking intensity and damage. Automatic, rapid generation of seismic intensity maps is accomplished by collecting shaking and damage reports from Internet users immediately following felt earthquakes in California (see Wald *et al.*, 1999c, for more details).

Intensity survey questionnaires, contributed from members of the community using forms made available through the Internet, are converted to numerical intensities based on an algorithm modified from Dengler and Dewey (1998). As information is received and processed through our World Wide Web site, the associated Postal ZIP code region is color-coded and an interactive, web-based, regional map of the seismic intensity distribution is updated. This application allows for much more rapid generation of intensity maps than the standard, labor-intensive practice of mailing intensity surveys and manual processing and interpretation.

Evaluation of this automated process has shown it provides robust results for questionnaire responses from recollected experiences of the 1994 Northridge earthquake as well as for several recent smaller earthquakes felt in southern California. This approach can be implemented on a regional or national scale, and we are in the process of coordinating such an effort. In the meantime, a magnitude 5.0 earthquake on August 17, 1999 occurred near Bolinas, California (just north of San Francisco) and we successfully logged and mapped over 1,100 responses.

Quite astonishingly, there were nearly ***25,000*** responses for the recent M7.1 Hector Mine earthquake (Figure 3). Nearly 5,000 responses were received, processed and mapped within the first 6 hours; 10,000 were processed within the first 12 hours. We are still evaluating the robustness of these voluntary responses and we will compare them to more traditional Modified Mercalli intensities after they are later determined.

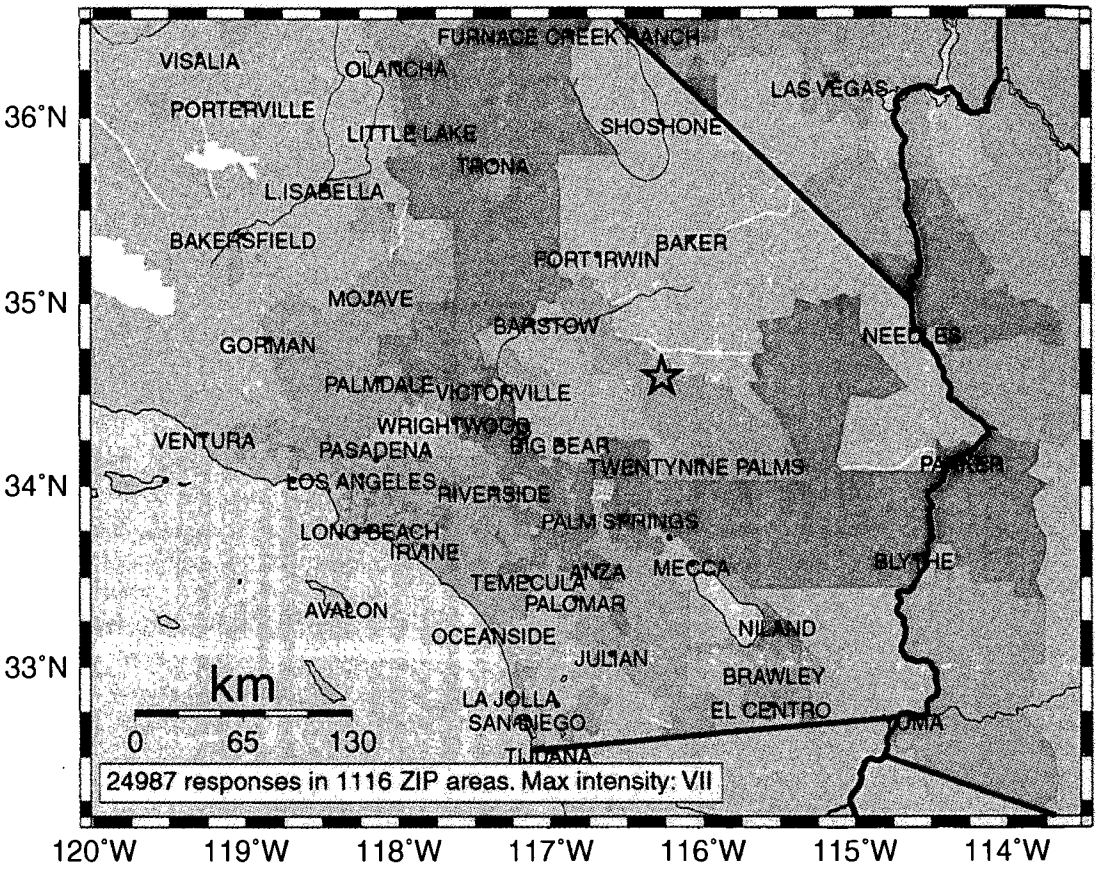
The resulting intensity maps serve several purposes. They provide a very rapid means of displaying the pattern of shaking independently of strong-motion seismographs. With sufficiently distributed responses it has been shown (Hales and Dengler, 1998) that even small-scale variations in intensity can be recovered. In addition, once fully calibrated, voluntary Internet contributions may significantly reduce the manpower required to collect intensity observations and interpret questionnaires as done traditionally. Finally, the interactive nature of the web-based questionnaire and mapping provides an unprecedented avenue for community involvement. The interactive Web site provides an avenue for feedback among the communities affected by earthquakes, the scientists studying their effects, and agencies responding to the disasters. With continued outreach and development, these maps will improve public understanding of the effects of earthquakes.

Hence, one unique aspect of this Community Internet Intensity System is that it fundamentally relies on and results in strong community involvement. The long-term hope is that such involvement will enhance the understanding of the variations of shaking and damage from earthquakes, and a sense of appreciation from the general public of the need of dense instrumentation to adequately and robustly record such data for damaging earthquakes.

Several factors make southern California a prime location for initiating, validating, and testing such a system. The relatively frequent occurrence of felt earthquakes and a high density of Internet users makes this area a natural laboratory. The existence of TriNet allow us to directly compare the Community Internet Intensity results with the seismically-determined location and magnitude of events and with the ground motions and instrumental intensities for the same earthquakes.

Initial comparison for intensities derived from ShakeMap (Figure 2) and the Community Internet Intensity Map (Figure 3) indicates favorable agreement with the exception of the near-source region, which is poorly sampled both in terms of seismic instrumentation as well as from exposed population. The reported Internet intensities are lower than the instrumental intensities primarily due to the fact that few of the personal observations are near the fault. Hence, the *average* reported intensity over ZIP codes in the near-source region (which are large in area in this sparsely populated region) is lower than it would have been given dense observations near the rupture *and* with smaller ZIP areas. In contrast, the near-fault

ShakeMap insturmental intensities are determined primarily from existing ground motion regressions because there are no near-source recordings in this sparse region. Since these motions are estimated on a dense grid, which includes the near-fault locations, high ground motions are estimated, and the corresponding intensities are likewise high.



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Figure 3. Community Internet Intensity Map of the 1999 (M7.1) Hector Mine, California, Earthquake. This map summarizes nearly 25,000 reported intensities in 1,116 Postal ZIP codes.

There are several ways that instrumental-derived intensities and more traditional observational intensities compliment each other. The Community Internet Intensity Map (CIIM) provides direct damage assessment; ShakeMap provides inferred seismic intensity from ground motion recordings. Having both data sets for an earthquake allows for improvement of relationships between observed damage and instrumental recordings. The CIIM can also provide information where no stations are present. This is the case for most of the United States (and much of the world) and hence, CIIM may add thousands of data points for both scientific and sociological analyses. However, *only* ShakeMap provides robust rapid response; CIIM can not be considered as reliable post-earthquake information (unless, perhaps, if it is the *only* information).

Nonetheless, only CIIM provides the human element: allows for interaction with community and participation in the scientific process.

"ShakeMap" and the "Community Internet Intensity Map" can be found on the World Wide Web at URL **www-socal.wr.usgs.gov**, from the links "*Shake Map*", and *"Did You Feel it?"*, respectively. Online versions of more detailed manuscripts explaining these systems can be found at those sites.

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Modeling of Phase Characteristics of Earthquake Motions in Spatial Field and Interpolation of Observed Earthquake Motions

SATO Tadanobu[1] and MURONO Yoshitaka[2]

ABSTRACT

The first part of this paper is related to the modeling of phase spectrum of earthquake ground motion using the concept of group delay time. In the second part we propose a model to define spatial correlation of group delay time and apply it to simulate earthquake motions at unobserved points using array observation data.

A simple method is presented for modeling the group delay time and non-stationary power of earthquake motion using the wavelet analysis. Using existing data sets of observed earthquake motions, we calculated the power and group delay time of each earthquake motion on compact supports of the Mayer wavelet. The mean of the group delay times and standard deviation were calculated on each support. Attenuation relations of power, the mean delay time and standard deviation on each support were obtained by regression analysis as functions of the earthquake's magnitude and epicentral distance. A method is also developed to simulate a sample earthquake motion using the attenuation relations.

A method is presented for simulating earthquake ground motions at local-field points under the condition that the power and group delay time of recorded motions on each support were specified at several locations. For this purpose the stochastic characteristics of power and group delay time in a concerned field were designated. On the assumption that the stochastic characteristic of group delay time is defined by a multi-dimensional normal distribution, the Kalman filtering technique is applied to simulate a sample group delay time on each support at each unobserved point. By integrating it with respect to frequency the phase spectrum is derived. A simulated sample phase spectra was used to simulate earthquake motions at each unobserved point. The simulated motions at observation points coincide with observed records.

Key Words: Group delay time, Wavelet transform, Interpolation of earthquake motion

1. INTRODUCTION

The classical procedure for simulating artificial earthquake motion is the superposition of harmonic waves of different amplitudes and phase angle. To generate a non-stationary time history an envelope

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function (Jennings,1968) is multiplied to a stationary time history simulated using random phase criteria (Shinozuka and Jan,1972). To model the nonstationary characteristics of earthquake motion the phase characteristics of earthquake motions should be, however, properly modeled to simulate realistic earthquake motions (Sato *et. al.*, 1999).

Several pioneer works clarified the nonstationary characteristics of earthquake motion through analyses of its phase characteristics. Osaki (1978) showed similarity between the distribution width of the phase difference and the duration of earthquake motion. Izumi and Katsukura (1983) using the concept of group delay time, showed that the average arrival time of earthquake energy and duration of earthquake motion can be evaluated by the mean of group delay time and the standard deviation. Kimura (1986) presented a way to simulate earthquake motion by controlling the group delay time, but it was not based on observed earthquake motion data.

The parameters that control the group delay time of earthquake motion were modeled as a function of the epicentral distance and earthquake magnitude, (*i.e.*, the attenuation relationship) using observed earthquake motion data sets. Sawada (1986) analyzed the phase difference of earthquake motions and derived an attenuation relationship for duration. Ishii (1987) derived attenuation relationships of the mean group delay time and its standard deviation for entire time history of earthquake motion. Satoh (1996) derived attenuation relationships of the mean group delay time and its standard deviation for fairly long period earthquake motion (period range 1-10s), using a wave form processed through a narrow band passed filter with the frequency of 0.02Hz.

In the first part of this paper we develop a model for simulating realistic group delay time of earthquake motion. The targeted frequency range was 0.2 to 10Hz. The general group delay time characteristic is assumed to be modeled by the mean value and its standard deviation. We calculated these values for the wavelet-transformed earthquake motions on each compact support of the Mayer wavelet (Yamaguchi *et. al*, 1990) and used regression analysis to derive the attenuation relationships of these values as functions of the epicentral distance, $\triangle$, and earthquake magnitude, M. As an application we resimulated the earthquake motions of the Off Sanriku event (1995) and compared them with the observed earthquake motions.

In the second part of this paper we develop a conditional simulation method of earthquake motions. Earthquake ground motions vary in space. Various methods for simulating space correlated ground motion have been proposed. The one most widely used is a probabilistic approach based on the cross-correlation function or cross-spectrum. The theory of random fields and its application to digital simulation of earthquake ground motions were well established [Vanmarcke, 1983]. As substantial databases of earthquake ground motions based on the dense strong motion arrays have been formed, the stochastic characteristics of the space correlation of earthquake motions are modeled by the function of the separation distance between two points, the traveling time of the wave, the frequency, and the wave number. Earthquake motions simulated by the random field theory, however, have been only sample motions.

Conditional simulation methods should be devised that allows realization of a sample field at an unobserved location, which satisfies the properties of a stochastic field and is compatible with measured values at observed locations. To obtain this kind of simulation a method that used closed form solutions of

conditional probability functions for Fourier coefficients [Kawakami, 1992], nonstochastic conditional simulation [Kameda and Morikawa, 1992], and application of the Kriging method [Vanmarck and Fenton, 1991, Hoshiya and Murayam,1993] were developed. These methods however used cross-spectrum to model spacial stochastic characteristics of earthquake motions, i.e., spacial amplitude characteristics.
After defining a special correlation of group delay time we propose a conditional simulation method of group delay time and use it to simulate earthquake motion at unobserved points

2. DATA BASE FOR THE ANALYSES

Earthquake motions were selected mainly from data sets recorded by the 87 type accelerometers of the Japan Meteorological Agency. Data sets distributed by the Kansai Earthquake Observation and Research Committee and the K-net of the Science and Technology Agency also were used. Five recent earthquake data sets are given in **Table 1**. **Figure 1** shows their distribution characteristics in the space of magnitude M and epicentral distance △. Earthquakes with long epicentral distances are those with large magnitudes, whereas those with short epicentral distances are only the 1995 Hyogoken Nambu (M7.2) and 1997 North-West Kagoshima Prefecture (M6.3) earthquakes.

Ground motions of the Off Southwest Hokkaido earthquake (1993, M7.8), the Off East Hokkaido earthquake (1994, M8.1) and the Off Sanriku earthquake (1994 M7.5) were recorded by the 87 type accelerometers of the Japan Meteorological Agency. The earthquake motions of the Hyogoken Nambu earthquake include records from both the Meteorological Agency and Kansai Earthquake Observation and Research Committee. All records for the Northwest Kagoshima event are from the K-net of the Science and Technology Agency.

Table 1 Earthquake data sets used in this study

Earthquake	Magnitude	the number of data sets
Hokkaido Nansei Oki (1993)	7.8	10 data
Hokkaido Toho Oki (1994)	8.1	42 data
Sanriku Haruka Oki (1994)	7.5	26 data
Hyogoken Nanbu (1995)	7.2	28 data
Kagoshimaken Hokuseibu (1997)	6.3	26 data

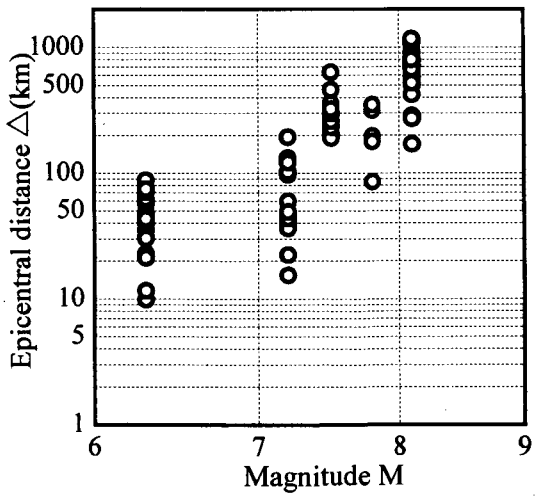


Figure 1 Relation between magnitude and epicentral distance of earthquake records used in this study

3. ANALYTICAL METHOD

Data used for the analyses are the horizontal components of the observed earthquake motions.

3.1 Definition of Group Delay Time

Group delay time is defined by the derivative of the Fourier phase spectrum $\phi(\omega)$ with respect to circular frequency ω [Papoulis, 1962];

$$t_{gr}(\omega) = \frac{d\phi(\omega)}{d\omega} \tag{1}$$

The average value of the group delay time within a certain frequency band with the central frequency ω expresses the arrival time of a wave component with frequency ω. The distribution width of the group delay time is related to the duration of the time history of the wave component. Because of these characteristics of group delay time, its modeling is much easier than direct modeling of the phase spectrum.

The calculated Fourier phase spectrum $\phi(\omega)$ must be unlapped to obtain the group delay time based on equation (1). Because the calculated group delay time depends on the number of data points in the time history, we applied the method of Sawada, Morikawa *et al* (1998), who showed that the calculated group delay time depends less on artificially added numbers of zeros to a time history of earthquake motion.

3.2 Average Group Delay Time and Its Standard Deviation

To show the nonstationary characteristic of earthquake motion in the time and frequency domains, wavelet analysis often is used because resolution in the time and frequency domains is guaranteed through the uncertainty criterion.

The discrete wavelet transformation of the function $x(t)$ and its inverse transformation were defined by [Yamaguchi and Yamada, 1990]

$$a_{j,k} = \int_{-\infty}^{\infty} \varphi_{j,k}^{*} \cdot x(t)dt \tag{2}$$

$$x(t) = \sum_{j} x_j(t) = \sum_{j}\sum_{k} a_{j,k} \cdot \varphi_{j,k}(t) \tag{3}$$

$$\varphi_{j,k}(t) = 2^{j/2} \cdot \varphi(2^j t - k) \quad j,\ k : \text{integer} \tag{4}$$

in which the value with the sign * expresses the complex conjugate of the original value, $\varphi(t)$ the wavelet function, j the scale factor, and k the factor expressing the time shift. As seen from equation (4), if scale factor j becomes large the treating frequency range goes to the high frequency region. If the inverse wavelet transformation exists, $\varphi(t)$ is called the analyzing wavelet. We used the method of Mayer [Meyer, 1989] to compose $\varphi(t)$ although there are several ways to define this function. The Fourier transformation of $\varphi(t)$ has a compact support for each scale factor j (named the j th compact support) defined by

$$\{2^j/3T_d \le f \le 2^{j+2}/3T_d\} \tag{5}$$

in which T_d (=$N\Delta t$, N: number of data, Δt: sampling interval) is the duration of earthquake motion.

For all oberved earthquake earthquake motions with a sampling interval of 0.01(sec) we added zero data until the total number of sampling data for each earthquake motion, N, became 131071 (=2^{17} i,e,j=1,2, $\cdots$,17). Using the wavelet transformation of each earthquake motion $x(t)$ we decomposed each time history of earthquake motion to a component time history of each scale factor j (j=1$\sim$17) . We called this the jth component time history, $x_j(t)$. The group delay time of this time history, $t_{gr}^{(j)}(\omega)$, was calculated. Its mean, $\mu_{tgr}^{(j)}(\omega)$, and standard deviation, $\sigma_{tgr}^{(j)}(\omega)$, on the jth compact support were then obtained from equations (6) and (7):

$$\mu_{tgr}^{(j)} = \sum_{i=1}^{N^{(j)}} \frac{t_{gr}^{(j)}(\omega_i)}{N^{(j)}} \tag{6}$$

$$\sigma_{tgr}^{(j)} = \sqrt{\frac{1}{N^{(j)}} \sum_{i=1}^{N^{(j)}} \left(t_{gr}^{(j)}(\omega_i) - \mu_{tgr}^{(j)}\right)^2} \tag{7}$$

in which $N^{(j)}$ is the number for the time history data at the jth scale factor defined by $N^{(j)}=2^j$, and $t_{gr}^{(j)}(\omega)$ the group delay time of the jth component time history at a circular frequency of ω_s as defined by equation (8);

$$t_{gr}{}^{(j)}(\omega_i) = \frac{d\phi}{d\omega} = -\frac{\phi(\omega_i) - \phi(\omega_{i+1})}{\Delta\omega} \tag{8}$$

4. A METHOD TO SIMULATE AN EARTHQUAKE MOTION USING GROUP DELAY TIME

Using equation (3) the Fourier transformation of jth component time history, $X_j(\omega)$, is expressed by [Sasaki *et al*, 1992]

$$X_j(\omega) = \sqrt{T} \cdot 2^{-j/2} \cdot \Psi\left(\frac{T_d}{2^j}\omega\right) \sum_{k=0}^{N^{(j)}-1} a_{j,k} \exp\left(-i\frac{T_d k}{2^j}\omega\right) \tag{9}$$

$$\Psi\left(\frac{T_d}{2^j}\omega\right) = \exp\left(-i\frac{T_d}{2^{j+1}}\omega\right) \sqrt{\left\{\Phi\left(\frac{T_d}{2^{j+1}}\omega\right)\right\}^2 + \left\{\Phi\left(\frac{T_d}{2^j}\omega\right)\right\}^2} \tag{10}$$

in which $\Psi(\omega)$ is a function to define the Mayer mother wavelet [Mayer, 1989] and the Fourier inverse transformation of $\Psi(\omega)$ is $\varphi(t)$. The phase spectrum of $X_j(\omega)$ is therfore expressed by

$$\phi_j(\omega) = \phi^p(\omega) + \omega\left(\frac{T}{2^{j+1}}\right) \tag{11}$$

in which

$$\tan\phi^{p}(\omega)=-\frac{\sum_{k=0}^{N-1}a_{j,k}\sin(\omega t_{jk})}{\sum_{k=0}^{N-1}a_{j,k}\cos(\omega t_{jk})} \tag{12}$$

From equations (11) and (12) we obtain the following equation

$$\sum_{k=0}^{N^{(j)}}\left\{\cos\left(\frac{T_d k}{2^j}\omega\right)\cdot\beta_j(\omega)+\sin\left(\frac{T_d k}{2^j}\omega\right)\right\}\cdot a_{j,k}=0 \tag{13}$$

The equation (13) can be used to determine the wavelet coefficients $a_{j,k}$. To solve equation (13) we assume $a_{j,0}=1.0$ because this equation is a homogeneous with respect to $a_{j,k}\ (k=0,1,2,\cdots,N^{(j)}-1)$. When we chose proper number of discrete points of circular frequency the equation (13) is rewritten

$$\begin{bmatrix}\alpha_{j1}(\omega_1) & \alpha_{j2}(\omega_1) & \cdots & \alpha_{jN^{(j)}-1}(\omega_1)\\ \alpha_{j1}(\omega_2) & \alpha_{j2}(\omega_2) & & \alpha_{jN^{(j)}-1}(\omega)\\ \vdots & & \ddots & \vdots\\ \alpha_{j1}(\omega_m) & \alpha_{j2}(\omega_m) & \cdots & \alpha_{jN^{(j)}-1}(\omega_m)\end{bmatrix}\begin{Bmatrix}a_{j,1}\\ a_{j,2}\\ \vdots\\ a_{j,N^{(j)}-1}\end{Bmatrix}=-\begin{Bmatrix}\alpha_{j0}(\omega_1)\\ \alpha_{j0}(\omega_2)\\ \vdots\\ \alpha_{j0}(\omega_m)\end{Bmatrix} \tag{14}$$

$$\alpha_{jk}(\omega_i)=\beta_j(\omega_i)\cdot\cos\left(\frac{T_d k}{2^j}\omega_i\right)+\sin\left(\frac{T_d k}{2^j}\omega_i\right)$$

The solution of equation (14) is expressed as $\bar{a}_{j,k}\ (k=1,2,\cdots,N^{(j)}-1)$. If the number m becomes lager than $N^{(j)}-1$ the least square minimum solution is used to obtain $\bar{a}_{j,k}$.

Using obtained solution $\bar{a}_{j,k}$ and $a_{j,0}=1.0$ the jth component time history $x_j(t)$ can be resimulated by equation (3) except the level of its amplitude. To determine amplitude the exact value of $a_{j,0}$ must be given. The power of the jth component time history, λ_j^2, is used to determine this value. The λ_j^2 is defined by

$$\lambda_j^2=\int_{-\infty}^{\infty}X_j(\omega)X_j^{*}(\omega)d\omega \tag{15}$$

This value is also defined by the square sum of wavelet coefficient on jth compact support as follows:

$$\lambda_j^2=\sum_{k=0}^{N^{(j)-1}}a_{j,k}^2\left(\int_{-\infty}^{\infty}\Psi(\omega)\Psi^{*}(\omega)d\omega\right)=2\pi\sum_{k=0}^{N^{(j)-1}}a_{j,k}^2 \tag{16}$$

Combining equations (15) and (16) we can obtain the expression of $a_{j,0}$

$$a_{j,0}=\lambda_j\Big/\sqrt{2\pi\sum_{k=0}^{n-1}\bar{a}_{j,k}^2}=\lambda_j\Big/\sqrt{2\pi\left(\sum_{k=1}^{n-1}\bar{a}_{j,k}^2+1.0\right)} \tag{17}$$

We used the proposed method to resimulate an earthquake motion record from the Morioka observation

station for the 1993 Far-off Sanriku earthquake.

An example of this earthquake motion decomposed into each component time history $x_j(t)$ is shown in **Figure 3**. As scale factor j becomes smaller, the duration lengthen and the central arrival time of the component time history is delayed. The Fourier amplitude spectrum on each compact support, $A_j(\omega)$, is shown in **Figure 4**. The Fourier amplitude on the jth compact support overlaps the Fourier amplitudes on both the (j-1)th and (j+1)th compact supports because the definition of the jth support is given by equation (5). The main frequency range in which the Fourier amplitude on the jth compact support predominates, is given by

$$\left\{2^{j-1}/T_d \le f \le 2^j/T_d\right\} \tag{18}$$

The vertical broken line in **Figure 4** shows the frequency range defined by this equation.

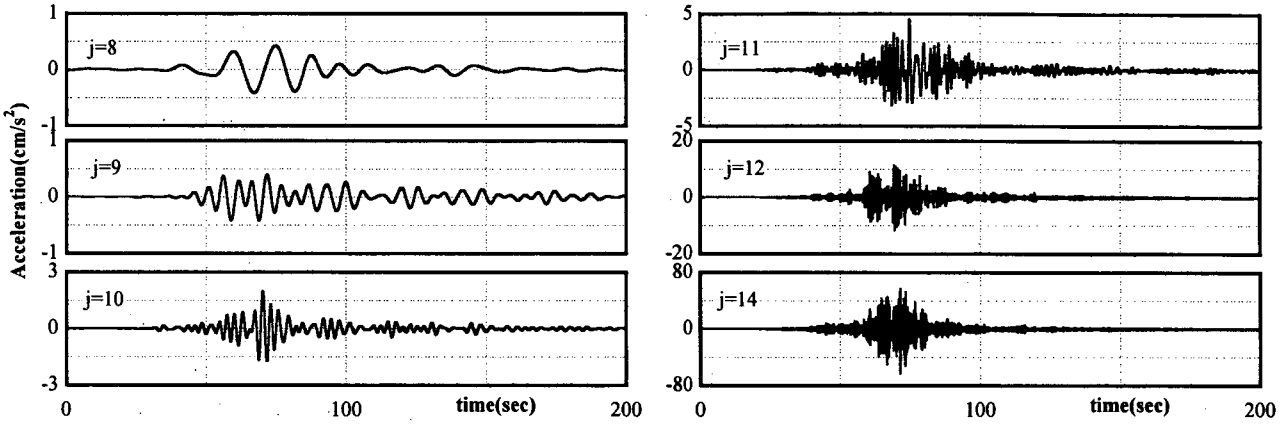


Figure.3 Wavelet decomposed waves on scale factor j (j=8～14)

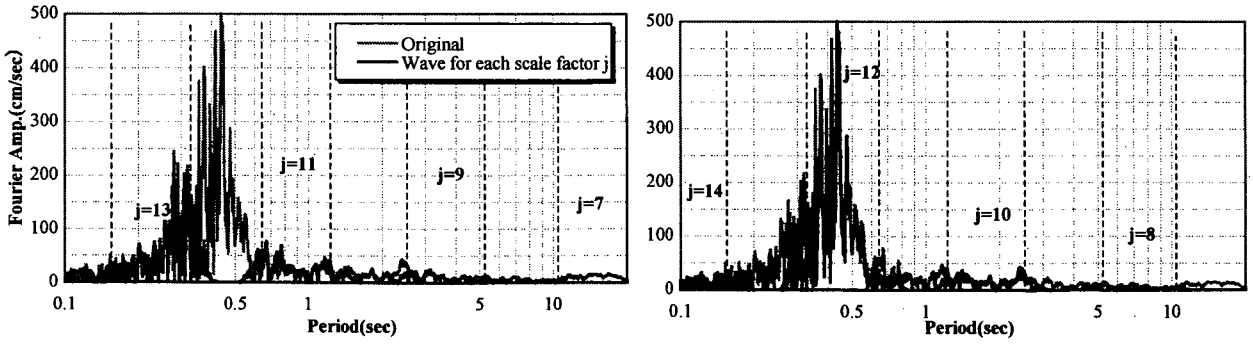


Figure.4 Fourier amplitude $A^{(j)}(\omega)$ on compact support j (j=8～14)

Values of $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ for the jth component time history $x_j(t)$ based on equations (6) and (7) are shown in **Figure 5**. The group delay time $t_{tgr}^{(j)}(\omega)$ calculated from the observed time history of the earthquake motion also is shown. The values $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ well indicate the group delay time of the observed earthquake motion. Comparison of **Figures 3** and **5** shows that the central arrival time of the jth

component time history coincides with $\mu_{tgr}^{(j)}$ and that the duration is well evaluated by $\sigma_{tgr}^{(j)}$.

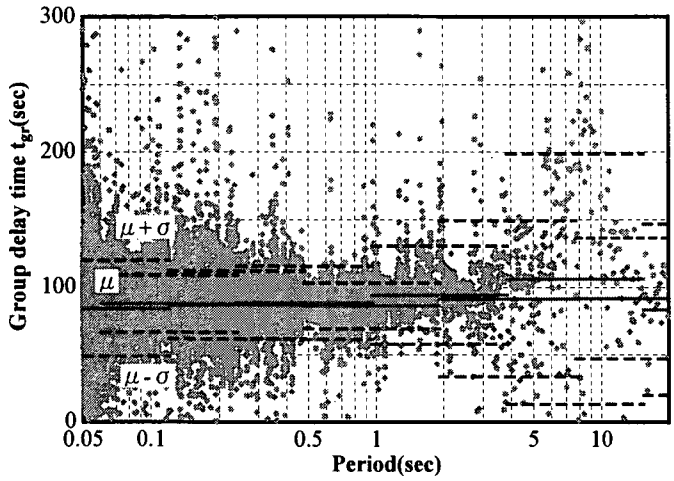


Figure 5. Average group delay time $\mu_{tgr}^{(j)}$ and its standard deviation $\sigma_{tgr}^{(j)}$ in each compact support

The distribution of group delay time on each compact support is shown in **Figure 6**. The examples for j=9 and 11 have the character of a normal distribution. When the value of j become small, the distribution character is distorted and approaches a log normal distribution. This tendency is confirmed by the fact that the envelop functions for cases of j=8,9 close to the log normal distribution function (**Figure 3**). We assume, however, that the values for group delay time have the normal distribution characteristic for all j values. Power of each jth component time history is given in **Table 2**.

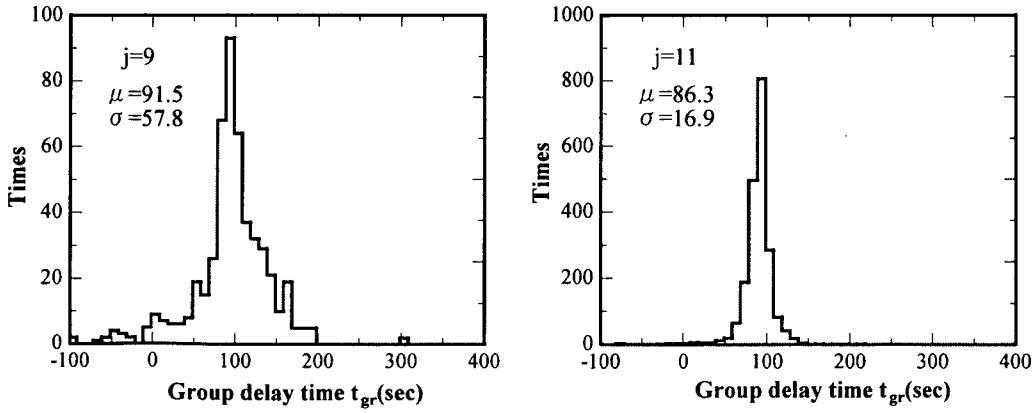


Figure 6. Distribution characteristics of group delay time $t_{gr}(\omega)$ on compact support j=9

By integrating the group delay time shown in **Figure 5** we obtain the phase spectrum of each jth component of time history. We can determine the wavelet coefficients based on equations (14) and (17). Once the wavelet coefficients are given we can simulate an earthquake motion using equation (3). **Figure 7**

shows examples of resimulated several jth component of time histories for the earthquake motion observed at Morioka. A resimulated earthquake motion by summing up all resimulated component time histories is shown in **Figure 8**. The resimulated earthquake motion agrees well with the observed earthquake motion.

Table 2. Power of each jth component time history

j	λ_j	j	λ_j	j	λ_j
1	6.87e-2	7	1.63e+1	13	3.96e+4
2	2.05e-2	8	3.81e+0	14	1.58e+4
3	4.00e-2	9	2.50e+1	15	1.95e+2
4	2.70e-2	10	1.33e+2	16	8.62e+1
5	9.21e-2	11	1.13e+3	17	2.08e+6
6	8.19e+0	12	3.27e+3		

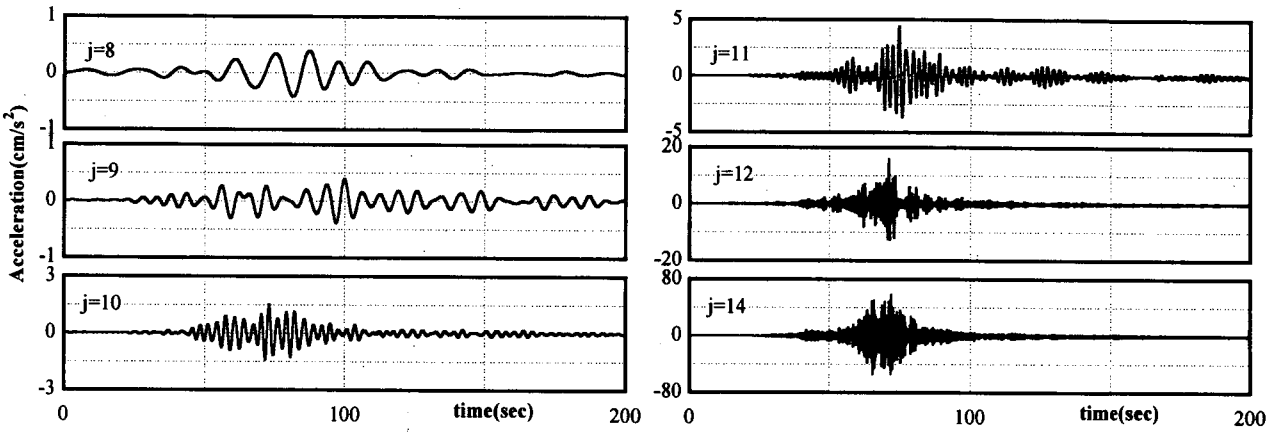


Figure7 Examples of re-simulated jth component time histories

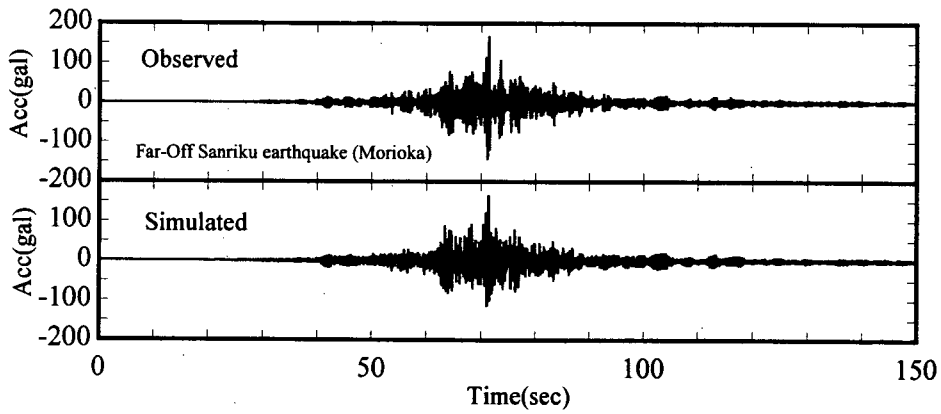


Figure8. Comparison of observed and re-simulated motion

5. MODELING OF GROUP DELAY TIME

The mean group delay time, $\mu_{tgr}^{(j)}$, and its standard deviation, $\sigma_{tgr}^{(j)}$, were calculated for all the

observed earthquake motions listed in **Table 1**. Because the trigger time of earthquake motion is recorded in all the observation data, the time origin of earthquake motion was defined by adding the theoretically calculated travel time of the direct S wave generated at the initial rupture point on the earthquake fault to the trigger time. The concerned period range in standard aseismic design procedures is 0.1-5 sec. The attenuation relations $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ for j=7-14 therefore were developed as functions of earthquake magnitude M and epicentral distance Δ (km).

$$\mu_{tgr}^{(j)} = \alpha_1^{(j)} \times 10^{\beta_1^{(j)} M} \times \Delta^{\gamma_1^{(j)}} \tag{19}$$

$$\sigma_{tgr}^{(j)} = \alpha_2^{(j)} \times 10^{\beta_2^{(j)} M} \times \Delta^{\gamma_2^{(j)}} \tag{20}$$

Table3 Results of regression analyses

j	$\alpha_1^{(j)}$	$\alpha_2^{(j)}$	$\alpha_3^{(j)}$	$\beta_1^{(j)}$	$\beta_2^{(j)}$	$\beta_3^{(j)}$	$\gamma_1^{(j)}$	$\gamma_2^{(j)}$	$\gamma_3^{(j)}$	the correlation coefficients		
										$\mu_{tgr}^{(j)}$	$\sigma_{tgr}^{(j)}$	$\lambda^{(j)}$
7	1.011	27.71	5.20E+1	0.0	0.0	0.0185	0.864	0.203	-0.219	0.86	0.41	0.14
8	0.830	14.58	8.53e-4	0.040	0.0	1.200	0.790	0.337	-1.779	0.94	0.71	0.59
9	0.543	17.97	1.90e-5	0.086	-0.030	1.626	0.700	0.344	-2.187	0.85	0.75	0.68
10	0.806	8.45	1.41e-2	0.060	-0.005	1.270	0.686	0.321	-1.990	0.97	0.73	0.64
11	0.850	2.97	3.78e+0	0.026	0.016	0.993	0.764	0.366	-1.908	0.98	0.77	0.69
12	0.511	0.39	1.66e-1	0.058	0.143	1.244	0.744	0.295	-2.023	0.99	0.83	0.69
13	0.367	0.08	1.76e-1	0.077	0.267	1.254	0.739	0.201	-2.117	0.99	0.87	0.65
14	0.330	0.06	8.77e+1	0.081	0.287	0.850	0.742	0.239	-2.280	0.99	0.81	0.68

in which $\alpha^{(j)}$, $\beta^{(j)}$ and $\gamma^{(j)}$ are regression coefficients on the jth compact support. Regression analysis results are shown in **Table 3** and **Figures 9** and **10**. The β values for j=7-8 are forced to be zero because in this range β has small negative values which means that the arrival time of the jth component time history $x_j(t)$ becomes earlier and the duration longer for the smaller the earthquake magnitude. These characteristics have no physical meaning, rather they are due to the scattering of data. The effective number of data on the jth compact support is given by

$$N^{(j)} = 2^j \tag{21}$$

As the number of data on the compact support for j=7-8 was insufficient, large scattering occurred. The respective values of the correlation coefficients $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ are 0.9 and 0.71～0.89 (less than 0.4 for j=7).

The value of $\mu^{(j)}{}_{tgr}$ becomes larger as the epicentral distance increases. The regression coefficient γ_1 has a constant range of 0.75-0.8 for all orders of j. This means that the arrival times of all the component time histories $\left(x_j(t), j = 7-14\right)$ are delayed as the transmitting path lengthens. Because the value of β_1 is less than 0.1, the effect of epicentral distance on the average group delay time is relatively greater than that of earthquake magnitude. The value of $\mu_{tgr}^{(j)}$ depends on the value of j; i.e., the average arrival time of the component time history is frequency dependent (**Figure 9**).

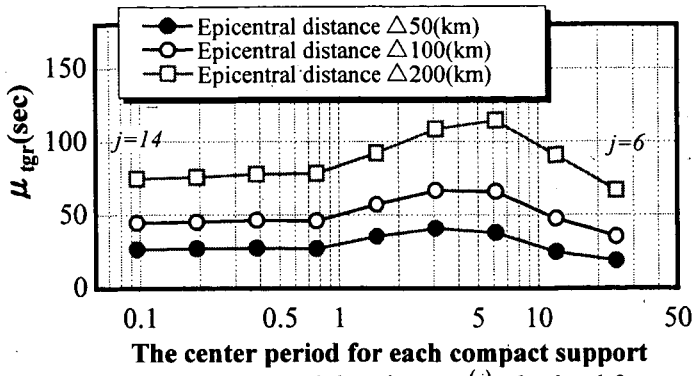
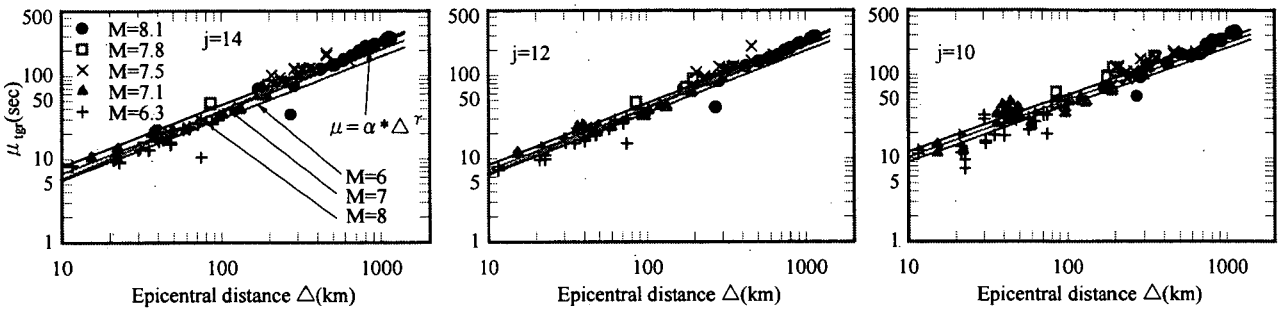
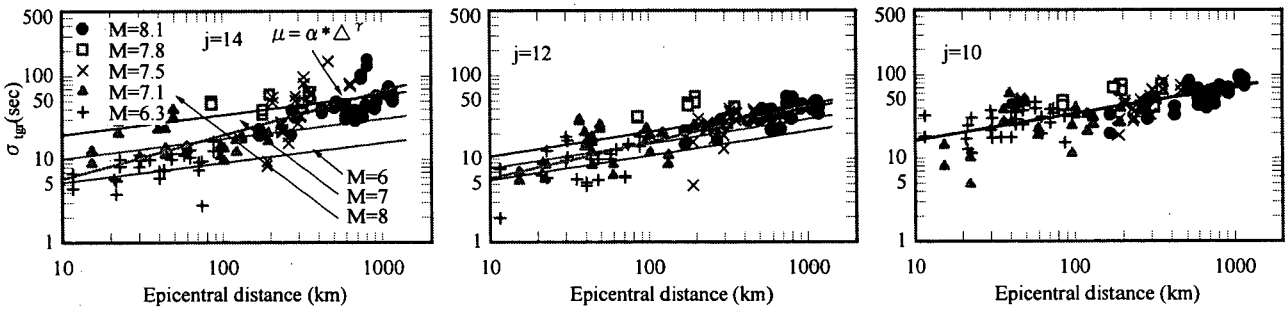


Figure 9 Average group delay time $\mu_{tgr}^{(j)}$ obtained from



(a) Average group delay time $\mu_{tgr}^{(j)}$



(b) Standard deviation of group delay time $\sigma_{tgr}^{(j)}$

Figure10 Attenuation relationships for $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ of earthquake motion on the *j*th compact support (*j*=10, 12, 14)

The attenuation relationship for the power of earthquake motion on the *j*th compact support is also derived based on the following function

$$\lambda_j = \alpha_3^{(j)} \times 10^{\beta_3^{(j)} M} \times \Delta^{\gamma_3^{(j)}} \tag{22}$$

The regression parameters are also shown in **Table 3** and **Figure 11**.

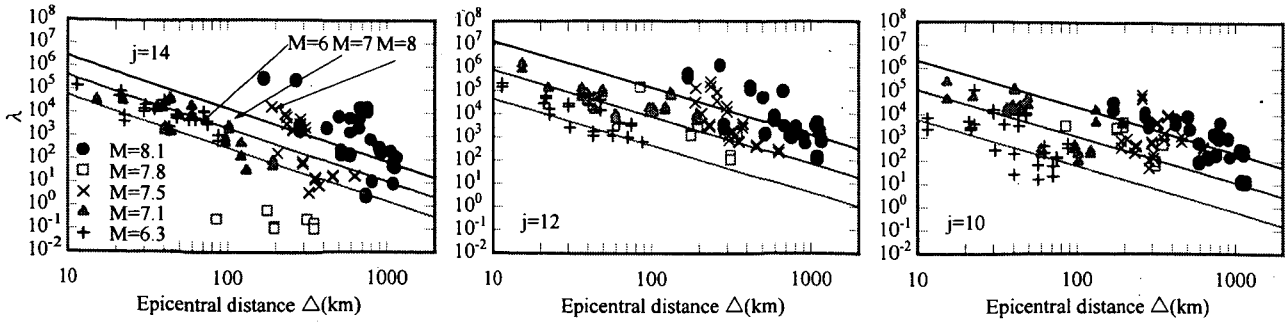


Figure11 Attenuation relationships for the power of earthquake motion on the *j*th compact support (*j*=10, 12, 14)

6. DERIVATION OF SPACIAL CORRELATION OF THE POWER AND GROUP DELAY TIME

We define the mean and special correlation of power and group delay time of earthquake motion. In the above section we calculated a mean value $\mu_{tgr}^{(j)}$ and standard deviation $\sigma_{tgr}^{(j)}$ of group delay time at an observation point $\boldsymbol{X}_p$ form the group delay time data on *j*th compact support. In the following section we use these values as the mean and standard deviation of group delay time of a concerned point at a circular frequency ω_s.

$$\mu_{tgr}^{(j)}(X_p,\omega_s)=\mu_{tgr}^{(j)}(f(X_p)) \tag{23}$$

$$\sigma_{tgr}^{(j)}(X_p,\omega_s)=\sigma_{tgr}^{(j)}(f(X_p)) \tag{24}$$

in which $f(X_p)$ is a function expressing the effect of the point on stochastic parameters of group delay time. In the following analyses we use the developed attenuation relationship to define $\mu_{tgr}^{(j)}$ and $\sigma_{tgr}^{(j)}$ therefore $f(X_p)$ becomes a function of epicentral distance Δ_p at the point X_p.

$$f(X_p)=\Delta_p \tag{25}$$

To define the special correlation of the group delay time we assume a following simple formula of covariance between two arbitrary points $\boldsymbol{X}_p$ and $\boldsymbol{X}_q$

$$M_{pq}^{(j)}=\sigma_{tgr}^{(j)}(X_p,\omega_s)\sigma_{tgr}^{(j)}(X_q,\omega_s)\exp\left(-\eta_{pq}^{(j)}f(|X_p-X_q|)\right) \tag{26}$$

in which $\eta_{pq}^{(j)}$ is a special distortion factor of group delay time. Throughout of this analyses we assume a constant value η .

The square root of mean value of the power of earthquake motion on the *j*th compact support $\mu_{\lambda}^{(j)}(X_p)$ at the point $\boldsymbol{X}_p$ can be derived by equation (22)

$$\mu_{\lambda}^{(j)}(X_p)=\lambda_j(f(X_p)) \tag{27}$$

The special correlation of this power is defined by

$$P_{pq}^{(j)} = \sigma_{\lambda}^{(j)}\left(f\left(X_p\right)\right)\sigma_{\lambda}^{(j)}\left(f\left(X_q\right)\right)\exp\left(-\xi_{pq}^{(j)} f\left(\left|X_p - X_q\right|\right)\right) \tag{28}$$

in which $\sigma_{\lambda}^{(j)}\left(f\left(X_p\right)\right)$ is the standard deviation of $\lambda_j\left(f\left(X_p\right)\right)$. In the following analyses we assume that this value is equal to the standard deviation of the attenuation relationship given by equation (22)

7. CONDITIONAL SIMULATION OF EARTHQUAKE MOTION BASED ON GROUP DELAY TIME

A vector composed of n-dimensional group delay time on the jth compact support is considered

$$Z^{(j)} = \left\{t_{gr}^{(j)}(X_1,\omega_s), t_{gr}^{(j)}(X_2,\omega_s), \cdots, t_{gr}^{(j)}(X_n,\omega_s)\right\}^T \tag{29}$$

in which $t_{gr}^{(j)}\left(X_p,\omega_s\right)$ is a group delay time at an observation point with coordinate X_p and a discrete circular frequency ω_s. The mean and covariance matrix of $Z^{(j)}$ is assumed to be expressed by

$$\overline{Z}^{(j)} = \left\{\mu_{tgr}^{(j)}(X_1,\omega_s), \mu_{tgr}^{(j)}(X_2,\omega_s), \cdots, \mu_{tgr}^{(j)}(X_n,\omega_s)\right\}^T \tag{30}$$

$$M^{(j)} = \left[M_{pq}^{(j)}\left(X_p, X_q, \omega_s\right)\right] \tag{31}$$

Consider the case in which the total number of points for which the earthquake ground motion needed is n, but records of earthquake motion are obtained only at m ($m<n$) observation points. In this case the group delay time on the jth compact support is given at m points as defined by

$$y^{(j)} = \left\{t_{gr}^{(j)}(X_1,\omega_s), t_{gr}^{(j)}(X_2,\omega_s), \cdots, t_{gr}^{(j)}(X_m,\omega_s)\right\} \tag{32}$$

The observation equation then is

$$y^{(j)} = HZ^{(j)} \qquad H = \left[I \quad 0\right] \tag{33}$$

in which $\boldsymbol{H}$ is the observation matrix with the dimension ($m \times n$) and $\boldsymbol{I}$ the unit matrix with the dimension ($m \times m$). This is a special case in that the observation vector $y^{(j)}$ and the vector $Z^{(j)}$ to be estimated have the same physical values [Hoshiya and Yoshida, 1996]. The covariance matrix of the observation noise, $R^{(j)}$, is therefore assumed to be the zero matrix

$$R^{(j)} = 0 \tag{34}$$

The Kalman filtering technique [Kalman, 1960] is used to obtain the posterior best estimator of group delay time conditioned by the observation equation. Because the apriori best estimator and its covariance matrix are given by equations (30) and (31), the posterior best estimator of $\hat{Z}^{(j)}$ and its covariance matrix $\hat{M}^{(j)}$ are

$$\hat{Z}^{(j)} = \overline{Z}^{(j)} + K^{(j)}\left(y^{(j)} - H\overline{Z}^{(j)}\right) \tag{35}$$

$$\hat{M}^{(j)} = M^{(j)} - K^{(j)} H M^{(j)} \tag{36}$$

in which $K^{(j)}$ is a Kalman gain at the discrete circular frequency ω_s and is defined as

$$K^{(j)} = M^{(j)} H \left(H M^{(j)} H^T + R^{(j)} \right)^{-1} \tag{37}$$

Partitioning the matrix $M^{(j)}$ into the observed and unobserved parts

$$M^{(j)} = \begin{bmatrix} M^{(j)}_{mm} & M^{(j)}_{m,n-m} \\ M^{(j)}_{n-m,m} & M^{(j)}_{n-m,n-m} \end{bmatrix} \tag{38}$$

and substituting the $\boldsymbol{H}$ matrix given in equation (33) and equation (38) into equations (36) and (37), the Kalman gain $K^{(j)}$ and covariance matrix $\hat{M}^{(j)}$ yield

$$K^{(j)} = \begin{bmatrix} I \\ \left(M^{(j)}_{m,n-m} \right)^T \left(M^{(j)}_{m,m} \right)^{-1} \end{bmatrix} \tag{39}$$

$$\hat{M}^{(j)} = \begin{bmatrix} 0 & 0 \\ 0 & M^{(j)}_{n-m,n-m} - \left(M^{(j)}_{m,n-m} \right)^T \left(M^{(j)}_{m,m} \right)^{-1} M^{(j)}_{m,n-m} \end{bmatrix} \tag{40}$$

Substituting equations (39) and (40) into equation (35) the best posterior estimator of group delay time is

$$\hat{Z}^{(j)} = \begin{Bmatrix} \hat{Z}^{(j)}_m \\ \hat{Z}^{(j)}_{n-m} \end{Bmatrix} = \begin{Bmatrix} y^{(j)} \\ \overline{Z}_{n-m} + \left(M^{(j)}_{m,n-m} \right)^T \left(M^{(j)}_{m,m} \right)^{-1} \left(y^{(j)} - H \overline{Z}^{(j)}_m \right) \end{Bmatrix} \tag{41}$$

These results show that the posterior best estimators of group delay time at observation points are identical to the observed values and that the components of covariance matrix become zero.

To obtain sample group delay time at an unobserved point we must add a sample fluctuation to the posterior best estimator of group delay time. The sample field is simulated by

$$Z^{(j)}_{n-m} = \hat{Z}^{(j)}_{n-m} + e \tag{42}$$

in which e is the sample error function vector simulated by multiply-correlated process with a zero mean vector, and covariance $\hat{M}^{(j)}_{n-mn-m}$ being defined by

$$\hat{M}^{(j)}_{n-m,n-m} = M^{(j)}_{n-m,n-m} - \left(M^{(j)}_{m,n-m} \right)^T \left(M^{(j)}_{m,m} \right)^{-1} M^{(j)}_{m,n-m} \tag{43}$$

By factoring matrix $\hat{M}^{(j)}_{n-mn-m}$ the error sample function is

$$e = LN(1,0) \qquad \hat{M}^{(j)}_{n-m,n-m} = LL^T \tag{44}$$

in which $N(1,0)$ is an n-m dimensional sample noise vector generated by the standard normal distribution density function.

Once we obtain a sample group delay time at unobservation points we can define the wavelet coefficients by equation (14). To define $a_{j,0}$ sample values of λ_j at unobservation points must be given.

These values are simulated by replacing the vector $Z^{(j)}$ and the covariance matrix $M^{(j)}$ by

$$Z^{(j)} = \{\lambda_j(X_1), \lambda_j(X_2), \cdots, \lambda_j(X_n)\} \tag{45}$$

$$M^{(j)} = \left[P_{pq}^{(j)}(X_p, X_q)\right] \tag{46}$$

and proceed same calculation through equations from (29) to (44)

8. CONCLUSTION

A method for modeling the phase spectrum of earthquake motion is proposed that is based on the concept of group delay time. We developed a conditional simulation method of earthquake motion using the concept of group delay time. The findings of this study are

1) A method to define wavelet coefficients from a phase spectrum of earthquake motion was developed.
2) Earthquake motions at sites where earthquake motions were recorded during the 1994 Far-off Sanriku earthquake were re-simulated by using developed method. The re-simulated motions agreed well with the recorded motions.
3) By using data sets of observed earthquake motions, the power, average group delay time and standard deviation on the compact support of Mayer wavelet were expressed as functions of earthquake magnitude and epicentral distance.
4) Special correlation of powers and also group delay times of earthquake motions were modeled based on the developed attenuation relationships.
5) Conditional simulation methods were devised that allows realization of a sample field at an unobserved location, which satisfies the properties of a stochastic field and is compatible with measured values at observed locations.

ACKNOWLEDGEMENT

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Session III: Crisis Management- Urgent Response Works and Restoration (2)

- SATURN- Seismic Assessment Tool for Urgent Response and Notification,
  Hideki Sugita (PWRI), Yasushi Ohtani, Tomofumi Nozaki*
- HAZUS Capabilities as A Near-Real Time Rapid Damage Assessment Tool,
  Stuart Nishenko (FEMA)
- The Earthquake Damage Estimation System of Tokyo Fire Department,
  Toru Fujita (Tokyo Fire Dept.)
- Seismic Disaster Information System for Hiroshima City, *Yasushi Sasaki **
  (Hiroshima Univ.), Hiroyuki Konishi, Satoshi Furukawa, Hiroaki Kubota
- "READY" A System for Real Time Assessment of Earthquake Disaster in Yokohama City,
  Masanori Saito(Yokohama City Univ.), Susumu Abe, Saburoh Midorikawa*

SATURN- SEISMIC ASSESSMENT TOOL FOR URGENT RESPONSE AND NOTIFCATION

Hideki SUGITA[1], Yasushi OHTANI[2] and Tomofumi NOZAKI[3]

ABSTRACT

Earthquake damage of road facilities does not only reduce their functions but affects the socio-economic activities in and around the damaged area. Besides improving the seismic performance of road facilities, therefore, post-earthquake emergency activities to reduce the damage effects must be jointly promoted.

This paper presents a seismic assessment tool for urgent response and notification: SATURN, which is developed at Public Works Research Institute, Ministry of Construction. By providing rough estimation on damage states and damage distributions of road facilities in a short time, the system will support decision-makers to facilitate emergency actions immediately after earthquakes.

KEYWORDS: Damage Estimation, Ground Liquefaction, Highway Bridge, Accelerographs Network, Urgent Response

1. INTRODUCTION

Emergency activities at sections that are in charge of road facilities can be classified into four stages [1] ; i.e. assuming magnitude of the earthquake, grasping a damage outline in a whole affected area, conducting temporary repair works to secure transportation functions and conducting permanent restorations. To establish a scope of works for a series of emergency activities, it is quite important to grasp a damage outline as early as possible.

1995 Hyogo-ken Nanbu Earthquake was a first destructive earthquake attacked a highly integrated urban area in Japan [2] . Based on that experience, following difficulties were pointed out for grasping a damage outline;

1) Much time was required for setting-up damage inspection teams,
2) Much time was required for investigations of widely spread severe damages, and
3) Adequate amount of damage information was not assembled at the headquarter due to disruptions/ congestion of telecommunication lines.

Table 1 Grasping Damage Outline at Headquarter

	Hyogo-ken Nanbu EQ (destructive)	Sanriku Haruka-oki EQ (moderate)
EQ Occurrence	05:46 1/ 17/ 1995	21:19 12/ 28 /1994
Damage Inspection	08:00 1/17 – 08:00 1/18	21:50 – 23:22 12/28
Required Time	Approx. 24 hours	Approx. 30 minutes

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Table 1 shows the required time for grasping damage outline at the headquarter. The table also describes the time required in 1994 Sanriku Haruka-oki Earthquake, in which severe damage was not developed on road facilities. For promoting a series of emergency activities against a destructive event, quick decision-making is indispensable in spite of the difficulty of assembling damage information. Applications of information systems to support the decision-making of sectors are therefore considered to be essential.

2. OUTLINE OF SATURN

Based on the past disaster experiences, development of information systems to support emergency activities has been conducted in PWRI[3] [4]. SATURN was developed as an essential tool for grasping damage outline automatically immediately after an earthquake by providing rough estimations on damage states and damage distributions of road facilities.

Fundamental functions of SATURN are as follows;
1) The system estimates possibilities of ground liquefaction and highway bridge damage
2) Damage estimation is carried out using the pre-stored ground/ structural condition data and earthquake ground motion data monitored by the accelerographs network
3) Damage estimation is completed within 15 min., by that time emergency investigation team can be set-up
4) Estimated information is visually displayed on the CRT using digital map

Implementation of SATURN is considered to be effective in the following aspects;
1) Severely damaged area can be assumed in a short time. Damage inspections can be effectively engaged by a restricted amount of inspectors,
2) Damage outline can be understood smoothly based on damage inspections, and
3) Decision-making on the buck-up organization and stuffs/ devices management can be initiated from the early period of emergency responses.

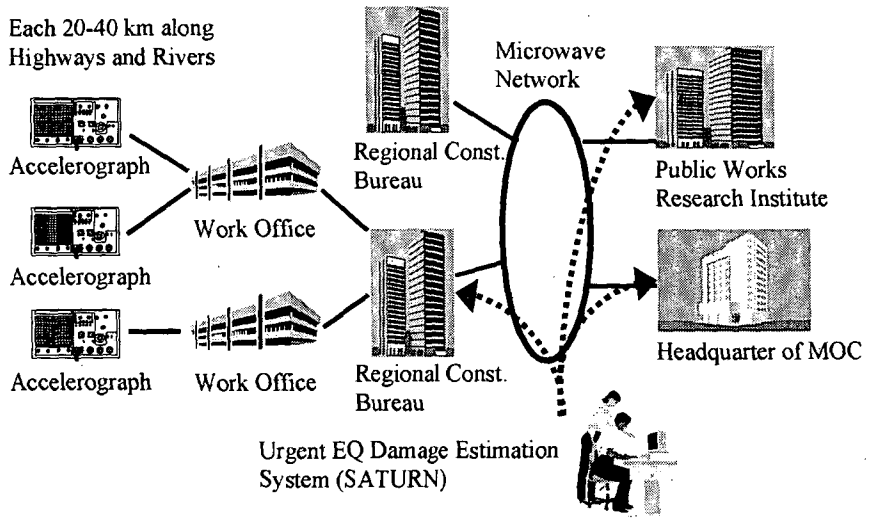
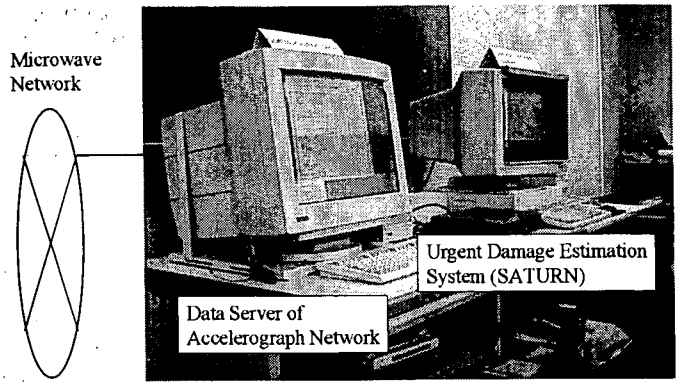


Fig.1 Accelerographs Network operated by MOC



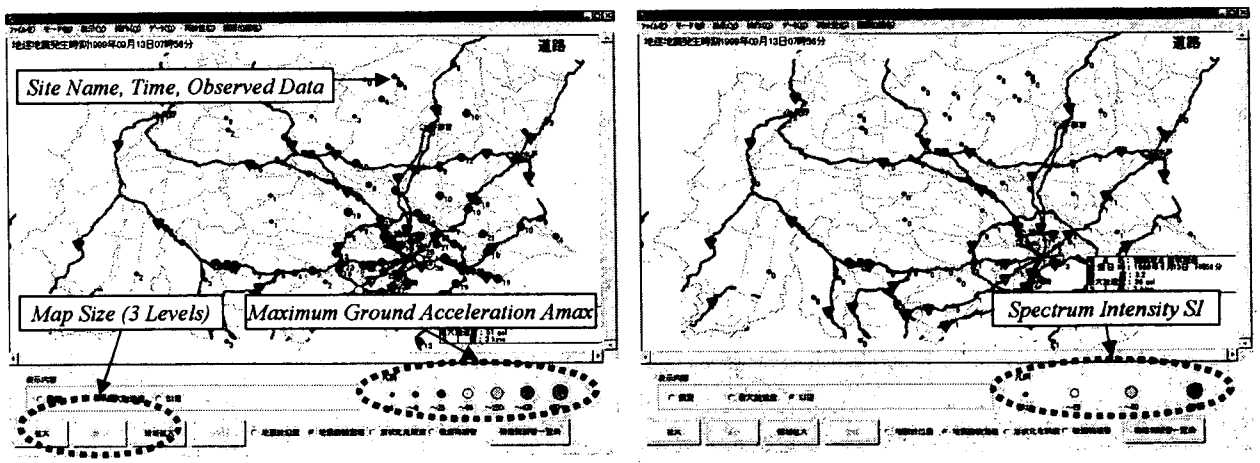
- Covers Tokyo Area (Tokyo and 8 Other Prefectures)
- Possibility of Ground Liquefaction (6,028 Highway Sites)
- Possibility of Highway Bridge Damage (368 Bridges)

Photo 1 Prototype System (under operation)

Fig.1 show a configuration of the accelerographs network operated by the Ministry of Construction. Approximately 700 strong motion accelerographs are installed along highways and rivers with an interval of 20-40 km. Ground motion data (maximum acceleration Amax and spectrum intensity SI) are transmitted real-timely to the headquarter and sectors in charge of emergency activities.

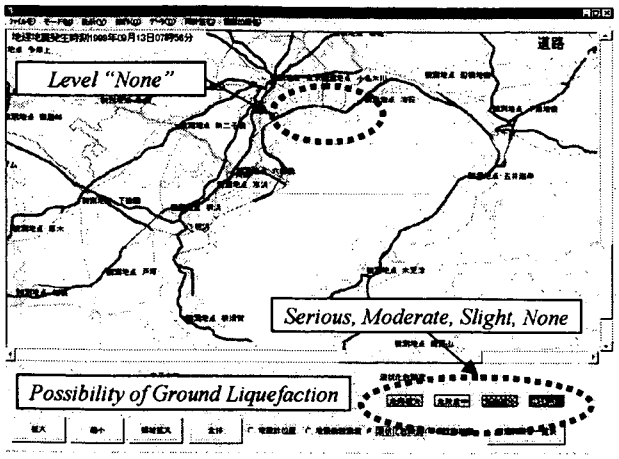
Photo 1 shows a prototype system installed at the regional construction bureau of MOC. The prototype system, which does not cover whole Japan but Kanto region (Tokyo and other 8 prefectures), has been under operation since 1997.4.

Fig.2 Shows the measured ground motion and estimated damage by an earthquake on September 13, 1999 (M5.0). Rough estimation of ground liquefaction states (at 6,028 highway sites) and bridge damage states (368 highway bridges) is available at this time. Maximum acceleration Amax and spectrum intensity SI (designated hereinafter as ground motion characteristic values) monitored by 110 accelerographs installed at ground surface in Kanto region is adopted for the calculation.

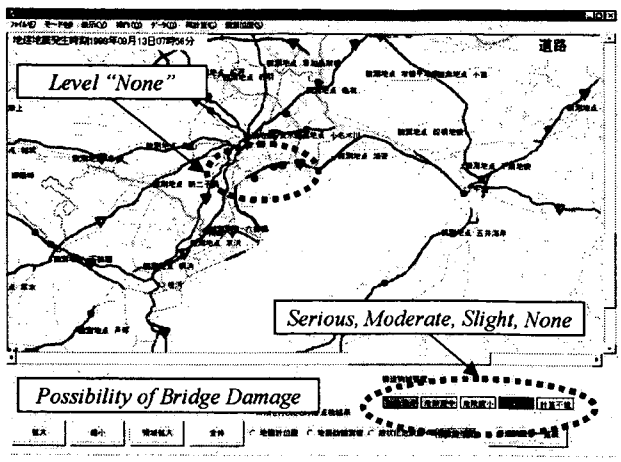


(a) Maximum Acceleration Amax

(b) Spectrum Intensity SI



(c) Possibility of Ground Liquefaction



(d) Possibility of Highway Bridge Damage

Fig.2 Estimated Damage by Prototype System (1999.9.13, M5.1)

3. DAMAGE ESTIMATION METHODOLOGY

3.1 Three Steps of Estimation

SATURN performs damage estimation by three steps as shown in **Fig.3**.

1) Estimation of Ground Motion Characteristic Values

For the judgement of ground liquefaction and bridge damage, ground motion characteristic values at the very site where the judgement is to be performed (designated hereinafter as a judgement site) are needed. Because the locations of observation sites are different from judgement sites, ground motion characteristic values have to be estimated analytically.

2) Possibility of Ground Liquefaction Possibility along Highway

Possibility of ground liquefaction is judged for each divided highway section. Division of highway sections is carried out so that the ground condition is assumed to be uniform in each section. Ground liquefaction states is judged based on a P_L value evaluated in each highway section. The P_L value is evaluated by eq.(1), where a liquefaction resistant ratio F_L[5] is evaluated by a ground condition and an estimated maximum acceleration in each highway section.

$$P_L = \int_0^{20} (1 - F_L)(10 - 0.5x)dx \cdots\cdots\cdots (1)$$

$$F_L = R / L$$

where,

x	: Depth from the surface (m)
FL	: Liquefaction resistant ratio
PL	: Potential of liquefaction
R	: Dynamic shear strength ratio
L	: Shear stress ratio during an earthquake

3) Possibility of Bridge Damage

Possibility of bridge damage is judged individually based on the structural database. As the structural database, bridge maintenance data accumulated at sectors are adopted in this estimation. Damage states of whole bridge is judged by comparing damage states of major bridge components. Damage states of major bridge components is judged by the SI value estimated at the judgement site. By using a SI value, it is possible to consider the cyclic effect of ground motion. The SI value is evaluated by eq.(2), where

S_{vi} means the i (sec) component of velocity response spectrum.

$$SI = \frac{1}{2.5}\sum_{i=0.1}^{2.5} S_{vi} \cdots\cdots\cdots (2)$$

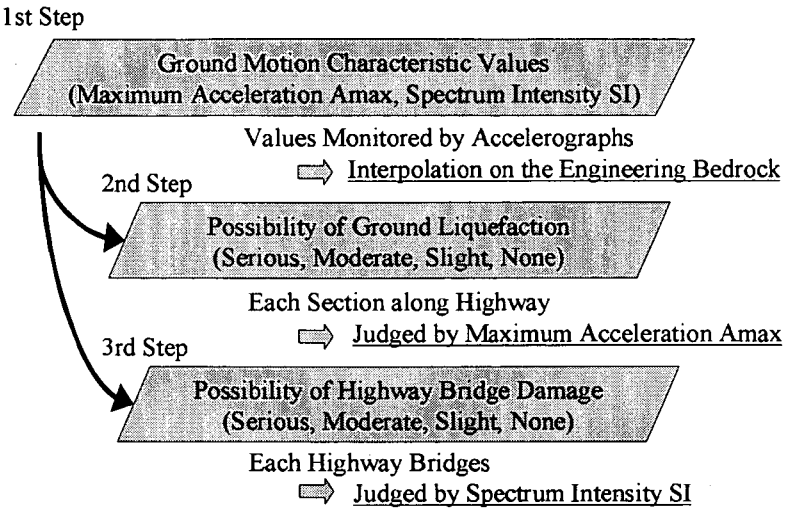


Fig.3 Flowchart of Damage Estimation

3.2 Classification of Damage States

Estimated ground liquefaction states and bridge damage states are displayed in four categories, i.e. "Serious", "Moderate", "Slight" and "None". As shown in **Table 2**, categories were defined as a combination of an assumed loss of transportation functions and a necessity of emergency repair works.

3.3 Estimation of ground motion Characteristic Values

Fig.4 shows the estimation steps of ground motion characteristic values at judgement sites. Following procedure is adopted in this system for minimizing the estimation time with enough accuracy.

1) Evaluating ground motion characteristic values right under each observation site by assuming a ground response amplification ratio.
2) Evaluating a characteristic value right under a judgement site by an interpolation.
3) Evaluating a characteristic value at a judgement site by assuming a ground response amplification ratio.

Table 2 Categories of Damage States

Classification	Influence to Transportation	Required Works
"Serious"	Interruption for Weeks	Demolition/ Reconstruction
"Moderate"	Interruption/ Restriction for Days	Temporary Repair
"Slight"	Restriction for Hours	Temporary Repair
"None"	No Restriction	None

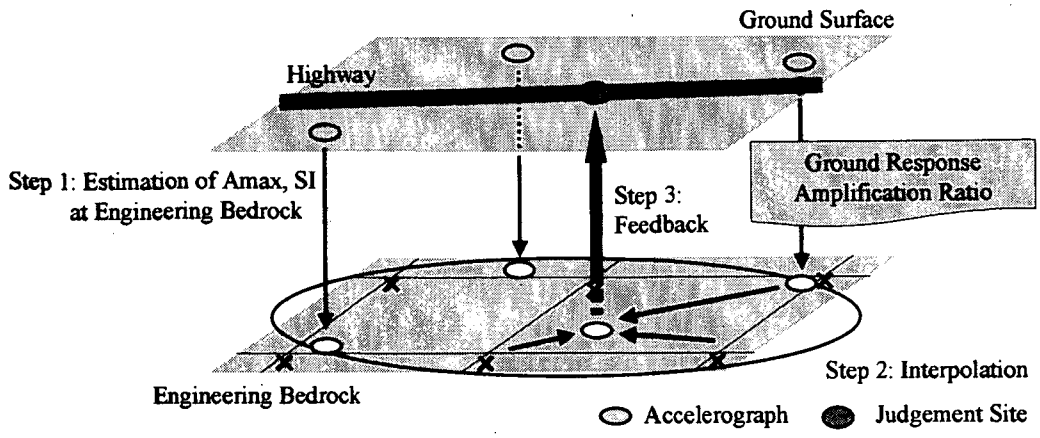


Fig.4 Estimation Steps of Ground Motion Characteristic Values

A ground response amplification ratio varies according to the cyclic characteristics of ground motions and non-linear property of ground soil deposit. For each observation/ judgement site, the amplification ratio α was calculated by "SHAKE" using a standard time history record. The Kaihoku Bridge record detected in 1978 Miyagiken-oki Earthquake was adopted as a standard time history because it provided the most average amplification ratio in trial calculations using five other typical records observed during past earthquakes. The non-linear property of ground can also be considered by eq.(3).

$$\alpha = a \times b^{-x} \cdots\cdots\cdots (3)$$

where, α :Ground response amplification ratio for each observation/ judgement site
x :Maximum acceleration (spectrum intensity) at engineering bedrock
a, b :Coefficients which represent the non-linear property of ground soil deposit

3.4 Estimation of Ground Liquefaction States along Highways

Table 3 shows a P_L~Ground Liquefaction States Table. Ground liquefaction states is judged with the Table by P_L value that is estimated for each highway sections. The Table was developed based on a series of experimental studies of past earthquake disasters at PWRI. By modifying the table in accordance with the future research development, accuracy of ground liquefaction states can be easily upgraded. Here, the P_L value for the damage state "Serious" was not defined in the table. This is because the ground liquefaction is hardly considered to induce serious damages to road facilities that would interrupt the transportation for a long time period.

Table 3 PL~Ground Liquefaction States Table

Classification of Ground Liquefaction State	Serious	Moderate	Slight	None
P_L value	----------	$P_L > 15$	$15 \geqq P_L > 5$	$5 \geqq P_L$

3.5 Estimation of Bridge Damage States

Table 4 shows the SI Value~Bridge Component Damage Table. Damage states of the major bridge components is judged with the table by the SI value that is estimated for each highway section including a bridge site. As for the damage states of major bridge components, following five failure mechanisms were considered due to their large effects on a whole bridge system, i.e. 1) bending failure of RC column,

2) shear failure of RC column, 3) buckling of ST column, 4) failure of bearing and 5) movement of foundation due to the liquefaction-induced ground flow.

Table 4 SI Value~Bridge Component Damage States Table (Bending Failure of RC Column)

Design Code	Yield Seismic Coefficient	Damage State of Component			
		Ultimate	Before Ultimate	Ultimate	Before Ultimate
1979	----------	SI>50	SI>30	SI>10	10≧SI
1990	----------	SI>50	SI>30	SI>10	10≧SI
1995	$0.6>k_{hy}$	SI>50	--------	---------	50≧SI
	$K_{hy}≧0.6$	SI>100	SI>50	---------	50≧SI

Table 5 Bridge Component Damage States Table~Bridge Damage States Table

Damage States of Bridge Component	Damage States of Bridge			
	Serious	Moderate	Slight	None
Bending Failure of RC Column	*Ultimate*	Before Ultimate	Yielding	Before Yielding
Shear Failure of RC Column	Failure	Before Failure	Shear Cracking	*Before Cracking*
Buckling of ST Column	Buckling	Before Buckling	Slight Deformation	Before Deformation
Failure of Bearing	Failure	Damage (tall bearing)	*Damage (short bearing)*	Slight Damage
Movement of Foundation	----------	Large Deformation	Small Deformation	*Slight Deformation*

● Damage state of bridge is evaluated by comparing estimated component damage.
● *Italic case*: Bridge damage is judged as "Serious".

The table was defined based on both a series of experimental studies and dynamic response analyses at PWRI. Basic concepts for the judgement of damage states are as follows;

1) Bending failure of RC column: Relationships between SI values and damage states were studied for several column types. Relationships were determined by the dynamic response analyses on approximately 400 columns. Column types were classified by structural specifications such as section size and weight. Damage states for each column type were classified by the SI value.
2) Shear failure of RC column: By a combination of h/D value and design year, a possibility of shear failure to be developed prior to the bending failure is estimated. h/D value is a ratio of a column height against a section size. Damage states were classified by the SI value based on a series of experimental studies of past earthquake disasters.
3) Buckling of ST column: A possibility of buckling is estimated by design year. Damage states were classified experimentally by the SI value.
4) Failure of bearing: A possibility of failure was classified experimentally by the SI value. Because a failure of bearing induces a gap of road surface, the damage states are to be judged by the bearing height.

5) Movement of foundation due to lateral ground spread: Verifying the distance between foundation sites and water lines, a possibility of the liquefaction-induced ground flow is estimated. Damage states were classified by a combination of a distance and a ground liquefaction state.

Table 5 shows a Bridge Component Damage States～Bridge Damage States Table. The damage state of a whole bridge system is judged by comparing the damage states of major bridge components, i.e. the maximum damage state among those of major bridge components represents the damage state of a whole bridge system.

4. FEASIBILITY STUDY

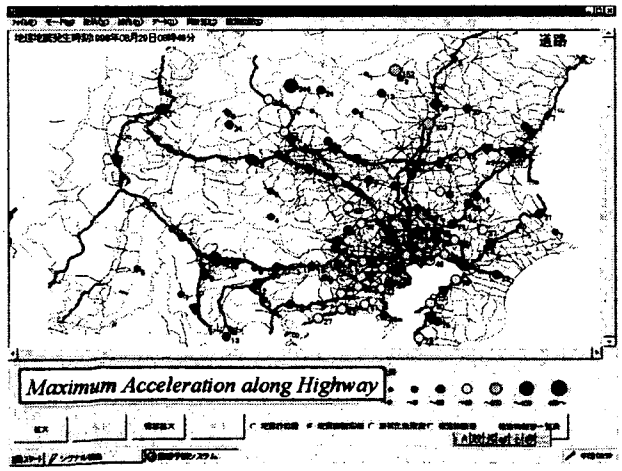
4.1 Observed Earthquakes

Table 6 shows characteristics of earthquakes observed in Kanto area during 1997.4- 1998.9. There were eight earthquakes with magnitude of 4.0 or larger in JMA scale. Feasibility study was carried out using maximum accelerations measured by the accelerograph network.

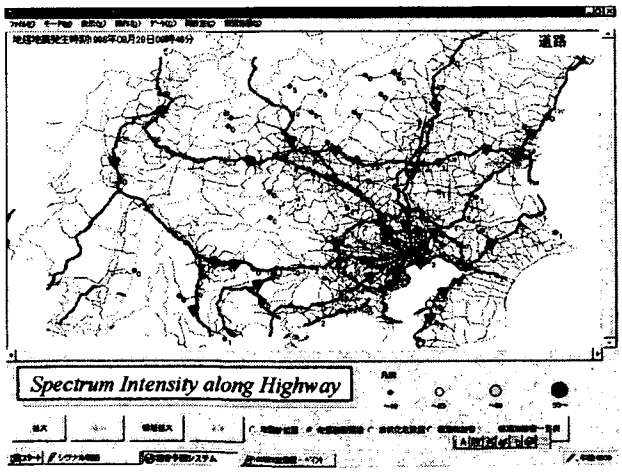
Table 6 Earthquakes observed in Kanto Area during 1997.4- 1998.9 (≧M4.0)

EQ No.	Date	Magnitude (JMA)	Depth (km)	Epicenter
EQ 1	1997/8/9	4.7	68	South suburb of Saitama pref.
EQ 2	1997/9/8	5.1	108	Tokyo bay
EQ 3	1997/12/6	4.6	56	North-west suburb of Chiba pref.
EQ 4	1998/3/23	5.3	45	Far east of Ibaraki pref.
EQ 5	1998/4/9	5.4	93	Far east of Fukushima pref.
EQ 6	1998/5/16	4.8	74	South suburb of Chiba pref.
EQ 7	1998/6/24	4.6	51	South suburb of Ibaraki pref.
EQ 8	1998/8/29	5.1	67	Tokyo bay

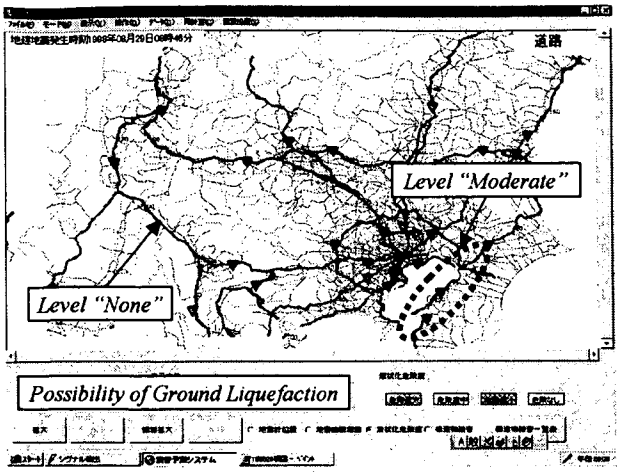
As an example, **Fig. 5** shows the measured ground motions and estimated damage possibilities by the EQ8 on August 29, 1998. "Moderate" possibility of ground liquefaction and "Slight" possibility of bridge damage were partially estimated around Tokyo Bay.



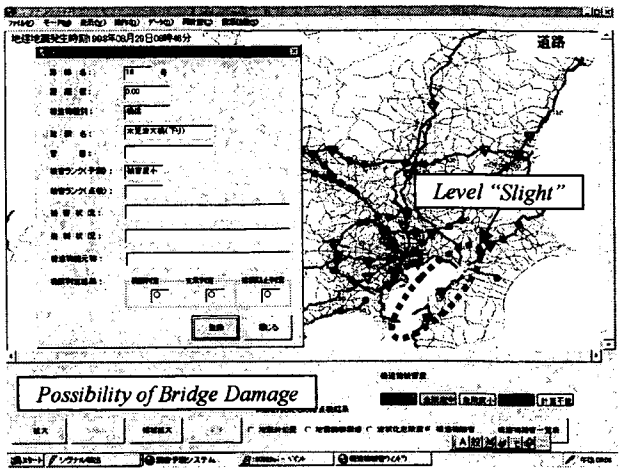
(a) Maximum Ground Acceleration along Highway



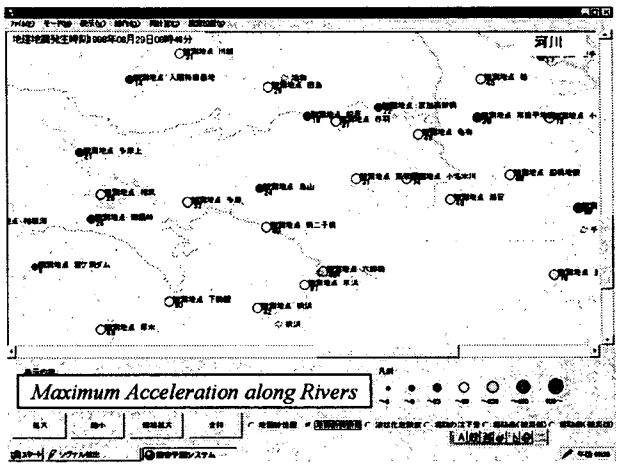
(b) Spectrum Intensity along Highway



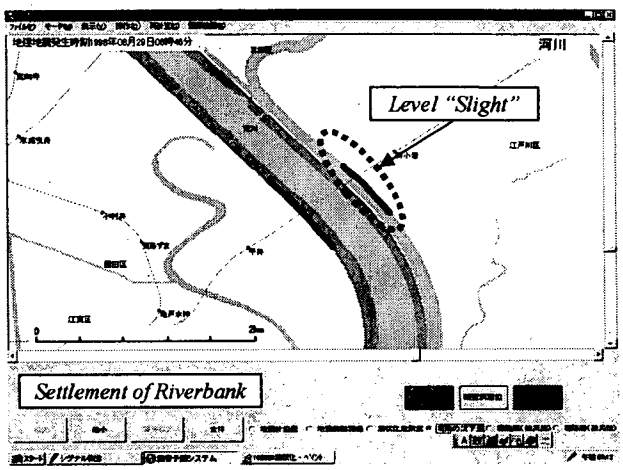
(c) Possibility of Ground Liquefaction



(d) Possibility of Bridge Damage



(e) Maximum Acceleration along River



(f) Possibility of Settlement of Riverbank
(Additional Function, under testing)

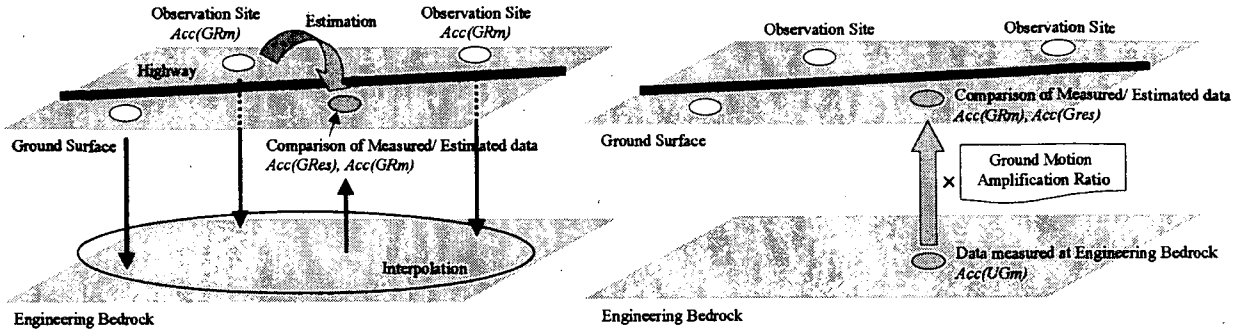
Fig.5 Estimated Damage Possibility by EQ8, August 29, 1998

4.2 Distribution of Ground Motion

A feasibility of the analytical model was studied using ground accelerations measured at the ground surface. As shown in **Fig.6(a)**, measured maximum ground acceleration was compared with estimated maximum acceleration supposing a observation site as a judgement site. **Fig.7(a)** and **Fig.7(b)** shows the comparison of measured/ estimated maximum ground accelerations for the EQ8 and eight earthquakes respectively.

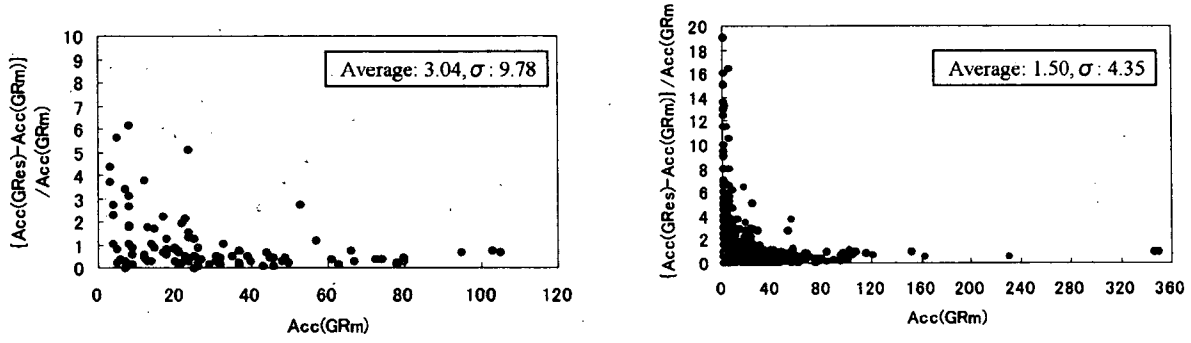
4.3 Ground Motion Amplification Ratio

A feasibility of the ground motion amplification ratio was studied using ground accelerations measured at the ground surface and the engineering bedrock. As shown in **Fig.6(b)**, measured maximum ground acceleration was compared with the maximum acceleration estimated by the amplification ratio. **Fig.8** shows the comparison of measured/ estimated maximum ground acceleration for eight earthquakes (EQ1-EQ8).



(a) Feasibility of Ground Motion Distribution (b) Feasibility of Ground Motion Amplification Ratio

Fig. 6 Comparison of Measured/ Estimated Maximum Ground Acceleration



(a) EQ8 **(b) Eight Earthquakes (EQ1-EQ8)**

Fig. 7 Feasibility of Analytical Model for Estimating Ground Motion Distribution

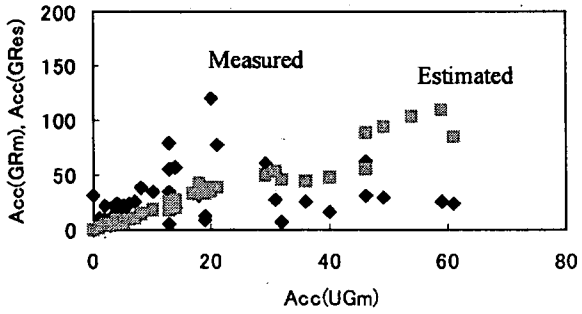


Fig. 8 Feasibility of Ground Motion Amplification Ratio

5. CONCLUSIONS

1. The seismic assessment tool for urgent response and notification: SATURN was introduced. By providing rough estimation on the damage states and damage distributions of road facilities immediately after an earthquake, the system will support decision-makers to facilitate emergency

works, i.e. damage inspections with restricted amount of inspectors, management of buck-up organization, and management of construction stuffs/ machinery.

2. SATURN estimates possibilities of ground liquefaction and highway bridge damage within 15 minutes. Damage estimation is carried out using pre-stored ground/ structural condition data and earthquake ground motion data monitored by the accelerographs network. Evaluation of damage states is made by the maximum acceleration Amax and spectrum intensity SI as judgement indexes.
3. Prototype system that covers Tokyo area is under operation at the regional construction bureau of MOC. For activating this system to the disaster prevention practice, further research will be required on the following subjects;
   1) Verification of damage estimation methodologies with use of the prototype system.
   2) Developments of damage estimation methodologies on the other road facilities, such as the slope failure, embankment sinking and damage of underground lifelines.
   3) Clarifying the seismic information system architecture including SATURN and other advanced information technologies, such as the wide area monitoring technology, data collecting technology, data analyzing technology using GIS, and decision-making support tools.

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HAZUS Capabilities as A Near-Real Time

Rapid Damage Assessment Tool

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Abstract

An early transmission and gathering system for post-earthquake ground data has numerous benefits. First, it provides with an idea of the severity and extent of the disaster that just happened. Second, it provides vital information to emergency response personnel to expedite field inspections, provide quantitative data for damage and loss estimation models, and prioritize early reconnaissance. As observed data becomes more available, this information will become the basis for further response decision-making.

This short paper illustrates how such data has been utilized by FEMA's risk assessment system, HAZUS (Hazards U.S.), during the October 16, 1999 Mw 7.2 Hector Mine, CA earthquake. Through HAZUS, damage was quickly estimated, thus providing critical information for the assessment of the nature and scope of emergency response needed. The more refined the analytical results predicted by HAZUS are, the more accurate the timely assessment is.

Results from three simulations through this process were obtained. First, right when the earthquake occurred, a preliminary epicenter location and a magnitude were available. Shortly after, the magnitude was revised downward. Then, some approximate ground shaking maps were developed based on the revised information as well as the readings from the seismic array spread out throughout Southern California.

This paper summarizes the damage predicted by HAZUS for three scenarios. These are:

- Scenario 1: using the preliminary epicenter location and magnitude (Ms=7.3) information along with a default rupture mechanism generated by HAZUS and a default inventory scheme for the impacted region.

- Scenario 2: using the revised epicenter location and magnitude (Ms=7.0) information and assuming rupture at the nearest fault (Bullion Fault).

- Scenario 3: using the approximate TriNet-based ground shaking maps along with an improved building inventory scheme for the impacted region.

TriNet is a multifunctional seismic network for earthquake research, monitoring and computerized alerts. It continuously monitors seismicity and ground shaking in Southern California. This monitoring produces rapid estimates of earthquake times, epicenter location, magnitude, depth, probable or causative fault, mapped ground motion, and aftershock information. The mapped ground motion is generated by ShakeMap, which employs a simplified geological classification scheme to achieve a regional scale site correction. Available as a set of GIS overlays, this scheme contains simplified Quaternary, Tertiary and Mesozoic (QTM) units, which are translated to a soil, soft rock and hard rock classification. The QTM methodology lacks adequate detail in terms of resolution and empirical data, but provides the basis for first-order site corrections (Wald et al., 1998).

Introduction

HAZUS is designed to produce loss estimates for use by state, regional and local governments in planning for earthquake loss mitigation, emergency preparedness and response and recovery. The methodology deals with nearly all aspects of the built environment, and with a wide range of different types of losses. The methodology has been tested against the experience from several past earthquakes and against the judgment of experts (HAZUS, 1999).

HAZUS consists of the six interdependent modules illustrated in Figure 1. This modular approach allows three levels of analysis to be performed; approximate results based on default national databases contained within HAZUS; refined results using inputs of detailed local geology and infrastructure characteristics; and more accurate results based on detailed engineering and geotechnical inputs that customize the methodology to a specific region.

Given the location and size of an earthquake, HAZUS estimates the level of ground shaking and the resulting physical damage to the infrastructure. Using these damage levels, HAZUS estimates the economic and social losses, as well as loss of functionality. In the case where ground motion data is available, the earth science hazards module (shown in Figure 1) is skipped.

HAZUS economic losses include structural and non-structural damage, costs of relocation, losses to business inventory, capital-related losses, income losses, and rental losses. HAZUS social losses are quantified in terms of casualties (four severity levels), displaced households, and short-term shelter needs.

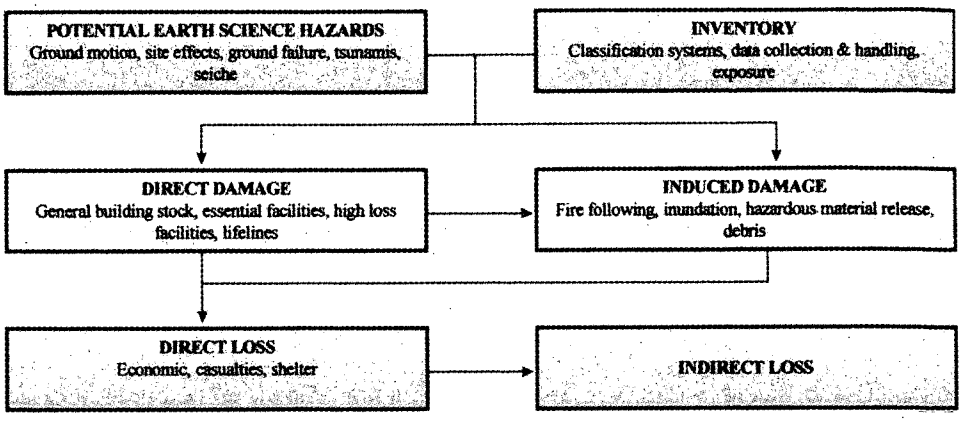


Figure 1. HAZUS Earthquake Loss Estimation Methodology Components

HAZUS Results for the October 16, 1999 Hector Mine Earthquake

Figure 2 below displays a sample ground shaking map produced by TriNet for the October 16, 1999 Hector Mine earthquake, while Figure 3 corresponds the population distribution in the impacted area, which is representative of how much was at risk.

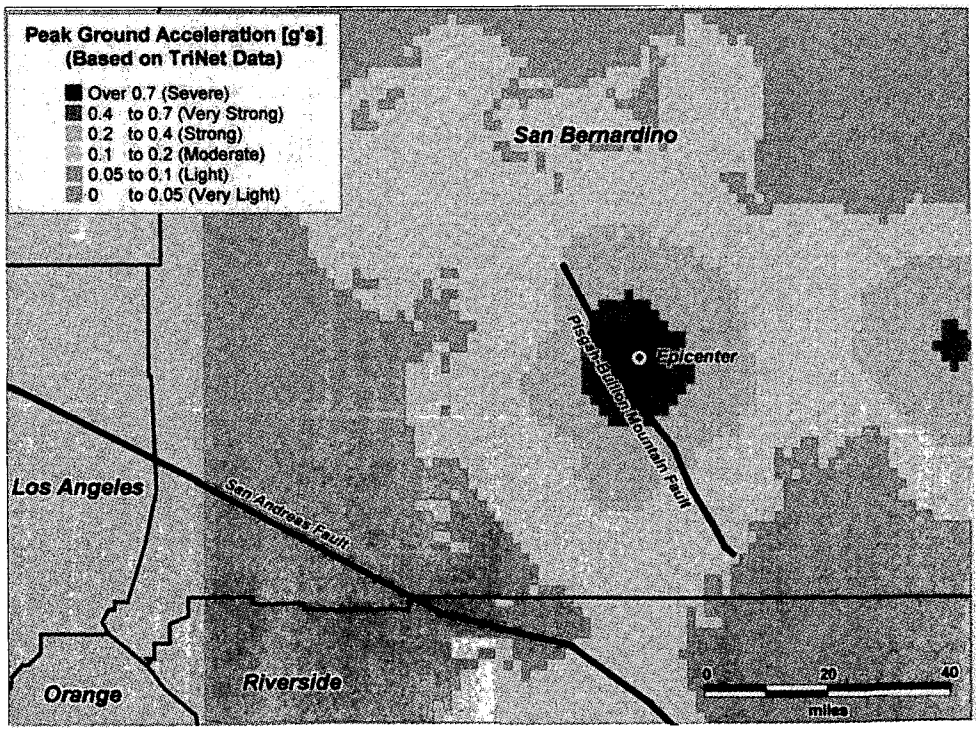


Figure 2. Sample TriNet based Ground Shaking (Peak Ground Acceleration) Map

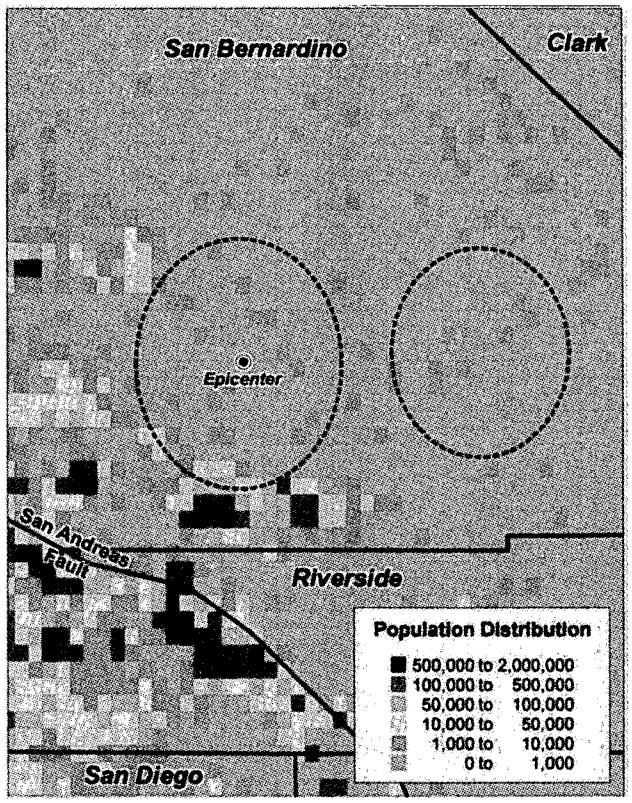


Figure 3. Population Distribution in the Vicinity of the Area Impacted by the October 16, 1999 Hector Minor Earthquake

Note that the dotted areas in Figure 3 (about 3,000 square miles) represent the areas subject to peak ground acceleration greater than 0.20g, which is about the threshold for shaking capable of causing moderate damage or worse. Each grid shown in Figure 3 is about 10 square miles. Clearly, one can understand how fortunate the United States was with respect to this earthquake, as very sparse population and therefore exposure exists in the region experiencing the severe shaking. By comparison, Figure 4 shows a similar map of the population distribution with respect to damaging levels of shaking for the January 17, 1994 6.7 Northridge earthquake; which caused about $ 40 Billion in total losses (Eguchi et al., 1998).

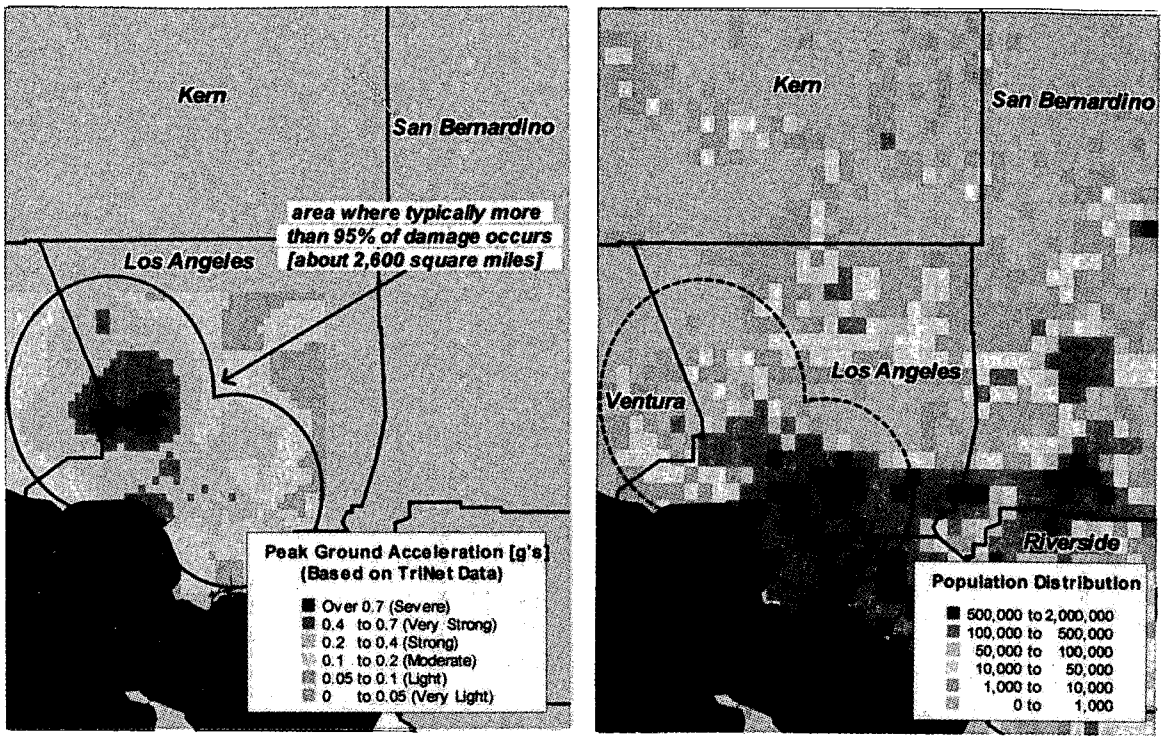


Figure 4. Population Distribution in the Vicinity of the Area Impacted by The January 17, 1994 Northridge Earthquake

Figures 5 and 6 below show the results obtained from HAZUS for building damage and social losses, respectively, corresponding to the three scenarios described at the beginning of this paper.

Figures 5 and 6 clearly indicate how the damage estimates have improved as better data became available and were used. For instance, the number of the heavily damaged buildings was improved by a factor of 15, while the property damage losses were refined by a factor of six from the preliminary estimate. Similarly, the casualty estimates were reduced by a factor of 10, and the shelter by a factor of 60.

These numbers also indicate that this event was a 'non event' in terms of requiring major emergency response.

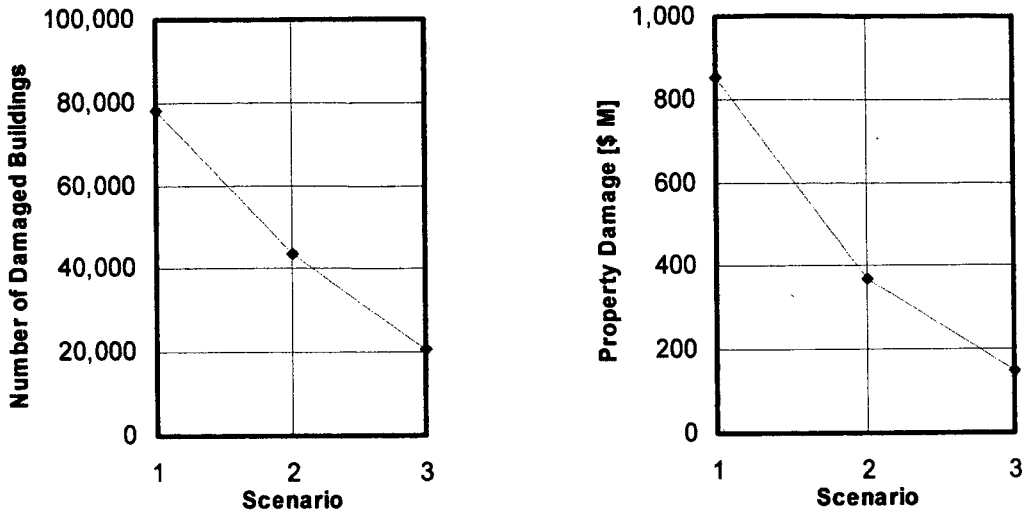


Figure 5. HAZUS Predicted Building Damage from the Three Simulations

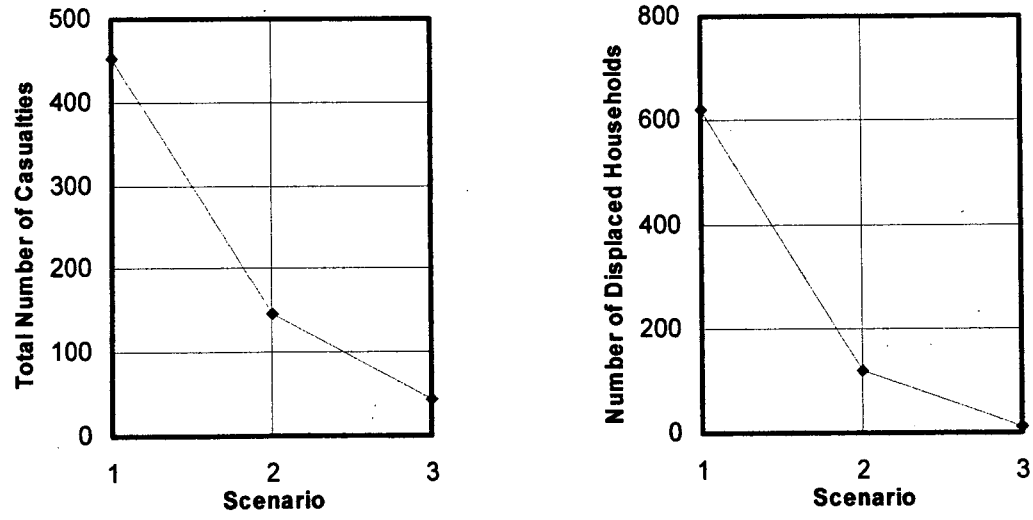


Figure 6. HAZUS Predicted Social Losses from the Three Simulations

Concluding Thoughts

Damage and losses depend not only on the size and location of the earthquake but also to a great extent upon the density of the population; the type, spatial distribution, and quality of construction; and the socio-economic makeup of the region, as indicated in Figure 7. If an earthquake occurs in an unpopulated region, there will be little to no effect on regional infrastructure and little likelihood of loss of life. However, if the same earthquake were to occur near a large city then one could expect significant damage and monetary as well as social losses. The October 16, 1999 Hector Mine earthquake just happened to be an example of the former case. As the world becomes progressively more urbanized and people move to and settle in densely populated metropolitan areas, earthquakes occurring near these urban areas would cause tremendous losses. The Northridge earthquake illustrates the impact of an earthquake in somewhat high-density environment. A strong earthquake on the Newport Inglewood fault zone will most likely cause five to ten times more damage than the one created by the Northridge event.

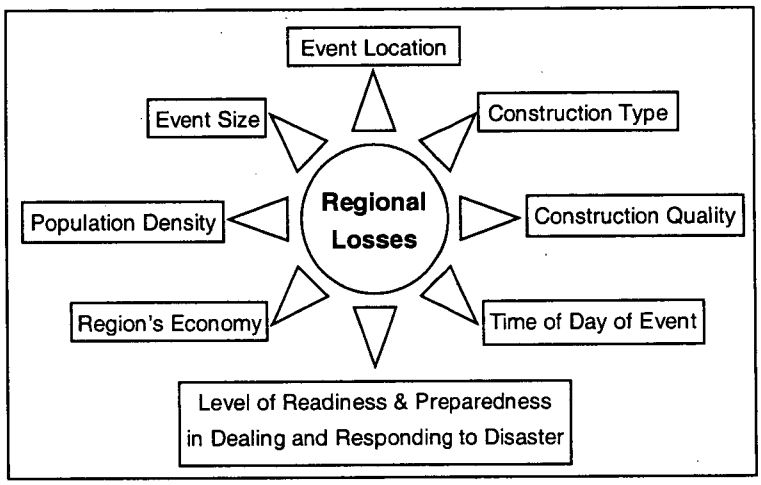


Figure 7. Factors Affecting the Extent of Damage During an Earthquake

The near real time and damage assessment generated by HAZUS along with the ground shaking maps produced by ShakeMap represent a significant step forward in providing the type of information needed by emergency planners in decision support, such as resource mobilization and prioritization of reconnaissance efforts. This earthquake event was a fortuitous event as it provided a great opportunity to exercise HAZUS near real time quick assessment and response capabilities for a significant earthquake.

References

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THE EARTHQUAKE DAMAGE ESTIMATION SYSTEM OF TOKYO FIRE DEPARTMENT

FUJITA Toru*

ABSTRACT

This paper introduces an outline of the Earthquake Damage Estimation System of Tokyo Fire Department (TFD), which gives information necessary for quick response to damaged areas in case of earthquake.

Linked seismograph network installed at 42 fire stations and 46 municipal government offices in Tokyo and automatically fed with shaking intensity and acceleration data, the Earthquake Damage Estimation System of TFD rapidly pinpoints the disaster-struck areas and provides estimation for human casualties, fires, collapsed buildings, etc., required for the initial earthquake operation.

KEY WORDS: Earthquake Damage Estimation System, Earthquake Operation

1. INTRODUCTION

Many earthquakes have struck Tokyo in the past, causing much damage. The South Kanto District, which includes Tokyo, is well known for its frequent earthquakes even in earthquake-prone Japan.

It was pointed out in 1988 by Central Disaster Prevention Council that " *It would be probable and urgent that an earthquake directly below the South Kanto Region could occur.*"

The Tokyo Metropolitan Government estimated the damage to be 7,000 deaths, 824 fires, 296,000 building collapse etc. in "*Investigation Report on Damage Hypotheses in case of Earthquake with Focus Directly Below Tokyo* (1997)".

Rapid grasp of damage enables us to speed and improve earthquake operation. This system has enabled us to provide grasp of a highly detailed damage by the seismograph network and the damage estimation.

2. OUTLINE OF THE EARTHQUAKE DAMAGE ESTIMATION SYSTEM OF TFD

The system is composed of a seismograph network, a host computer, and personal computer terminals as shown in Figure 1.

The seismographs have been installed at 42 fire stations and 46 municipal governments (wards, cities, towns and villages), and these 88 seismographs altogether form a network.

When an earthquake occurs, the seismographs measure acceleration and shaking intensity and these data are automatically inputted to the host computer with LAN.

Various damage estimate items are calculated based on inputted data, and the results of calculation are displayed graphically on a PC terminal monitor using an area color-coded map according to the seriousness of estimated damage, with either suburb/street names or a 250-m

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mesh grid as shown in figure 2.
Moreover, a similar estimation can be done by PC terminals in fire stations.
It is also possible to input the position, the depth, and the magnitude of the hypocenter arbitrarily to this system, therefore the system can be used for fire drill, city planning for disaster prevention.

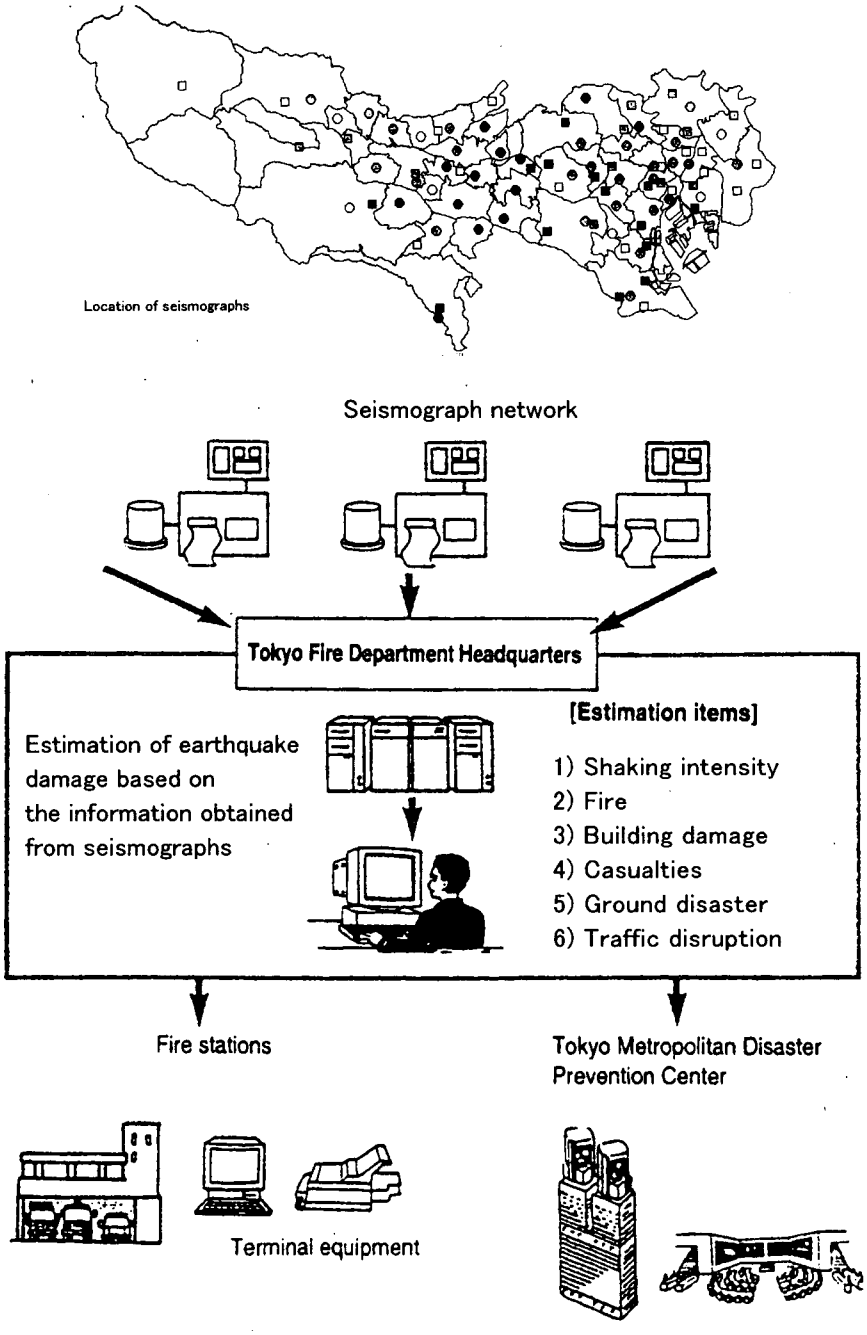


Figure 1 The Seismograph network and the Earthquake Damage Estimation System of TFD

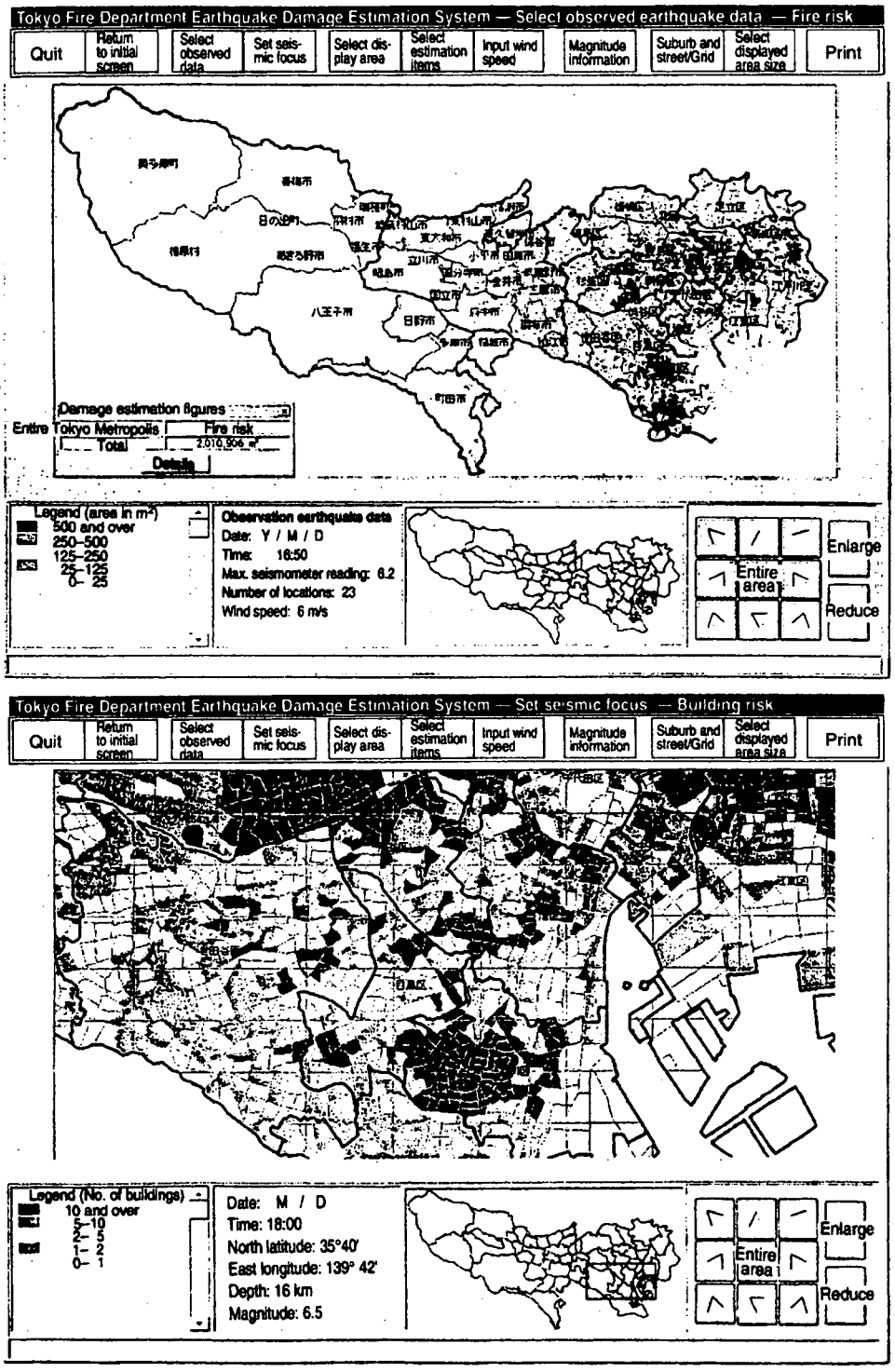


Figure 2 Screen Display Example of the Earthquake Disaster Estimation System of TFD (Up:Fire ; Down: Building Damage)

3. ITEMS OF DAMAGE ESTIMATION

The damage estimation items required for effective earthquake operation, are largely integrated into 6 main items. If necessary, 35 detailed items can be available.

(1) Intensity of ground shaking

Shaking intensity at a point is calculated from observed acceleration data and the ground database.[1,2]

On the other hand, it is possible to set an arbitrary hypocenter. In this case the acceleration at an arbitrary point is presented by Watabe and Toudou's formula[3] :

$$\log_{10}A=0.440M-1.38\log_{10}X+1.04$$

where, A: Acceleration in base(cm/s^2) where S wave speed is 1.1km/s.
M: Magnitude
X: Hypocentral distance (km)

(2) Fire

Fire potential can be expressed by product of probability of fire breaking out and fire spread areas.

Probability of the fire breakout for each building type is calculated based on the event tree analysis and the distribution of each building type.[4]

Fire spread area after an hour is calculated based on the fire spread rate equation (TFD formula 97).[5] This equation is used in the Fire Spreading Simulation System of TFD.

(3) Building damage

Building damage is estimated by the relation between the building damage and acceleration in the Great Hanshin Earthquake and the influence of liquefaction. This method is based on "*the Damage Hypotheses with Focus Direct below Tokyo*". The probability of liquefaction is calculated based on the PL value (Potential of Liquefaction) and the ground database.

(4) Casualties

The probability of death and wound by cause is calculated based on event tree analysis referring to the Great Hanshin earthquake.[6] The causes of death and wound are building collapse, block wall collapse and fire. Distribution of population by cause is calculated based on National Census(1995) and Person Trip Survey(1990).

(5) Ground disaster

Ground disaster risk can be expressed by the sum of ranked Liquefaction risk and Landslide risk.
The probability of liquefaction is calculated based on the PL value and the ground database.
The house damage is calculated based on the data of house damage in Kozu town caused by Izu Oshima Sea Earthquake(1978) and Survey of Landslide Risk(1991).

(6) Traffic disruption

Traffic disruption in an area can be presented by the average speed of cars passing through the area. This average speed is affected by liquefaction and collapse of buildings facing roads.
Average speed in passing through every 250-m mesh area in ordinary days is calculated based on

Road Traffic Census (Ministry of Construction, 1996) and the traffic possibility is calculated based on the evaluation method of the traffic disruption.[7]

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Seismic Disaster Information System for Hiroshima City

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Abstract

The city of Hiroshima is now developing a seismic disaster information system to support its decision making at the Fire Services Bureau in case of a big earthquake. The system consists of strong motion monitoring subsystem, damage estimation subsystem, information delivery subsystem, soil condition database and facilities database. In February, 1999 when the ground motion monitoring accelerometers have been installed, a set of records of a M_{JMA}=4 earthquake was obtained. It was proved that the strong motion monitoring subsystem works normally. And it was also known that the GIS system incorporated in this system is very useful not only for earthquake disaster but for rain induced disaster.

1. Introduction

In 1995-1997 after the Hyogoken-nanbu earthquake, Hiroshima city conducted a damage assessment survey around the area against the possible big earthquake in the future [Hiroshima city, 1977]. As part of the lessons learnt from the earthquake, it was well recognized that a big earthquake may simultaneously cause various and numerous damage at spots spread widely. And it was noticed necessary to be prepared by not only administrative agency but by citizens themselves. With this in mind, maps indicating the possible damage in the region and evacuation areas have been distributed to all households to educate the citizens.

At the same time, to create a city prepared against earthquakes, it was also strongly recognized the importance of preparation to grasp the damage status in the city in real-time manner, so that the city can conduct smooth rescue activities and can prevent the spread of damage during an earthquake.

Thus the Hiroshima city is now developing a disaster information network system for the city area since 1997 [Sasaki et al. 2000]. The system is to have a capability of displaying the seismic intensity around the area in 3 minutes, and also it can show the damage distribution in the area within 20 minutes estimated from the observed ground motions at 8 locations in the city.

In February, 1999 when the ground motion monitoring accelerometers have been installed, a set of records of a M_{JMA}=4.0 earthquake was obtained.

This paper will summarize the seismic condition around the area, framework of the system, and the structure of the prepared database, the way of estimating the damage from observed ground motion together with brief description about the ground motion records obtained by now.

2. Seismic condition near the area

Hiroshima city is located in Chugoku Region in western part of the Honsyu Island, about 300 km apart from Osaka, and has been developed on the delta of the Ohta River, which flows into the Seto Inland Sea.

The old city area was originally developed on the natural deposit of the delta, and has been extended towards

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the coast on reclaimed land [Aboshi, 1991], so the susceptibility of liquefaction of this land is highly anticipated. And as it is extended on the artificial fill work in Meiji era, the old city area includes an area of so-called "zero meter area" of which altitude is below full tide. The six rivers that flow through the delta are expected to provide fire-break functions, but they also represent obstacles to a clear route of escape.
As a result of a recent concentration of population in the urban area, Hiroshima has now grown to over 1.1 million people, with urbanization now spread widely on the hilly areas behind the delta and the low-lying areas along the river valley.

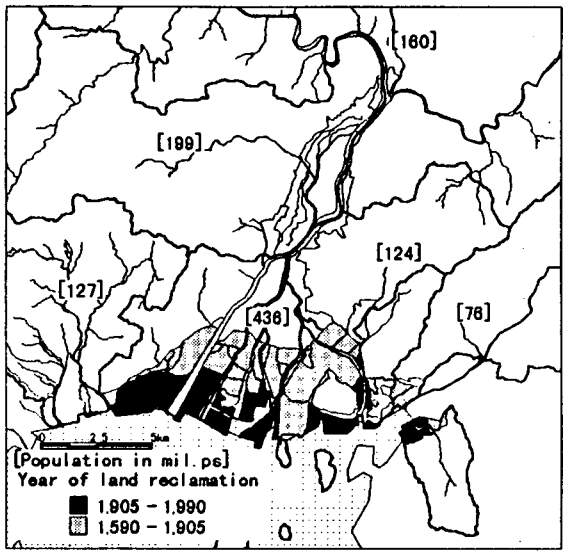


Fig.2.1: No. of habitants in the city and land reclamation history in Hiroshima delta

The area of the newly developed residential area in the hilly areas reaches almost 93% of the city's approximately 5,400 hectares of the exclusive residential area. As the original topography of these areas was mountainous, the area was developed by cut and bank work utilizing the decomposed granite soil nearby. And gorges and slopes are surrounding the areas, which has potential danger of failure in case of big earthquakes. So, it is important to remember that if a big earthquake hits the area, the access roads may be blocked and may cause difficulty to rescue activities.

Earthquakes with the potential to cause damage to the Hiroshima city area are roughly divided into two types: earthquakes originating in troughs off the Pacific coast, and along active faults inside the land. The trough type earthquake can be further divided into inter-plate earthquakes and intra-plate earthquakes.

Table 2.1: Anticipated earthquakes near Hiroshima

Trough Type	Inter-plate Type –Nankai Trough off the coast of Shikoku Plate-edge Type—Sea of Akinada-Iyonada
Active Fault	Koi Fault,Itsukaichi fault,Ogata-Oze Fault,Median Tectonic Line,Iwakuni fault,Kikukawa Fault,Yamazaki Fault,Others

Representative earthquakes of the inter-plate type are major ones that occur frequently along the Nankai Trough. However, as the epicenteral distance of such earthquakes is long, the effect on Hiroshima city is not major. The earthquakes classified into the ones occur at plate edge around the Sea of Aki-nada and the Sea of

Iyo-nada took places several times in the past as shown in Table 2.2 [Usami, 1987]. Though their magnitude is not large, as the epicenter of these earthquakes is located nearby, their effect on the Hiroshima city area was significant. Those records show that earthquakes in this region have a relatively high rate of recurrence.

Table 2.2: Past earthquakes in sea of Aki-nada and Iyo-nada

Date	M	Main damage
1649.3.17	7.1	Collapse of residential houses
1686.1.4	7.0	Large damage in western part of Hiroshima Pref.
1857.10.12	6.4	Collapse of residential houses and causalities
1905.6.2	7 1/4	Totally Collapsed house 36, Partly Collapsed house20, Dead 4, wounded 73

Faults that could cause an earthquake that might affect the area are also shown in Table 2.1. Of such earthquakes, according to an active fault survey conducted by Hiroshima city in 1996 [Hiroshima city, 1996], it was judged from the evidence that it acted about 1,000 years ago, that the Koi fault had latent danger associated with it, despite its low recurrent frequency.

3. Frame of the system

Main objective of this system is to support the decision making at the Fire Services Bureau of the city in case of disastrous earthquakes. The Bureau has to decide the proper response activities immediately after the earthquakes. This decision includes whether or not to initiate the disaster headquarter, the size of the mobilized personnel, prioritization of the area where the damage information should be collected in detail, and the necessity of requests for assistance from neighboring local governments or Japan's Self Defense Forces.

To meet this objective, the system has to compile the locations and features of damage in the city into a damage distribution map in a real time manner so that the Bureau can easily grasp the damage status as soon as possible. Therefore, the ground motion monitoring stations are to be deployed to send the observed motion during the shaking, and the system provides the seismic intensity distribution and rough estimation of liquefaction occurrence area in the city within 3 minutes after an earthquake (primary estimate). Within 20 minutes after an earthquake, the system provides information about the damage in the city (secondary estimate). Those damage information has to include casualties and structural damage to buildings and facilities as shown in Table 3.1, which is needed for judging the necessary degree of response by the Bureau.

Table 3.1: Damage indices estimated from the observed ground motion

Ground Motion	Ground Failure	Estimated damage
Seismic intensity		
maximum acceleration	Liquefaction potential Land slide potential	Water supply system
Spectral intensity		Lifeline System, Bridges
Response velocity spectrum		Buildings ,Fire,Casualties

However, as it is almost impossible to get the whole damage in a short period even if a survey on the actual damage is conducted, it was decided to estimate the damage status as follows. Firstly the ground motion distribution in the city is estimated, followed by the estimation about damage to structures from the ground motion and ground failure such as soil liquefaction or slope failure. The soil liquefaction or slope failure are estimated from the ground motion and the soil condition model. Casualties are estimated from the calculated structural damage. Figure 3.1 illustrates the concept to provide necessary information by this system.

In order to satisfy this concept, as indicated in Fig. 3.2, the system comprises strong motion monitoring

subsystem, damage estimation subsystem, information delivery subsystem, soil condition database, and building and facilities database.

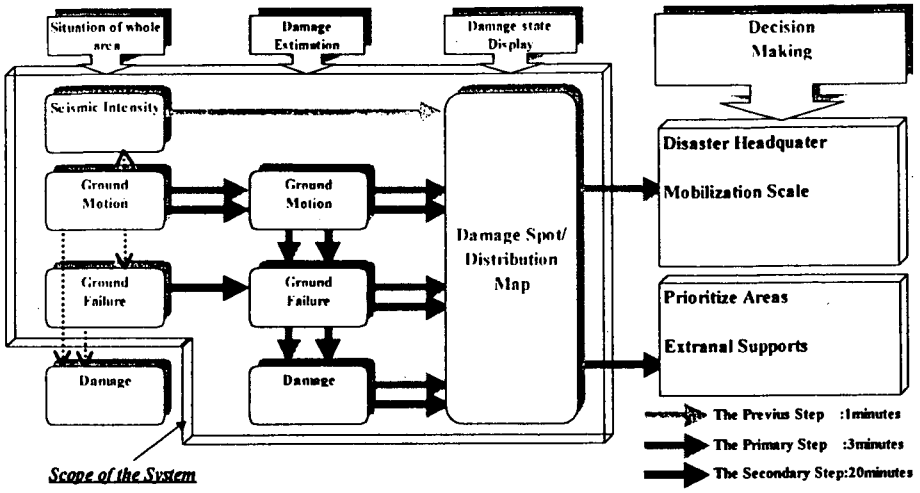


Fig. 3.1: Concept for accomplishing the objective

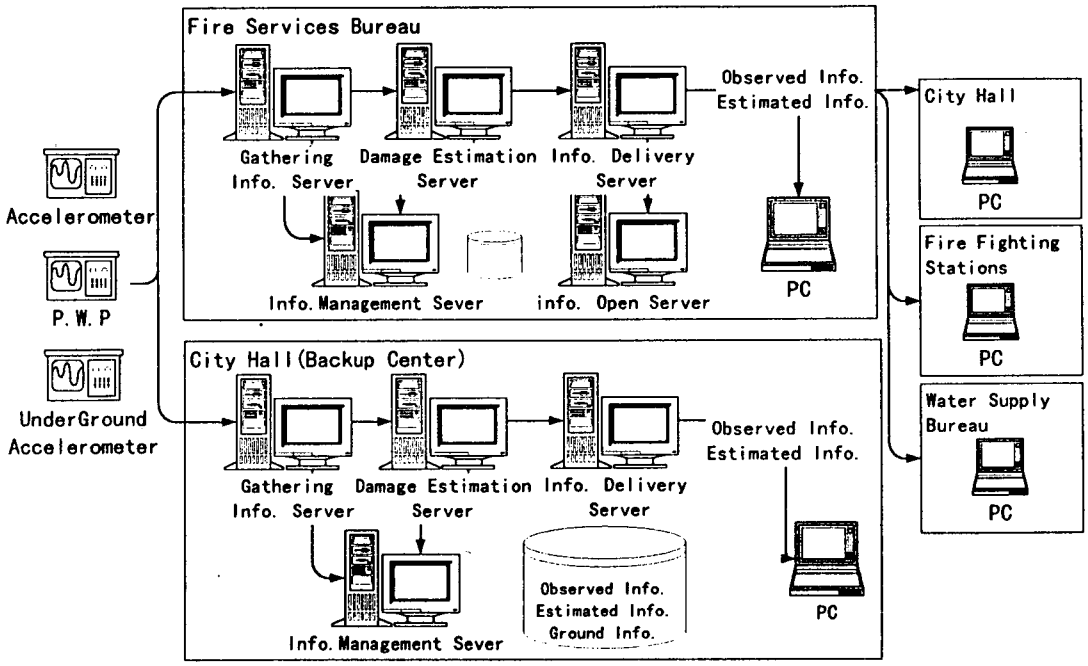


Fig. 3.2: Combination of the system equipment

The system's main center is located at the Fire Services Bureau of the city, and even if unexpected situations occur to the main center, its regular functions can be maintained by a back-up center in the city hall.

The ground motion monitoring subsystem transmits observed data to both the main and back-up centers, upon which each handle the data with independent systems. In addition, there are two sets of transmission lines that run from the earthquake monitoring stations to the centers – ordinary public lines and a wireless system – in the event of convergence or interruption of transmission lines. As all functions of the entire system are backed

up in this way, the system's construction is reliable even should damage to the facilities in the centers occur or if there is a partial loss of their functions.

4. Ground motion monitoring subsystem

The ground motion monitoring stations number a total of 8, and are located, 1 each, in the 8 administrative wards of the city as shown in Fig. 4.1. Of these 8 monitoring stations, at the Ushita Water Purification Plant, Sports Park and the Training Center for Fire-fighting, the bedrock depth lies at least 5 meters beneath the soil surface, with that of the other 5 monitoring stations at about 17~45 meters (Table 4.1). At the Fire Bureau Air Base, a vertical array has been deployed, including accelerometers at 3 depths to monitor the amplification characteristics of the ground motion in the delta's alluvium layer. At this monitoring station, as well as the Yano-Shinmachi Park and the Minori Park, pore pressure meters have been also installed.

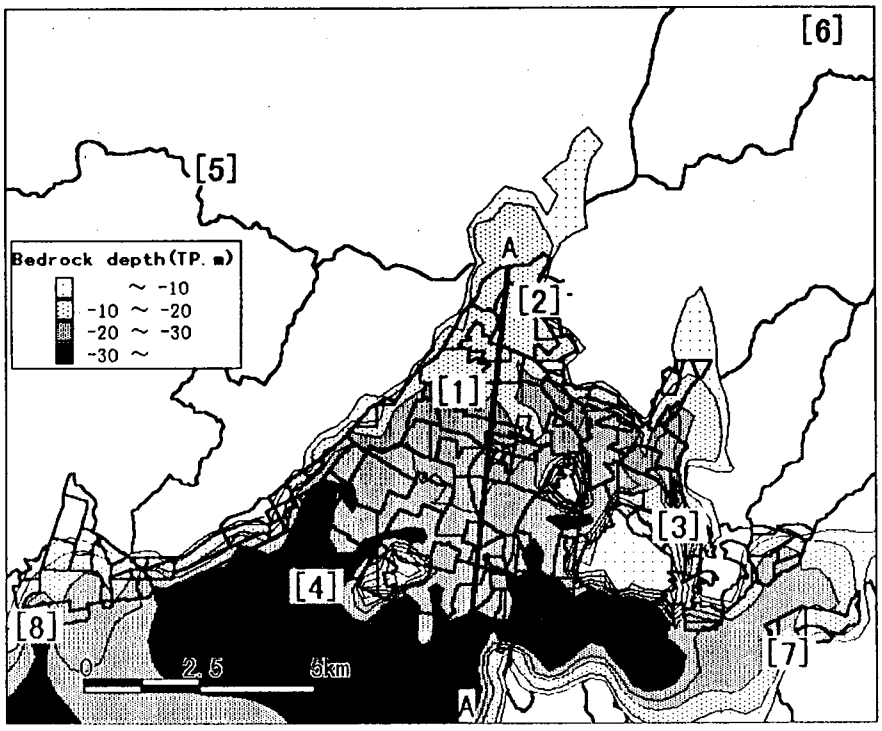


Fig. 4.1: Base rock depth and location of observation stations (location numbers in [ ] are No. in Table 4.1)

Table 4.1: Site conditions at each station.

No.	Observation station	Accelero-meter	P.W.P	Bedrock depth m
[1]	Hirose-kita Park	GL 0		27
[2]	Ushita Water Plant	GL 0		4
[3]	Garbage Station	GL 0		17
[4]	Fire Bureau Air Base	GL 0, -8, -21, -36	GL-5.8	34
[5]	Sports Park	GL 0		2
[6]	T.C for firefighting Works	GL 0		5
[7]	Yano-Shinmachi Park	GL 0	GL-4.8	33
[8]	Minori Park	GL 0	GL-3.3	44

Figure 4.2 and 4.3 show the monitoring station and the soil profile at the Fire Bureau Air Base as an example of all the monitoring stations.

The accelerometers used are three-component servo-type accelerometers, having a measurement range 0-2,000 gals, sampling frequency of 100 Hz, and a delay unit for 15 seconds, and their trigger level is set to be 1.5 gal. The measuring system has functions to calculate the seismic intensity, acceleration response spectrum and SI values from monitored acceleration records. These values along with time-history of acceleration and pore pressure are to be transferred to main computers either over public telephone lines or a wireless communication system.

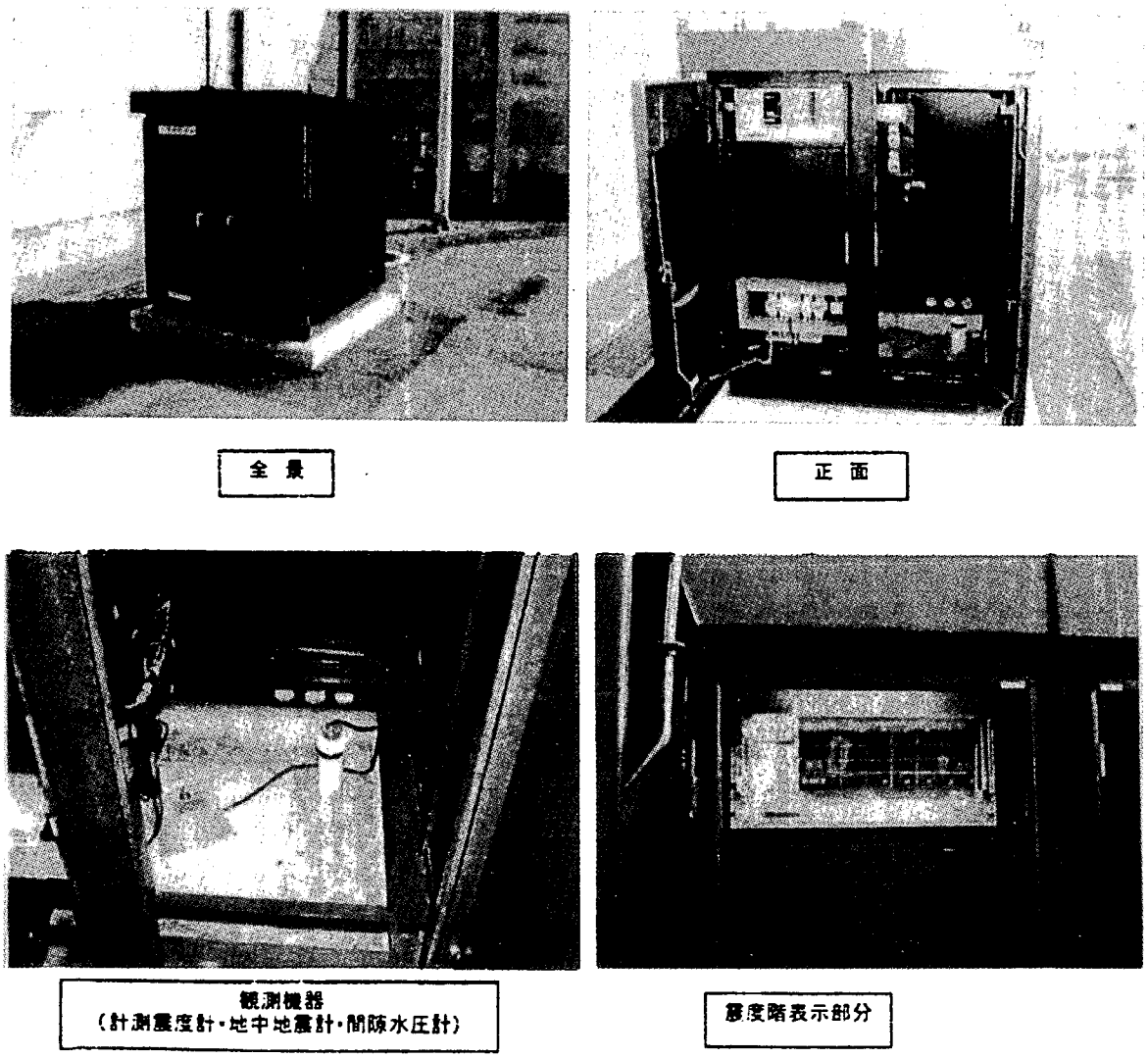


Fig. 4.2: Pictures of the monitoring station (Fire Bureau Air Base)

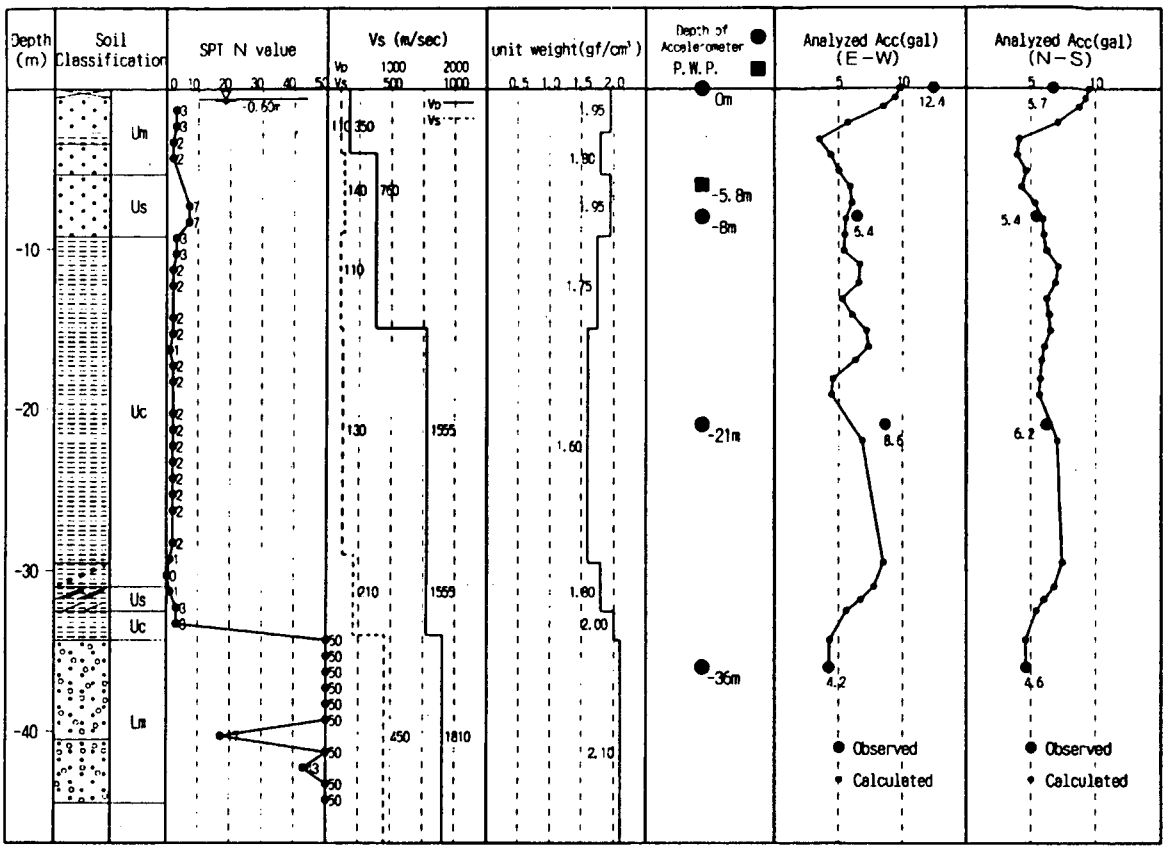


Fig. 4.3: Soil profile at Fire Bureau Air Base Station

5. Soil condition modeling

Seismic damage is usually caused by either or both of the ground motion at sites and the ground failure at sites such as soil liquefaction or slope failure. As mentioned before, the damage of the area is to be estimated from the monitored ground motion at 8 sites in the city, it is necessary to supplement the ground motion in between these monitoring sites to estimate the whole area of the city, which will be described later. For this purpose and to estimate the ground failure induced by an earthquake, it is necessary to model the soil condition of the area.

In order to establish a soil condition model for this area, existing boring logs and manhole data of the sewerage system, which contains the altitude of their locations, were collected and compiled into a soil condition database. The total number of collected boring logs reaches almost 6,500. From this database, idealized soil profiles were established and allocated to each point where the calculation is conducted to estimate the seismic response or liquefaction susceptibility. Those calculating points must be chosen properly so that the necessary computing time is reduced and to well represent the soil strata around them. In lowland area in the delta, administrative zoning was basically chosen as the subdivided sections for this purpose, though in this administrative zoning was further subdivided into smaller sections in accord with the results of the examination described below. And in the hilly area, basically the computing points are allocated in the center of the 500 m by 500 m mesh in the urbanized area. The total number of points thus selected for lowland area is 588 points and 1,151 points for the hilly area. Those 1,739 points are the addresses of idealized soil profiles in the soil condition model of the area. Figure 5.1 and 5.2 show the locations of these calculating points.

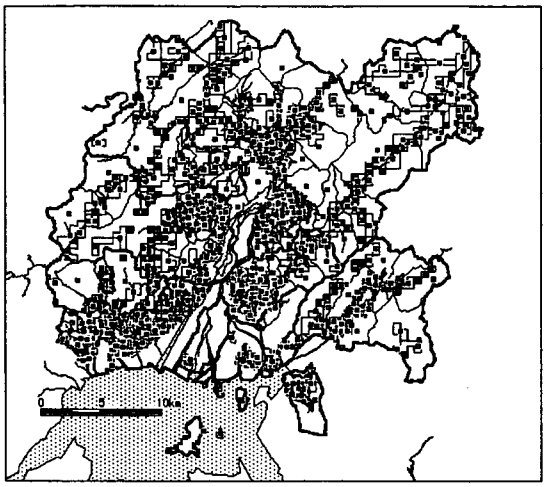


Fig.5.1: Calculating spots excluding lowland area (1,151 Spots)

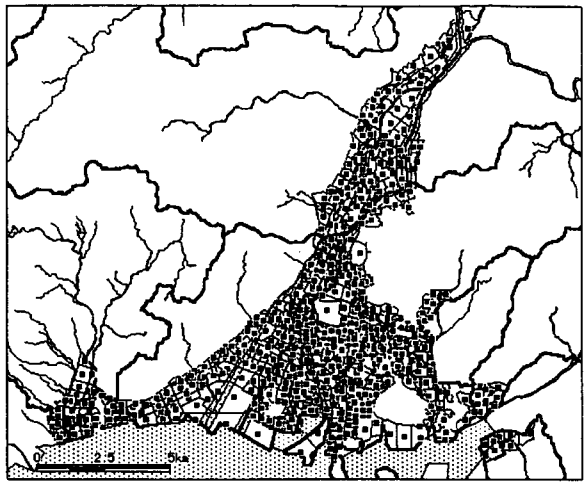


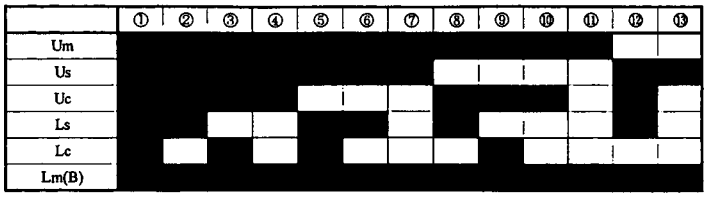
Fig.5.2: Calculating s pots in lowland area (588 spots)

The idealized soil profiles were compiled by following procedure.

Firstly the area was classified into 14 categories from the view point of its formation judged from geo-morphological feature, 4 for hilly area and 10 for lowland in the delta. Next from the bedrock depth of each subdivided area, they were classified into 6 cases in accord with their depth by 5 m interval. By combining this subdivision and the geo-morphological classification makes the 42 types of the soil condition for subdivided area in lowland area whereas the 8 types in the hilly area. Furthermore the soil stratum at each section was examined to find out the idealized stratum. Generally the soil stratum in the Hiroshima delta is composed of uppermost surface layer, alluvial sand layer, alluvial clay layer, lower sand and gravelly layer, and base rock layer. In some subdivided sections, some of these layers are lacked and types of the soil condition from soil strata were found to be 13. Finally by combining this classification from stratum and the classification from formation and base rock depth, established soil condition model were composed of 126 types.

As a result of this procedure, one of these 126 different types of idealized soil profile is allocated to each aforementioned computing point along with their unit weight, shear wave velocity, and SPT N values in the soil condition model.

Figure 5.3 and 5.4 show the procedure to establish soil condition model and the comparison between the modeled and actual profile along the line A-A in Fig. 4.1.



(1)Geo-morphology	(2)Base rock Depth	(3)Strata ①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	Σ(Soil Condition Model)
Mountain	~5m											1			1
	1 *CASE*											1			1
Mt.Foot Slope	5~10m						1								1
	1*CASE*						1								1
Artificial Cut or Bank	~5m							1						1	2
	5~10							1							1
	10~15							1							1
	15~20							1							1
	25~30							1							1
	5*CASE*							5						1	6
Flood Plane or Low-lying Land in Valley	5~10m						1	1						1	3
	1*CASE*						1	1						1	3
Subtotal	8	0	0	0	0	0	2	6	0	0	0	1	0	2	11

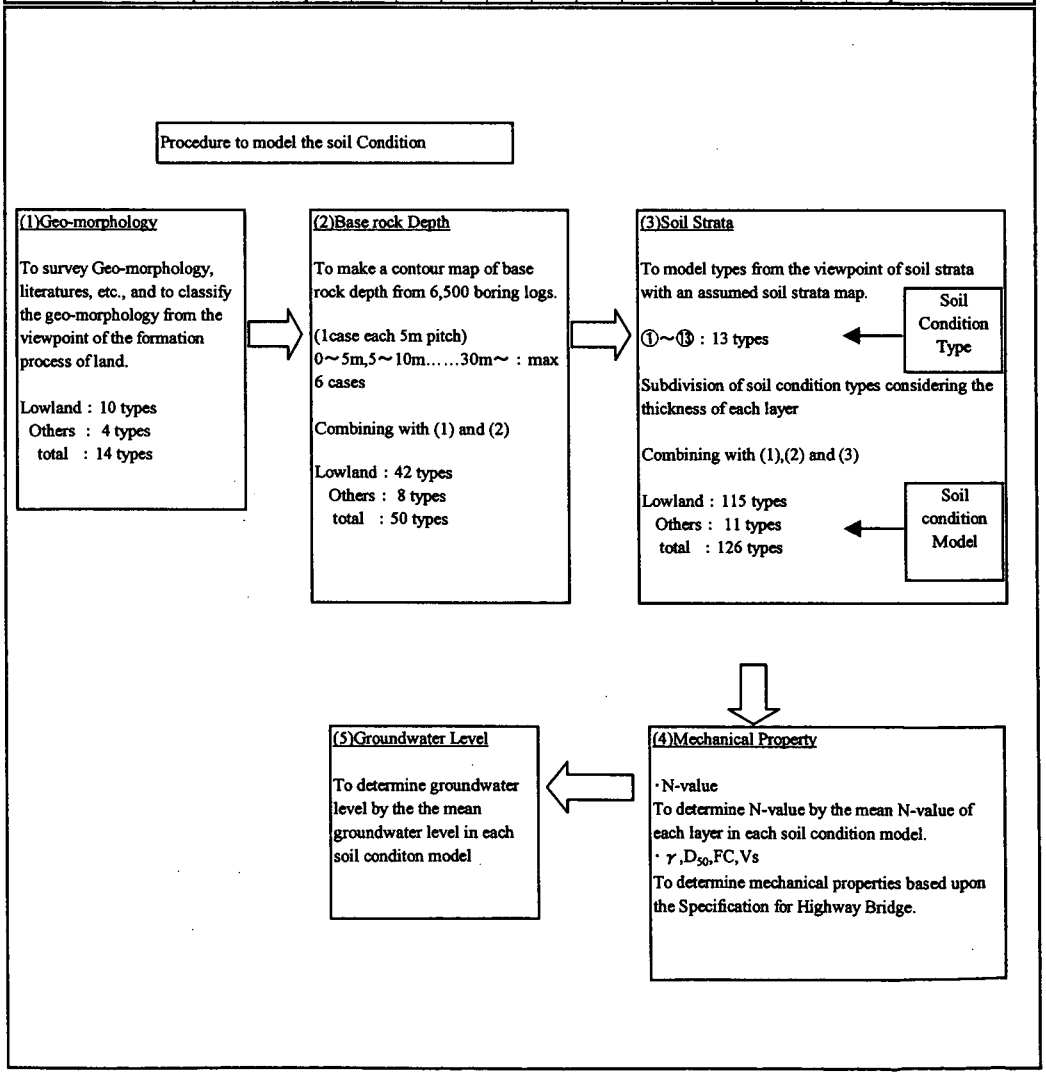
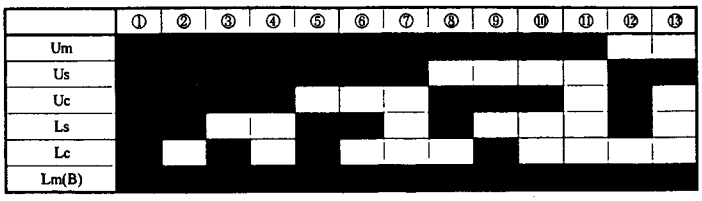


Fig. 5.3(a): The procedure to establish soil condition model



(1)Geo-morphology		(2)Base rock Depth	(3)Strata ①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	Σ(Soil Condition Model)
Lowland	Lowland of down Ohta River	~5m							1							1
		5~10							1	1						2
		10~15						1								1
		3CASE						1	2	1						4
	Ohta River	5~10m		1				1					1			3
		10~15				1		1								2
		15~20		2			1	1								4
		20~25		5				1								6
		25~30	1	4												5
		5CASE	1	12		1	1	4					1			20
		15~20m		2		1		1								4
		20~25		3		1		1								5
		25~30	1	12		1										14
		30~	1	4												5
		4CASE	2	21		3		2								28
		5~10m							1					1		2
		10~15		1					1			1				3
		15~20		1				2								3
		20~25		4												4
		25~30		5							1					6
		30~		3												3
		6CASE		14				2	2		1	1		1		21
		15~20m				1										1
		20~25				1										1
		25~30		2		2										4
		30~		5												5
		4CASE		7		4										11
		5~10m						1								1
		15~20								1						1
		20~25								1						1
		25~30								1						1
		30~								2						2
		5CASE						1		5						6
		30m~								3						3
		1CASE								3						3
	Fuchu Lowland	10~15m						1								1
		15~20		1												1
		20~25								1						1
		25~30								1						1
		4CASE		1				1		2						4
	Seno River Delta	5~10m										1				1
		10~15							1			1				2
		15~20		1	1											2
		20~25		1						2						3
		25~30		1						2						3
		5CASE		3	1				1	4		2				11
	Yahata River Delta	5~10m						1								1
		10~15						1								1
		15~20		1				1								2
		20~25		2												2
		25~30		1												1
		5CASE		4				3								7
Subtotal		42	3	62	1	8	1	14	5	15	1	3	1	1	0	115
Total		50	3	62	1	8	1	16	11	15	1	3	2	1	2	126

Fig. 5.3(b): The procedure to establish soil condition model

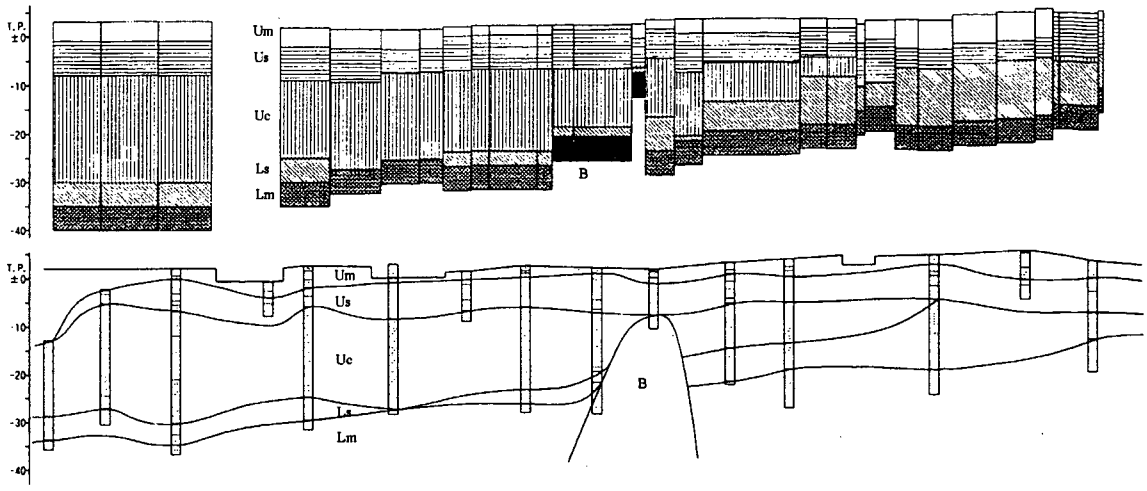


Fig. 5.4: represents an example of the ground modeling using the aforementioned method

6. Damage estimation subsystem

As mentioned before in Chapter 3, damage in the area is estimated from ground motion distribution and ground failure. Different kind of indices to express the ground motion listed in Table 3.1are utilized for different facilities to estimate their damage.

Ground motion distribution is obtained from calculating the motion at 1,739 spots from the observed records of the motion at 8 stations as illustrated in Fig. 6.1. In primary estimate, base rock motions at 8 sites are converted from the observed records divided by the prepared amplification factor at each site. Instead, at the secondary estimation, those conversion to base rock motion is accomplished using recorded time history by the equivalent linear method, which can consider the frequency dependence of the reference strain [Sugito, 1994]. Then the base rock motion at 1,739 spots are supplemented from those converted base rock motions at 8 sites by using the contour line drawing method [Shiono, 1988]. The ground motion at surface at each spot is then calculated by multiplying the prepared amplification factor at each spot.

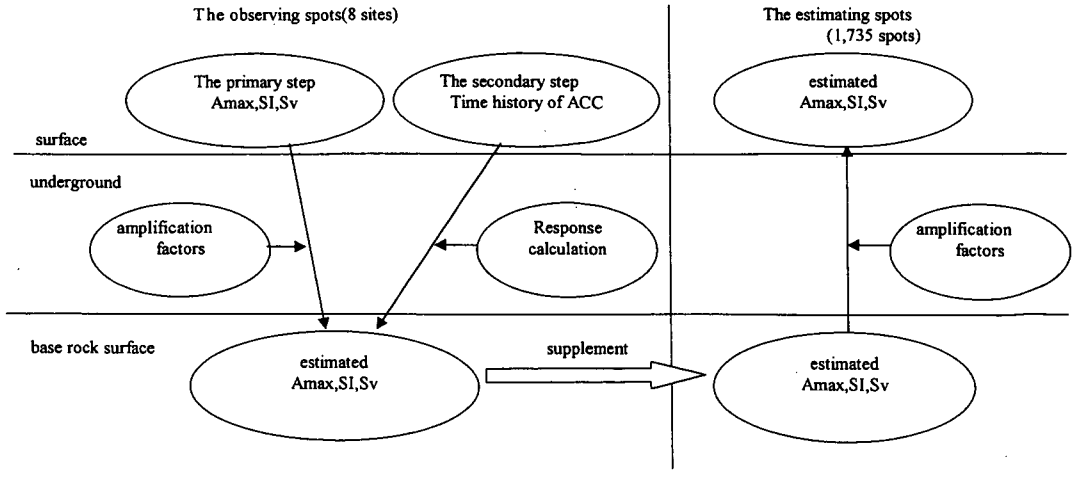


Fig. 6.1: Flow of ground motion calculation

Liquefaction potential at lowland area is estimated from the maximum accelerations at surface and the soil condition model at calculating spots by using the similar manner that is used in the Specification for Highway Bridge in Japan. Only the difference is that the method to estimate the shear stress ratio in depth. In the Specification, always the same reduction factor obtained from the equation r_d =1-0.015Z (where Z is depth in meters) is used to estimate the dynamic shear stress ratio at depth. However, the reduction factor has to be varied in accord with the soil condition and the input motion [Sato et al. 1998]. So a table of reduction factors for each calculating spot in lowland area was prepared. The prepared reduction factors were obtained from a response analyses for each spot against several levels from 50 to 400 gal of input motion of an earthquake which is anticipated in the Sea of Akinada.

Figure 6.2 show the comparison between the results obtained against an event which might be induced by the Koi Fault. The figure illustrates the distribution of the liquefaction Index P_L. P_L is obtained from the summation of F_L value at each spot considering the weighting factor due to the depth. From this figure, it is shown that the modified method coupled into this system gives the closer distribution of P_L to that obtained in the case where the shear stress is given from the response analysis.

Figure 6.3 and 6.4 show examples of the image displayed on the screens deployed at the Fire Services Bureau, city government offices, branch offices of the Bureau, ward offices, and the Hiroshima university. Those are for the monitored seismic intensity and the estimated liquefaction potential in the city.

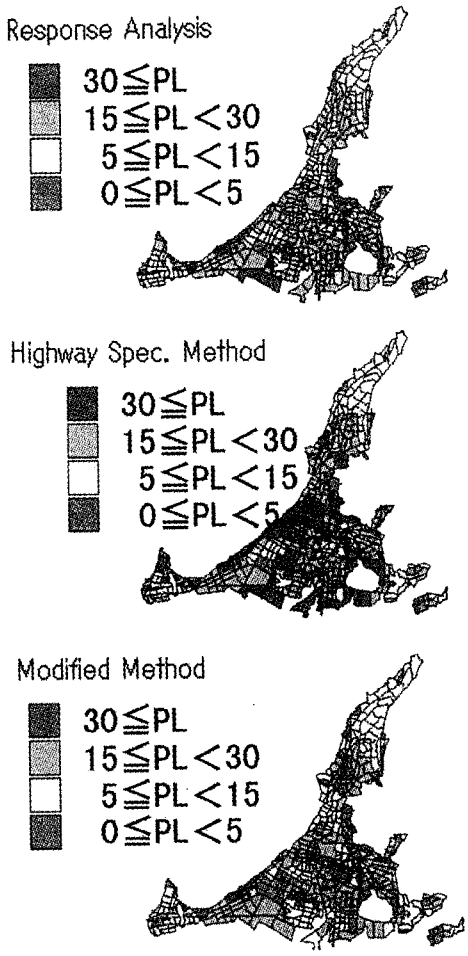


Fig. 6.2: comparison between the results obtained against an event by the Koi Fault

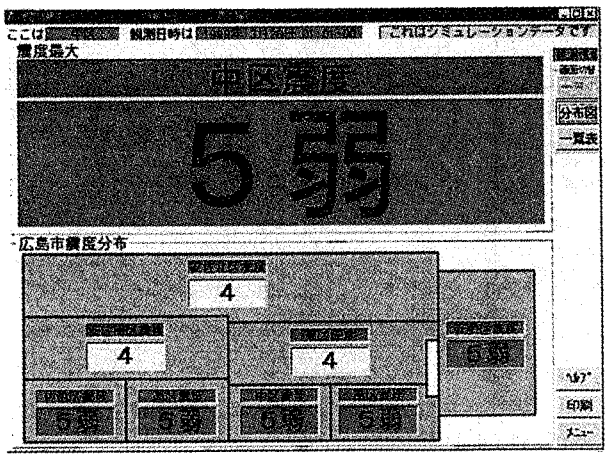


Fig. 6.3: Seismic intensity display

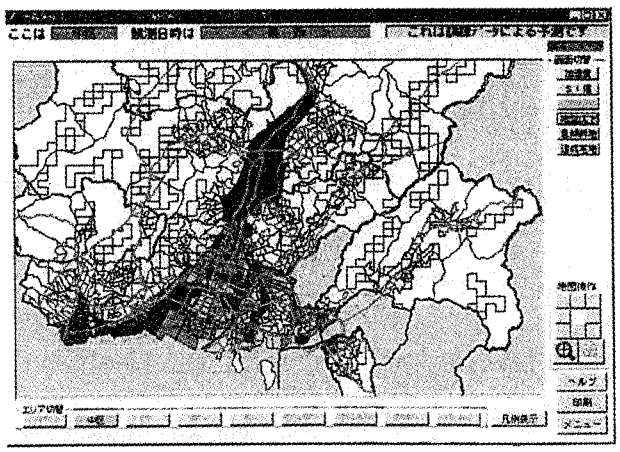


Fig. 6.4: Estimated liquefaction potential display

7. Observed ground motion during the earthquake of February 7, 1999

During the development of the System, when the installation of the monitoring system was just completed an earthquake of JMA magnitude 4.1 occurred nearby the area in Yamaguchi prefecture where is apart by about 30 km from the city. The event, although it was not so big earthquake, was successfully recorded by the monitoring subsystem [Kano and Sasaki, 1999]. Figure 7.1 shows the recorded acceleration at the ground surface of the Fire Services Air Base station as an example of record during this event.

The calm state during first 13-14 seconds in Fig. 7.1 shows that the delayed recording system worked normally.

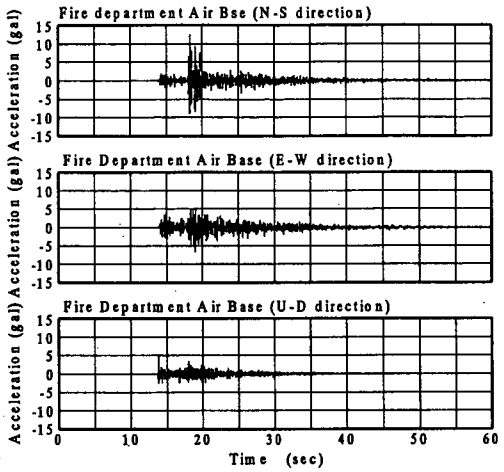


Fig. 7.1: Recorded acceleration

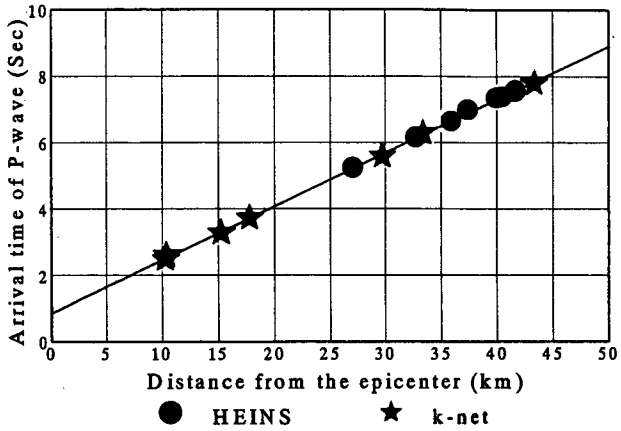


Fig. 7.2: Arrival time of P wave to each station

Table 7.1: A_{max}, V_{max}, D_{max} and T_d at each point

	Base rock depth(m)	A_{max} cm²/sec	V_{max} cm/sec	D_{max} mm	T_d sec
Hirose-kita Park	27	12.0	0.38	0.19	19.7
Ushita Water Plant	4	7.0	0.16	0.08	15.07
Garbage Station	17	7.6	0.17	0.06	16.18
Fire Department Air Base	34	12.5	0.26	0.15	16.31
Sports Park	2	6.9	0.14	0.05	15.17
T.C for fire Works	5	-	-	-	-
Yano-Shinmachi Park	33	5.0	0.14	0.08	14.72
Minori Park	44	27.7	0.59	0.37	20.65

Figure 7.2 shows the relationship between the epicentral distance and an arrival time of primary wave. An arrival time was calculated as the difference between the origin time of the earthquake and arrival instance of P-wave to each point. The relationship between them is linear and V_p, the velocity of primary wave in the bedrock, is calculated as about 6.21 km/sec.

The maximum acceleration (A_{max}), maximum velocity (V_{max}), maximum displacement (D_{max}) and duration of shaking (T_d) at each station are shown in Table 7.1. Velocities and displacements were calculated from recorded accelerations and the duration was calculated as the time while the acceleration amplitude exceeds 1-gal. According to Table 7.1, A_{max}, V_{max}, D_{max} and T_d were almost proportional to the depth of base rock and they were comparatively larger inside the delta than those outside the delta, while they were in inverse

proportional to the distance from the epicenter. It is thought that the easily amplified region in Hiroshima city area will be identified by accumulating the data like the record shown here.

Fig. 7.3 shows an image of animation, which illustrates the distribution of displacements at each station when the maximum displacement was observed at the Minori park station. By dynamically displaying the whole displacements at every station simultaneously, the ground motion is shown like animation.

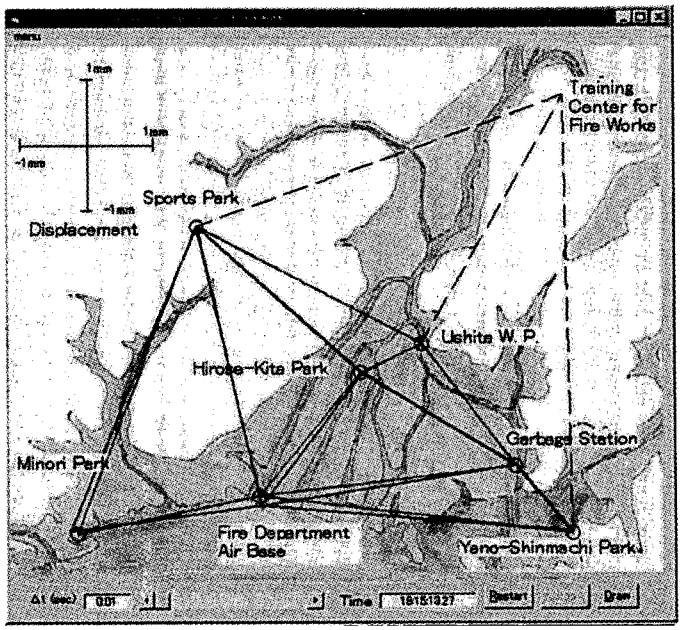


Fig. 7.3: Displacement distribution

By now, earthquake records are obtained during the events listed in Table 7.2.

Table 7.2: Earthquakes observed by now

	No.1	No.2	No.3
Origin time	Feb.07.1999, 18:14:55.5	Jun.30.1999, 01:17:00	Jul.16.1999, 02:59:09.3
Epicentral Location	E.L. 132° 05' 48" N.L. 34° 13' 48"	E.L. 132.7° N.L. 34.3°	E.L. 133° 11' 48" N.L. 34° 25' 30"
Epicenter Depth	≒14 k m	≒20 k m	≒20 k m
Magnitude (JMA)	4.0	3.7	4.4
Maximum of Acceleration	27.8	9	37

8. Afterword

This paper described briefly about the capability of the Seismic Information Network System for Hiroshima city. To estimate seismic damage over the entire 740km2 area of Hiroshima city area using the strong motion records monitored at the 8 stations, earthquake motions over the entire city area have to be supplemented from observed records. For this purpose, a technique for drawing a contour map has been incorporated into the system as mentioned above. This function and the geographical database in this System played an important role in a certain occasion.

On June 29, 1999, heavy rainfall caused a disastrous slope failures and debris flow in the western part of the Hiroshima Prefecture including the city, and 31 people were killed. When the first author of this paper conducted an emergency survey of this disaster, it was noticed that the locations at which landslide damage took place were concentrated into extremely specific areas. This implied that there was strong relation between the location of damaged slope and the distribution of strong rainfall. So a contour map of the precipitation amount using rainfall data from 183 locations in the prefecture was formulated. For carrying out this work, a contour map drawing function in the System together with the GIS function were utilized to create the precipitation distribution map in a short time.

As a result, it became clear that from 2:00 p.m. to about 5:00 p.m. on June 29, heavy rains fell on specific areas in western Hiroshima Prefecture, as well as how the rain moved over time. Fig. 8.1 represents a part of the contour map showing rainfall depicting the time of heavy rain on which is superimposed the landslide damage concentration (damage rate), showing a close correlation between the two factors [Sasaki, 1999].

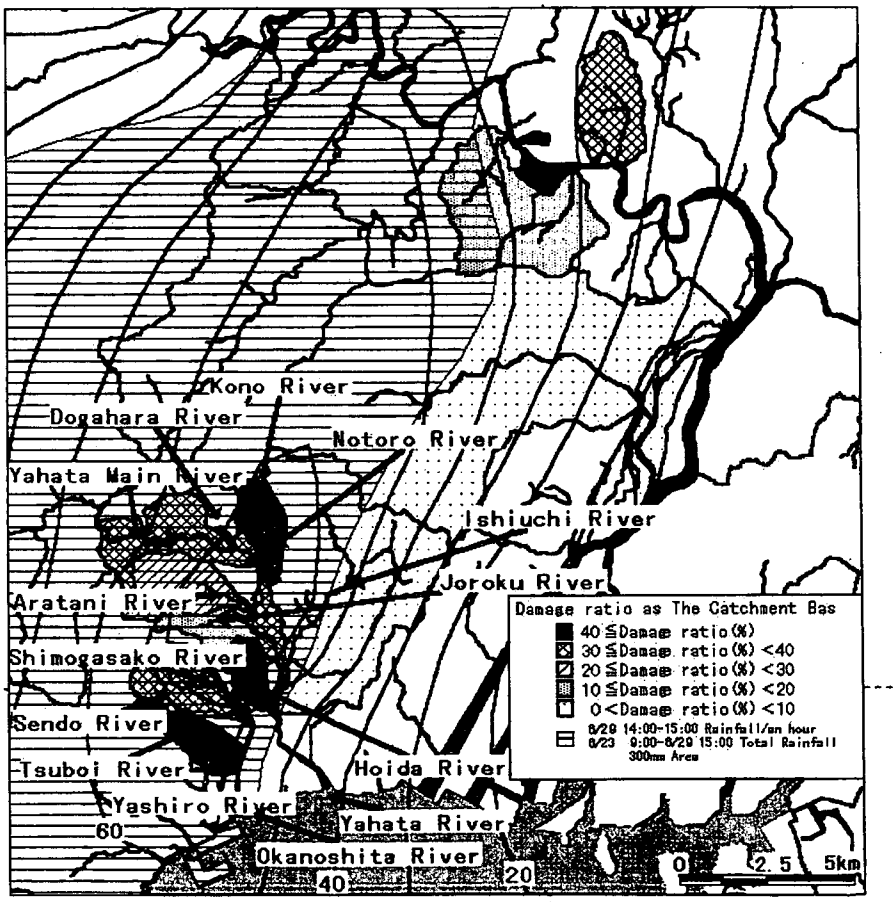


Fig. 8.1: Rainfall induced damage and Precipitation contour

This experience teaches us that if the precipitation map showing the movement of the heavy rainfall area is delivered to citizens through TV news, it might be helpful to judge the necessity to evacuate from the danger of the disaster. Although different from the rainfall induced disaster, earthquake disaster is caused instantaneously and unexpectedly, it is concluded that the disaster information system to grasp the damage status of the whole area is inevitable to mitigate the disaster.

And as mentioned before, the ground motion monitoring function works normally, the system is expected to provide important information for proper response at the Bureau.

Acknowledgment

The system is being developed by the financial support partly by the Science and Technology Agency, and the discussion during the Technical committee was inevitable to establish the system. Those who were contributed to construct the system are acknowledged

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"READY"
A SYSTEM FOR REAL TIME ASSESSMENT OF EARTHQUAKE DISASTER IN YOKOHAMA CITY

SAITO Masanori[1], ABE Susumu[2], and MIDORIKAWA Saburoh[3]

Abstract

This paper discribes the Dense Strong Motion Seismographic Network as a part of the real time disaster assessment system operared by the City of Yokohama. The network consists of 150 surface stations and 9 borehole seismometers, distributed in the city at an average interval of 1.7 km. The parametric outputs of the network are obtained within 3 minutes of an earthquake occurrence and fed to the system for earthquake damage estimation. Within 20 minutes, seismic intensity, damage to wooden buildings and liquefaction are estimated at every 50 m square mesh. These estimations are used to activate rescue operations.

KEYWORDS: Strong Motion Network, Earthquake Disaster Mitigation, Real Time Earthquake Disaster Assessment

1. INTRODUCTION

Yokohama City is the second largest city in Japan, with a population of 3.4 million in a total area of 433 km^2. It suffered severe earthquake damages in the past. Among all, the Great Kanto Earthquake of 1923 caused an almost annihilating damage to the city. Just after the Kobe Earthquake (Hanshin-Awaji Earthquake) of January 1995, learning many lessons from it, the City of Yokohama set up a special committee led by the mayor in Feburuary 1995 for the promotion of intensified earthquake disaster mitigation. Advices and projects proposed by the committee and subcommittees materialised into, among all, the Dense Strong Motion Network and the READY (REaltime Assessment of earthquake Disasters in Yokohama) system, which are now operating in good condition.

2. Dense Strong Motion Network

The Dense Strong Motion Network consits of 150 surface strong motion seismographic stations plus 9 borehole stations. Each station is equipped with three component accelerometers with a GPS receiver for time keeper. Since the total area of Yokohama City is about 433 km^2, the average distance between the stations is only 1.7 km. This must be the densest network in the world.

The stations and the three monitoring centers, the Disaster Control Office, the Fire Defence Bureau and Yokohama City University, are linked by the ISDN networks operated by NTT, and the monitoring centers are linked by leased lines. Moreover, 18 stations are linked by satellite to the Disaster Control Office.

The purpose of this network is twofold. The first, and most important, is to get ground motion informations as soon as possible after the occurrence of earthquake. Thus the ground motion at

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each station is parametrised and the parameters are sent to the three centers. The parameters include; 1) seismic intensity in JMA (Japan Meteorological Agency) scale, 2) maximum accelerations, 3) predominant frequencies, 4) seismic wave energy, 5) duration, and 6) response spectrum. These parameters are computed at each station independently when the station observes ground acceleration greater than 2 gals. On receiving more than 10 reports in a prescribed time interval, the centers activate alert systems; transmit data to JMA, pagers, and CATV's, and update City Home Page. Further, the READY system starts to calculate damage estimation. Our experience shows that these parametrised data are collected in 2 to 3 minutes after the earthquake, and damage estimation within 20 minutes.

The second purpose of this network is to get high quality seismic waveform data for later analysis. The waveform is sampled at 200 Hz and as long as 5 minutes data can be sent to the centers. About 100 events have been recorded and filed since the full operation started in May 1998, the largest event being of intensity IV in JMA scale.

3. Geology in Yokohama

Yokohama city is located at the south-west coast of Tokyo Bay and consists of hilly areas, plataeaus, terraces, low-lying areas, and reclaimed lands along the sea coast and rivers. Northern parts of the city are mostly covered with loam but at the southern tips Tertiary groups crops out.

Many kinds of geological and geophysical data in Yokohama City are available. These include surface geology map at every 50 m square mesh point, seismic refraction profiles, seismic reflection profiles, and gravity map. At each strong motion station seismic PS velocity log to the basement is also available.

The largest ground motion observed since the operation of network started is intensity IV (JMA scale), corresponding to the maximum acceleration about 80 gals. At this size of earthquakes, predominant period of ground motion is less than 1 second and the knowledge of physical properties down to about 100 m from the surface are sufficient to predict peak ground motions. However, high-rise buildings and large structures such as suspension bridges are increasing day-to-day in our target area, and deeper subsurface structure, especially the seismic S wave structure, is essential to predict longer period response. For this purpose we are doing S-wave velocity survey by array microtremor measurements. So far 25 array measurements have been completed and inversion analyses are under way.

4. Concluding Remarks

As described above, the Dense Strong Motion Network in Yokohama is quite dirrerent from other existing seismographic networks; high density of stations, and quantities of geological and geophysical data. Thus, the network will serve as a test site for the development of real time earthquake information system.

Session IV: Crisis Management- Urgent Response Works and Restoration (3)

- Systems Related to Disaster Countermeasure in NTT, *Kazuhiko Fujihashi** *(NTT co. ltd.), Kenzo Shigeta*
- Managing Utility Earthquake Risk, *Norman Abrahamson , William Savage* (FEMA)*
- Development of SUPREME, *Yoshihisa Shimizu (Tokyo Gas co., ltd.)*

SYSTEMS RELATED TO DISASTER COUNTERMEASURE IN NTT

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ABSTRACT

The disaster restoration was delayed because the grasp of the disaster situation and the information transmission were extremely difficult immediately after the occurrence of the 1995 Hanshin-Awaji great earthquake disaster. To make the best use of this lesson NTT has developed various disaster countermeasure systems, service, and related technologies. The following four points are described in this text. 1) "Disaster information system" and "Maintenance information network" which supports circulation of information and information sharing among headquarters, branch, departments and NTT group when disaster occurred. 2) "Emergency message dial" which is service to prevent telephone congestion. 3) "Access Network Underground Route Earthquake-proof Performance Evaluation AP" and "Access System Struck Situation Grasp System" which is tool for presumption/grasp of struck situation of access system facilities. 4) "Common map information database" expected to be applied to disaster countermeasure system.

1. INTRODUCTION

Because the Hyogo-ken Nanbu Earthquake was a large earthquake that regionally the seismic intensity had considered being 7 and a large-scale liquefaction was generated in the coast part, telecommunication facilities of NTT were also not able to avoid suffering damage[1]. At first, the grasp of the struck situation and the transmission of information stagnated, and it made the emergency measures difficult. At the same time telephone call rushed into Kobe requesting information from whole country, which made the network congested. The importance of information on the disaster was recognized again by these facts. After the Hyogo-ken Nanbu Earthquake, NTT set up "Large city fierceness disaster countermeasure committee" in the headquarters reinforce and review the contingency plan of both hardware and software in consideration of the importance of the communication service in informationalized society. The committee was divided into seven TC and examined disaster countermeasure from various viewpoints. In this text, the systems related to the disaster countermeasure introducing or developing through such an examination are described. Table 1 shows the relation between the basic items of the committee's examination and the systems described in this text.

2. SYSTEMS AND SERVICE RELATED TO DISASTER COUNTERMEASURE

When the disaster occurred, we used to transmit information mainly by telephone and FAX. Because the information was shared with white board and bulletin board, It is difficult to say that promptness, accuracy and additional value of information were enough. To solve these problems, we have constructed disaster countermeasure LAN that connects between personal computers at each branch or related companies and server at the disaster countermeasure headquarters. "Disaster information system" and "Maintenance information network" which is the application program uses this disaster countermeasure LAN is described[2,4]. Moreover, "Message dial for the disaster" introduced as a congestion measures at the disaster is also described[3].

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Table 1 Relation between Examination Content of the Committee and Systems Related to Disaster Countermeasure

Item	Content	Systems
1. Security and control of communication resource	◆Destruction prevention of communication facilities and securing of communication resource by reliability improvement ◆Destruction prevention in network and reinforcement of network control function	
2. Allotment and distribution of communication resource	Allotment, distribution and operation of communication resource when facilities are destructed or network is congested	◆Emergency message dial
3. Information network in damaged region	Construction of information circulation schemes using ISDN line, PC, LAN etc.	
4. Crisis management and restoration system	◆Maintenance of crisis-management system. ◆Early grasps of damage of access systems.	◆Disaster information system ◆Maintenance information network ◆Access network underground route earthquake-proof performance evaluation AP ◆Access system struck situation grasp system ◆Common map information database

2.1 DISASTER INFORMATION SYSTEM

2.1.1 OUTLINE OF THE SYSTEM

The disaster information system manages the activity matter of the disaster countermeasure headquarters, information on the damage situation and the restoration situation, etc. by various databases at the disaster, and circulates information. Information is displayed in the map or by text in the window.

This system is performing uniform management with the server of the disaster countermeasure headquarters in the client-server method to using in-house LAN. And "Lotus Notes" which has the groupware function is used.

Table 2 Data Classification of Disaster Information System

Situation	Normal circumstances	Disastrous circumstances	
Input/output	Input		Output
Classification	Beforehand input data	Input data at disaster	Display data
Contents	Facility data ◆Switching facility ◆Transmission facility ◆Electric power equipment ◆Urgent measure equipment	Disaster information ◆Switching function ◆Transmission function ◆Electric power ◆Outside plant ◆Traffic restriction etc.	◆Switching function · Damaged branch · Damaged area ◆Transmission function · Damaged transmission route ◆Electric power · Power failure ◆Outside plant · Damaged facility ◆Emergency measure equipment · Destination etc.
	Building data ◆Office buildings ◆Advancement base etc.		
	Map position data ◆Building position ◆Distribution of Switchboard ◆Service area etc.		

When struck information is input from the client by the disaster or the accident's occurring, the damaged part and the damaged area are displayed on the map. It is possible to refer to damage information by clicking them. Information of the damaged part can be input on the map in "×" sign and polygon. It is possible to display the data like the current state of facilities and equipment by using equipment administration DB of this system at normal circumstances. The table shows the classification and the content of the data that relates to this system.

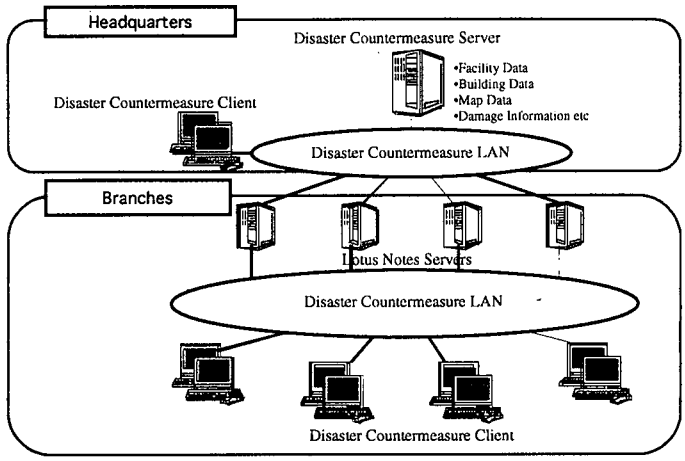


Fig.1 Disaster Information System

Besides "Disaster countermeasure system information", "Damaged facility restoration information", and "The113rd breakdown reception information", etc. are also preserved as "Information management data". This information can be classified by using "Time", "Information source" or "Information type". Moreover, information necessary when disaster occurred, such as "Emergency measure equipment list", "Emergency measure materials list" are preserved in the database.



Fig.2 Display of Disaster Information System (example)

2.1.2 EFFECTS

(1) Information will circulate by e-mail instead of FAX and telephone which makes paperless.
(2) Data can be shared and accessed freely using any terminal.
(3) The data processing can be prompt and facilitate.

2.2 MAINTENANCE INFORMATION NETWORK

The maintenance information network (MI-NET) is, so to speak, an electronic bulletin board. It is possible to access from all PC terminals of the NTT 4 companies and the PC terminal in specific networks of NTT groups with the Web browser software, and the information between each organization can be shared. Figure 2 shows information maintenance network configuration.

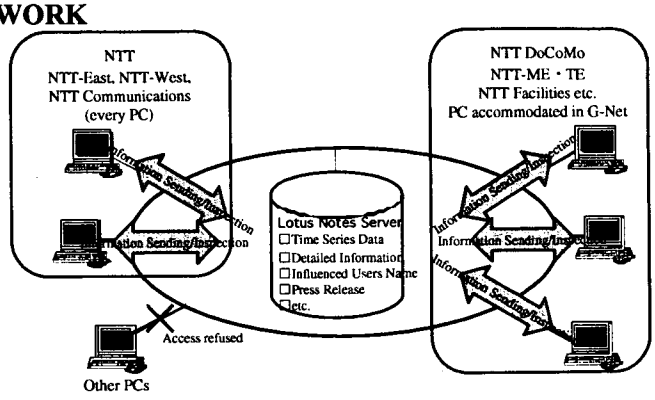


Fig. 3 Outline of Maintenance Information

In April 21 the large-scale breakdown maneuver, assuming lease line accident was executed to verify the action at the disaster under new system. This system was used as one of tools for information in this maneuver, and operation and effectiveness were confirmed. As a result, it was confirmed to say that this system was effective to the speed-up of the information transmission and information sharing. However, because some accidents had turned out in the retrieval of aimed information, this function has judged to be reinforced (completed on June 10).

2.3 EMERGENCY MESSAGE DIAL

In 1995 Hanshin-Awaji great earthquake disaster, the telephone to confirm safety has increased explosively immediately after it occurred. Though NTT increased more than 5,000 lines in the emergency, the telephone call rushed to Kobe and exceeded the capacity. Therefore, the telephone from nationwide to Kobe did not hang easily (congestion) for about five days.

Thus, the telephone which was familiar communication method was not able to correspond enough to the sudden increase of information needs etc. concerning the safety of the life at this large disaster.

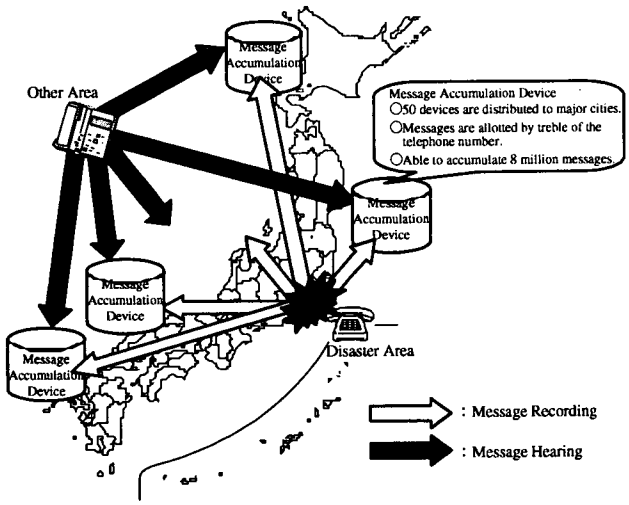


Fig.4 Outline of Emergency Massage Dial

Taking this trouble as a lesson, NTT introduced "Emergency message dial" which is an information transfer system strong in the telephone congestion at a large-scale disaster. This system can be used in a nationwide scale.

2.3.1 OUTLINE OF THE SYSTEM

The message dial for the disaster is voice mail (Figure 3) which makes the telephone number in the damage region a key, and transmits information on safety etc. by the voice. First, the users dial 171 and then they can record or hear the message by following the instruction.

One of the characteristics of this system which differ form existing voice mail systems is that treble end of the registration telephone number of the messages are distinguished and based on the number, the messages are distributed to the accumulation device set up in the whole country. Thus, this system uses the communication network in the whole country, and is an information transfer system to evade congestion by the huge communication generated after the disaster occurred.

Additional features of this system are as follows. 1) This system offers the communication means to the people who cannot respond to the telephone. 2) This system offers the communication means to the people who cannot use the telephone of own house because of blacking out or damage. 3) Because the telephone calls to/within the damaged area decreases, the influence on the communication for the disaster rescue and restoration the activities can be reduced.

2.3.2 OPERATION POLICY OF THE SYSTEM

To make emergency message dial play an effective role when the disaster occurred, it is necessary for us to inform the customer of the existence and usage of this system as the social infrastructure. It is also necessary to construct the operation policy that matches timely to needs for confirming safety or transmitting messages both inside and outside of the damaged area.

Therefore, we held the emergency message dial operation examination association with the disaster researcher, administration, municipality, press (key station of TV and radio) and the user representatives. And discussed the operation policy from the aspect of the CB (common base) mutual aid, and constructed system operation policy and cooperation system with press.

When a large disaster occurs, NTT promptly offers the emergency message dial service by the following operation policies (Table 3).

Table 3 Operation Policy of Emergency Message Dial System

Index	Contents
1.Usable telephone	◆General NTT telephone (push type, dial type), pay phone, ISDN terminal ◆Portable phone, PHS (scheduled to expand gradually)
2. Standard of operation judgement	◆When earthquake larger than 6- JMA seismic intensity occurred. ◆When other natural disaster or large accident occurred and telephone network is congested.
3. Telephone numbers that can record or hear the messages.	Telephone numbers in damage region and circumference (commuting area) Numbers are specified in prefecture. A prior use contract is unnecessary.
4. Number and length of the message	1-10 messages (according to scale of damage region) Within 30 seconds per one message.
5.Retention period of message	2 days (48 hours)
6. Deletion of message	Delete automatically when retention period passes.
7. Charge	Telephone call fee between place of dispatch and damage region (necessary both when recording and hearing)
8. Message with personalized number	Possible to use

As the private information, the safety information has the top priority when disaster occurs. The recording of the message will be enabled immediately after disaster occurred from damaged region One outside damaged region can only hear the recorded messages at this phase. After the use for the safety

confirmation in the damage region settles, we enable the message registration to the damage region excluding the damage region (Table 4).

Tables 4 Classification of service offer form immediately after disaster occurs

	Recording	Hearing
Damaged area	Possible	Possible
Other area	Restricted Be able to use after the use for the safety confirmation in damaged area settles.	Possible

Based on prior mutual understanding concerning their operational systems, NTT, press and municipality should notify the existence and usage of the emergency message dial to people and construct the cooperation system that answers the national common needs.

NTT built the cooperation system with press and when the disaster occurs, press offers people the use guide of the emergency message dial according to the phase of the disaster (Fig.5). We are popularizing the existence and use of this system at municipality, fire fighting group and school using video and pamphlet. We are also requesting cooperation to other related organization to publish the use guide of this system on their disaster prevention leaflet.

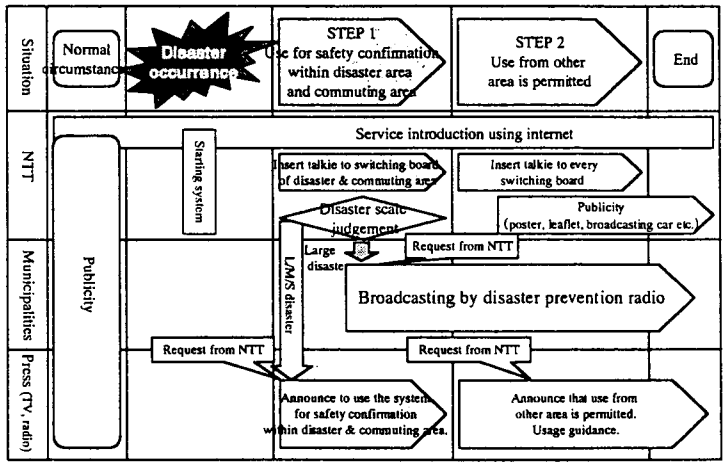


Fig. 5 Cooperation of NTT, Press, and Municipality

3. SYSTEMS RELATED TO DISASTER COUNTERMEASURE OF ACCESS SYSTEM FACILITIES

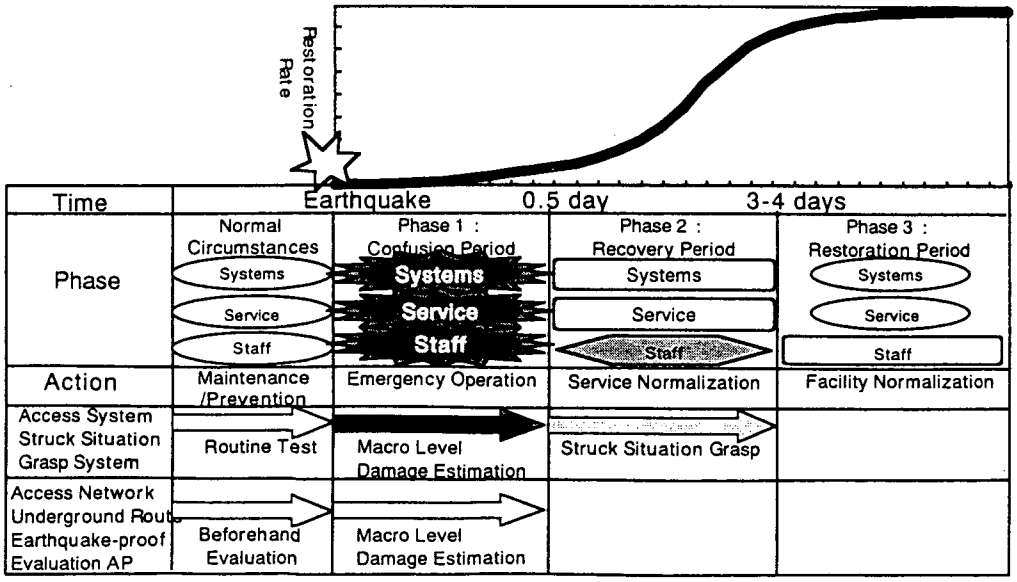


Fig.6 Role of Damage Estimation/Grasp Tools

This chapter introduces "System access underground route earthquake-proof evaluation application (hereafter, AP)" and "Access system struck situation grasp system" developed as "Grasp tool of the early stage of the access system struck situation". Figure 6 shows the role of these tools[14].

3.1 COMPOSITION OF OUTSIDE TELECOMMUNICATION FACILITIES

NTT provides telecommunication services by laying telecommunication cables from telecommunication center buildings containing switchboards to customer houses through outdoor facilities consisting of civil and lines facilities. Civil telecommunication facilities are broadly classified into the two types of telephone tunnel and conduit facilities, and are used to house and protect underground telecommunication cables. In metropolitan areas, these cables are laid to customer buildings through underground distribution conduits, and in residential and other areas, cables are raised on telephone poles and led into customer houses using aerial distribution lines. An outline of NTT's outdoor telecommunication facilities is shown in Fig. 7.

Of these outdoor telecommunication facilities, telephone tunnel facilities are tunnels with a diameter of 3 to 5 meters that are used exclusively for telecommunication cables. These facilities are constructed at relatively deep levels about 20 to 40 m below the ground surface, and house dozens of telecommunication cables.

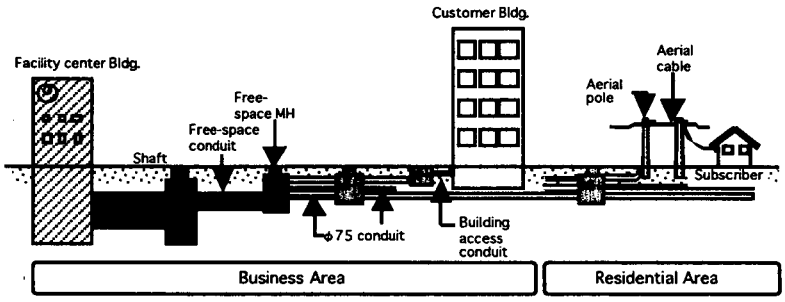


Fig. 7 Outline of Outdoor Telecommunication Facilities

Conduit facilities are divided by conduit diameter into the two types of free-space conduits and ϕ 75 mm conduits (main line conduits). Free-space conduits are steel or cast iron pipes with a nominal diameter of 300 to 600 mm which are buried using the microtunneling method, and contain from about 7 to 27 spacers for housing telecommunication cables. On the other hand, main line conduit facilities consist of multiple layers of multiple ϕ 75 mm pipes that are buried at shallow depths of about 1 to 2 m below the ground surface, with each conduit housing a single telecommunication cable. ϕ 75 mm conduits are generally polyvinyl pipes (hereafter "PV pipes") in consideration of cost efficiency, but metal pipes are used in sections where countermeasures against ground liquefaction and induction are necessary.

Underground distribution conduits are mainly pipes with a nominal diameter of 25 mm and 50 mm.

3.2 OUTLINE OF MARIOS

The Management Support System for Access Task Reengineering Innovation Objects, or MARIOS, is an information analysis system which supports management tasks such as determining the current condition of facilities, developing the overall design for basic infrastructure facilities and so on. An overview of MARIOS is shown in Fig.2. MARIOS can be used to process and work on various types of data, such as customer DBs, facility DBs, and map DBs, in an integrated and multifaceted manner. Processed data can then be displayed in a variety of forms, including distribution area maps, route diagrams, graphs, and tables. In addition, users can create and renovate applications since the operating system is based on object oriented programming. MARIOS is based on a client-server design, whereby clients situated at branch offices and outlets are linked with DB servers via digital public lines. Currently some 300-client terminals are installed throughout Japan and are used on a daily basis.

3.3 ACCESS NETWORK UNDERGROUND ROUTE EARTHQUAKE-PROOF PERFORMANCE EVALUATION APPLICATION

3.3.1OUTLINE OF AP

The telecommunication facilities have been designed to have a certain level of aseismic capability, but ground conditions vary widely at installation sites. Thus there is a possibility that conduit will be subject to earthquake forces exceeding their design strength. If a major earthquake were to occur, a certain level of damage to facilities would be inevitable. Therefore, it is important to be able to determine the weak points in facilities before an earthquake, and to quickly determine the extent of damages immediately after an earthquake.

The Access Network Underground Route Earthquake-proof Performance Evaluation Application (hereinafter referred to as "AP") is a tool for evaluating the earthquake withstanding capability of underground conduit facilities based on various data pertaining to earthquakes, ground, and facilities before an earthquake occurs[5]. Fig.8 shows the role of this AP. Following an earthquake, it can be used to predict macro-level damage. Under normal conditions, we use this tool to conduct advance evaluations in relation to overall facility plans and renovation plans. When an earthquake occurs, we use it for purposes such as estimating restoration costs and resource introduction planning based on macro damage predictions.

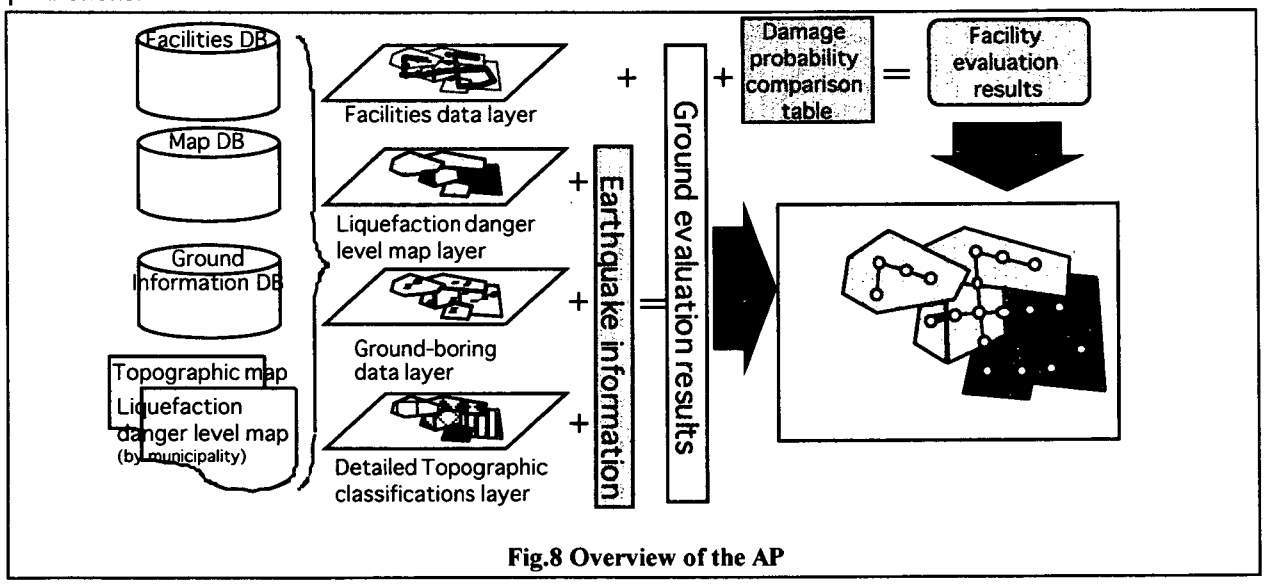


Fig.8 Overview of the AP

3.3.2 EVALUATION PROCESS FLOW

Fig. 9 presents an overview of the evaluation process flow. An analysis of the emergency survey on underground conduit facilities conducted immediately after the Hyogo-ken Nanbu Earthquake showed that the main factors related to damage in underground conduit facilities are whether or not the ground liquefied, the earthquake scale, the pipe type, and passage years since the facilities were installed. Thus the AP is broadly split between a ground evaluation part and a facility evaluation part. The main features of the evaluation process flow with this AP are as follows:

1) The overall liquefaction judgment is made using detailed topographic classifications, boring data and liquefaction danger level maps prepared by municipalities. 2) Ground evaluations are made based on the fixed distribution areas that NTT uses in managing the communications network.

Details are presented in the following sections.

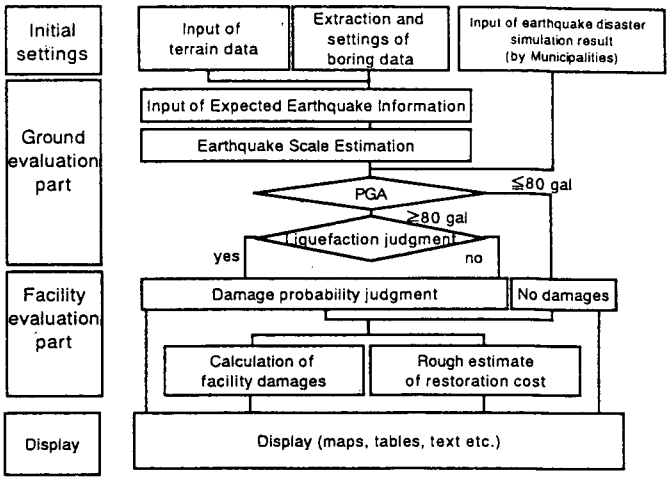


Fig.9 Evaluation/Estimation Process Flow

3.3.3 INITIAL SETTINGS

In initial settings, the data to evaluate the ground are set or processed and registered.

(1) Detailed topographic data

At an initial stage of development, we overlapped a fixed distribution area map for the facility building area and a topographic classification map to read and register detailed topographic classification data for each fixed distribution area. Because the operator had been doing this work by hand work, it took long time. Moreover, it was thought that the individual variation appeared in data. As a solution of this issue, we decided to use numerical geographic information data provided by the Geographical Survey Institute. Since this data is a mesh unit, and the geographical features of each mesh shows the overall tendency, it is not suitable to use them for liquefaction judgment as they are. So we converted this data in consideration of using it to judge liquefaction [8]. Refer to the bibliography for details.

(2)Boring data

The ground information DB is accessed to extract boring data for the facility building area in order to define the relationship between the fixed distribution areas and the boring data collected for them. Ground classifications are made using N values of boring data. It should be noted that this is the operation that does not involve manual tasks; the user simply clicks buttons with the mouse to process the data automatically.

(3)Data provided by the municipalities

The fixed distribution area map is stacked together with a map containing earthquake intensity estimates and a map which classifies the liquefaction danger levels in two or three levels prepared by the municipality where the facility building is located. The operator then enters the liquefaction danger level and the estimated earthquake level for each fixed distribution area.

It is not necessary to enter all three types of data; just entering one type can make a liquefaction judgment.

3.3.4 ENTRY OF EARTHQUAKE INFORMATION

The list of past large-scale earthquakes and assumption earthquakes that each municipality is examining are prepared in the program. When the earthquake to be evaluated is selected from this list, the earthquake name, epicenter position, epicenter depth, magnitude, and earthquake type are displayed. These items can be also input manually, so when estimating damages after an earthquake occurs, data released by the Meteorological Agency are entered. The earthquake data is registered in the database.

3.3.5 EARTHQUAKE SCALE ESTIMATION

The earthquake scales (PGA, PGV, instrumental seismic intensity) are presumed by the distance attenuation formula after the distance from epicenter position to each bore investigation position or fixed distribution position is calculated. We are using the formula shown below (Formula 1), which was

presented in 1997 by Yamazaki et al [9]. In the equation, "y" shows the earthquake scale, "r" shows the distance from epicenter, "h" shows the depth of epicenter and "M" shows the magnitude. "b_1", "b_2", "b_3" and "b_4" are parameters given by the earthquake type. And "c" is a point coefficient given by the ground condition.

$$\log \alpha = b_0 + b_1 M + b_2 r + b_3 \log r + b_4 h + c_i + c_{gi} \quad (1)$$

3.3.6 LIQUEFACTION JUDGEMENT

In judgments made using liquefaction danger level maps, detailed topographic classifications and boring data with this AP, the overall liquefaction judgment falls onto the highest danger levels.

When liquefaction danger level maps are used, the results judged by the operator and entered for each fixed distribution area are used directly as judgment results.

When using detailed topographic classification data to make a judgment, "liquefaction" and "non-liquefaction" are judged by the combination of PGV and liquefaction level of each terrain type. Table 5 presents the relationship between terrain type and liquefaction level.

Table 5 Relationship between Terrain Type and Liquefaction Level

Liquefaction level	Description (Liquefaction when)	Terrain type used in liquefaction predication
1	PGV≧15kine	gradual slopes at edges of dunes, low ground between dunes, old canals,
2	PGV≧25kine	sandbars, deltas, embankment, flood plain, etc.
3	PGV≧35kine	Dunes, gradual alluvial fans
4	Low possibility	plateaus, terraces, alluvial fans, hills, etc.

When using boring data in the ground information DB to make a judgment, the necessity of providing a liquefaction judgment is determined. And then the FL value and PL value are calculated [7]. The liquefaction judgment is processed automatically.

3.3.7 FACILITY EVALUATION

Table 6 Damage Probability Comparison (trunk conduits)

		Liquefaction	Non-liquefaction		
		80≦PGA	400≦PGA	250≦PGA<400	80≦PGA<250
Steel pipes	Y<1953	0.50	0.45	0.35	0.25
	1954≦Y<1981	0.30	0.20	0.15	0.10
	1982≦Y	0.10	0.00	0.00	0.00

Six types of facilities are evaluated: manholes, handholes, lead-in cable pipes, bridging facilities, trunk conduits, and distribution conduits. Individual facilities are divided into a number of classifications based on their structure type and the number of years since installation. The probability of damages can be estimated based on a combination of the earthquake intensity and whether or not there is liquefaction. Table 6 presents a comparison of damage probabilities in steel pipe trunk conduits. Damage probability is determined based on an analysis of damages in the Hyogo-ken Nanbu Earthquake. This figure represents an estimate of the number of pipes that will sustain damage in a given span between manholes, based on pipe type and installation year.

A single span contains a mixture of new and old types of varying types. Thus after calculating the damage probabilities of the individual conduits, the average, maximum and minimum damage probabilities are calculated. These values are calculated automatically.

3.3.8 DISPLAYS

The map display function, which is a basic function in MARIOS, can be used to provide color-coded displays of fixed distribution areas in a building area based on liquefaction judgment results, earthquake intensity estimate results, and detailed topographic classification. In addition, it is possible to display a facility route diagram stacked on the liquefaction judgment results, and to display the color-coded damage probabilities for each span.

When a fixed distribution area is selected with the mouse, information such as the fixed distribution area number, liquefaction judgment results and earthquake intensity level is displayed in the window. When a span is selected with the mouse, information such as the facility name, facility distribution area, average, maximum and minimum damage probabilities is displayed in the window. A window containing detailed information such as the damage probabilities of the individual conduits, and the types of accommodated cables can also be displayed. Fig. 10 illustrates the image of evaluation results screen display.

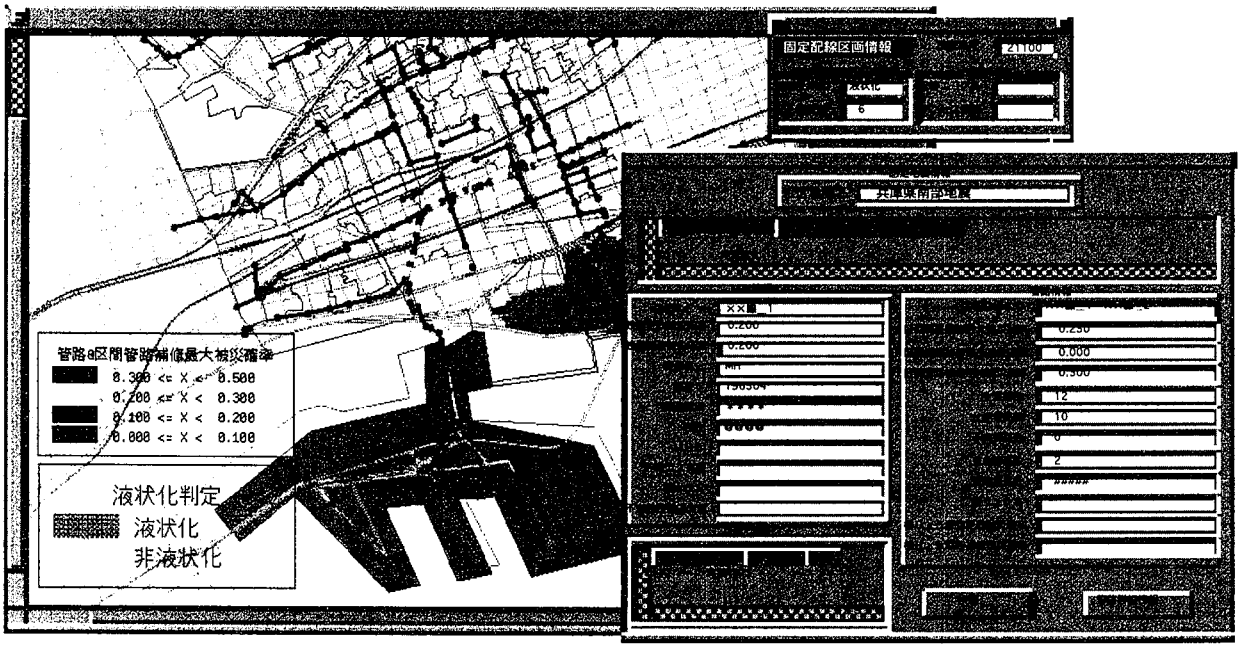


Fig.10 Image of Evaluation Result Display

3.3.9 OTHER FUNCTIONS

The locations of major users in the facility building area can be displayed on a map. When any customer building is selected with the mouse, the conduit and manhole routes accommodating the cables installed between the facility center building and the customer building are displayed .

It is possible to calculate the approximate costs of emergency restoration and full restoration by calculating factors such as conduit repair costs, cable replacement costs and structure renovation costs based on the amount of cable and the amount of facilities predicted to have sustained damage in the building area.

3.3.10 EXPECTED EFFECT

This report has presented an overview of the Access Network Underground Route Earthquake-proof Performance Evaluation Application, which was developed based on our experience with the Hyogo-ken Nanbu Earthquake. This AP was introduced in a beta version in April 1998. The time required to evaluate the earthquake withstanding capability of all facilities in the accommodation area of a single facility center building using this AP is approximately one month, including preparations and initial setup. The cost has also been reduced 50 to 60%. Once initial setup is completed and the ground DB is compiled, subsequent evaluations take only 30 to 40 minutes.

3.4 ACCESS SYSTEM STRUCK SITUATION GRASP SYSTEM

Currently, if a large-scale disaster such as the Hyogo-ken Nanbu Earthquake strikes an urban area, it takes quite some time to inspect underground telecommunication facilities, which are spread out over a wide area, thus extending the recovery period. Therefore, when large-scale disasters occur, it is vital that initial disaster measures be carried out accurately and that recovery work and the lifeline mission of announcing disaster conditions to local residents and other concerned parties be performed efficiently and quickly. The concepts behind understanding damage conditions and the policies during each phase are shown in Fig. 6. Of these, a system that performs metal access facility tests using order lines and displays affected regions by fixed distribution area using MARIOS has been developed as a method for quickly understanding access system macro damage condition (Fig. 11)[10].

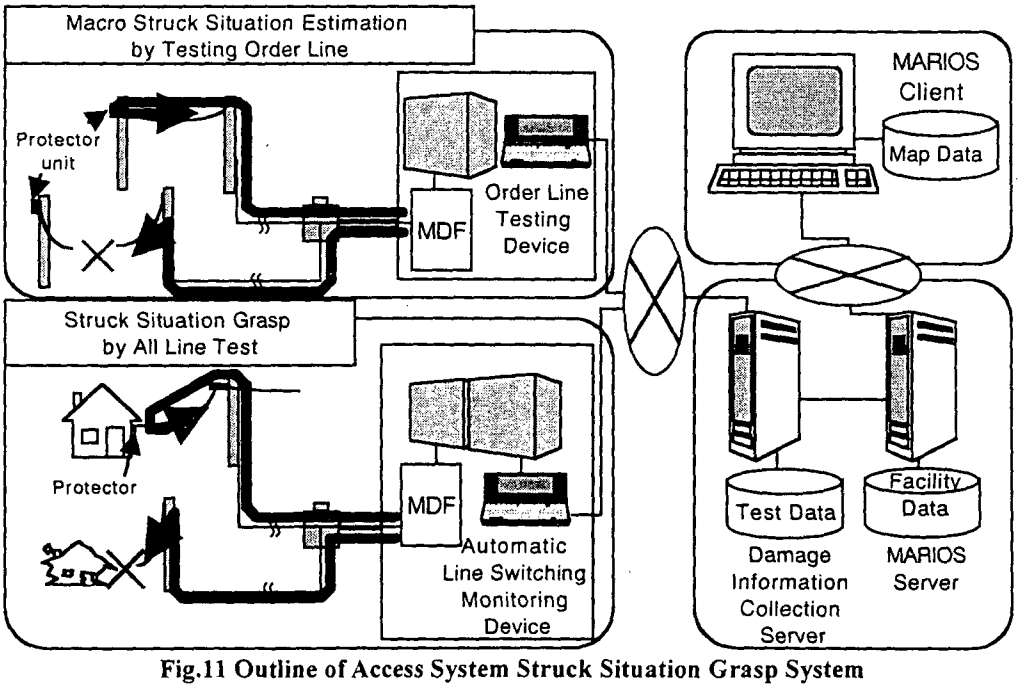


Fig.11 Outline of Access System Struck Situation Grasp System

Understanding damage conditions can be divided into 1) estimating macro damage conditions in about half a day immediately after a disaster strikes, and 2) understanding damage conditions during the restoration period.

3.4.2 MACRO STRUCK SITUATION ESTIMATION BY TESTING ORDER LINES

Estimating macro damage conditions consists of first GO/NO GO testing the order lines installed in each fixed distribution area using an order line tester, and then accumulating these results in the disaster information collection server. These test results are then combined with the facility information in the MARIOS server and the map information in the MARIOS terminals to estimate the macro damage conditions for each fixed distribution area and display the results on maps and ledgers. This makes it possible to understand the conditions for even the largest class of buildings in about an hour and a half.

3.4.3 STRUCK SITUATION GRASP BY ALL LINE TEST

On the other hand, understanding damage conditions during the restoration period consists of performing all core tests directly from the MDF using portable automatic line switching monitoring devices and accumulating these results in the disaster information collection server. Like macro estimates, the damage conditions are displayed on maps and ledgers using MARIOS. This makes it possible to understand the conditions for even the largest class of buildings in about twelve hours.

3.4.4 OTHER FUNCTIONS AND FEATURES

Open transfer technology has been established to allow reliable data transfer even under disaster conditions for both macro estimations immediately following disasters and understanding damage conditions during the restoration period. This technology can be supported by multiple means of communication including general public lines, leased lines and cellular telephones, and has a high degree of freedom with respect to terminal type, OS and communication software. This increases access freedom while at the same time ensuring security, and realizes a real-time database using the disaster information collection server.

This system employs the MARIOS platform, allowing full use of the powerful data processing technology and versatile display functions. In addition, this system is also equipped with diverse and advanced analysis functions that combine the MARIOS facility data, customer data and damage data, and is capable of flexibly expanding functions in the future.

4. DEVELOPMENT OF COMMON MAP INFORMATION DATABASE

NTT we have been developing the common map information database system (GEOS ; Geographic information system for shared spatial database) which is the system to construct digitized residential quarter chart database which can be called the infrastructure data in the multimedia age[11,12]. We are now constructing the database. On the other hand, systems to support the works that uses map information and applied technologies of map information have been under development. Development started in 1995, and system and database are in trial introduction.

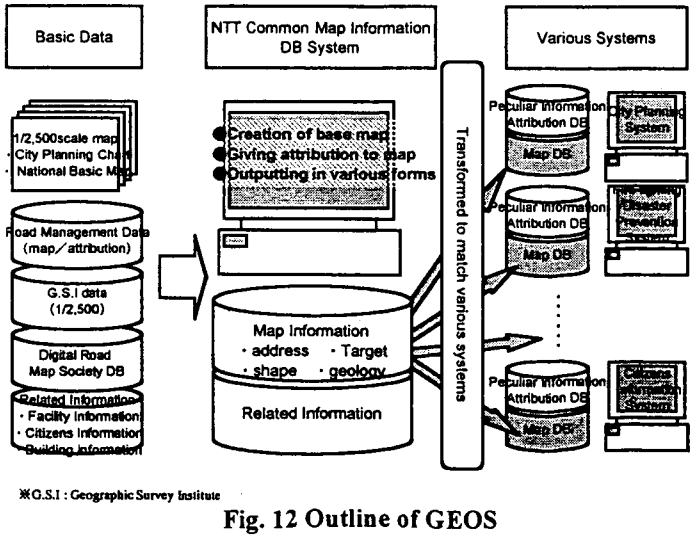


Fig. 12 Outline of GEOS

4.1 SYSTEM CONFIGURATION

This system is composed of the client server system, and consists of

two distributed databases of the map information management database and the attribute information management database. Moreover, this system is roughly divided into two systems according to the function. They are common geographic information system which constructs the map information database and various maps use systems that use map information. The use system here indicates the system that can treat map information, and a specific system is not indicated.

NTT had developed the information system that used the map data in the past, but generally those database could only be used with a system concerned. This system can supply the position coordinate data of map information from graphic data or the attribute data. In addition, graphic data can be supplied by various data layouts. Moreover, map information on an existing system like the road management system etc. can be used as a shared database of this system (Fig.12).

4.2 APPLICATION OF COMMON MAP INFORMATION DATABASE TO DISASTER COUNTERMEASURE

The application example to the disaster countermeasure system of the common map information database is introduced as follows[13,14].

4.2.1 SITE INVESTIGATION USING MOBILE TERMINAL

Since works using map information includes outdoor works such as facility investigation, we have been developing the system that handles map information with a mobile terminal. Mobile terminal of the pen input type was adopted in consideration of use in various situations.

We use portable telephone to transmit and receive data. We also use GPS positioning and retrieve map information of the area around current position. Not only text data but also image data could be transmitted by cooperation with a digital camera.

This technology can be applied to the struck situation investigation of the facility after the disaster occurs(Fig.13)

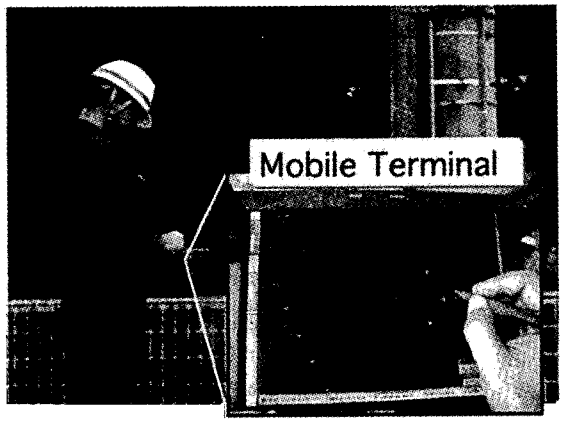


Fig. 13 Site Investigation with Mobile Terminal

4.2.2 DAMAGE SITUATION GRASP AND RETRIVAL OF STRUCK FACILITY CHART

The damage will be investigated when the disaster occurs, and the struck situation is registered in the database by photograph or text as the attribute information. When the region or the facility on the map is selected, the registered damage information will be displayed overlapped with the map. The burnt down region, the collapse house, and the struck equipment, etc. are extracted and understood by overlapping the aerial photograph taken immediately after the disaster occur with an digitized map. Moreover, Facilities in the damage region is retrieved, and the chart of the facility is selected and displayed (Figure 14).

4.2.3 RETRIEVAL OF STRUCK HOUSES AND DISASTER PREVENTION FACILITIES

The investigation result of the struck situation of the house is registered in the data base as attribute information, and houses could be extracted and displayed with highlight according to the state. The houses that the influence reaches is retrieved and displayed by registering struck information on the lifeline facilities. Disaster prevention facilities like shelter place, police and fire fighting etc. registered beforehand are retrieved and displayed

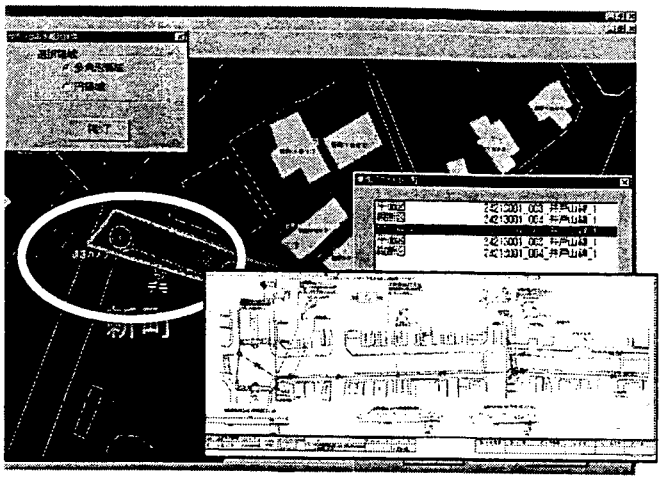


Fig.14 Damage Situation Grasp and Retrieval of Struck Facility Chart

4.2.4 ARRANGEMENT OF RESTORATION WORK

This system are combined with the position detection system which uses PHS, and the restoration work vehicle and the struck location are displayed on the map, and the work group is dispatched and arranged appropriately (Figure 15).

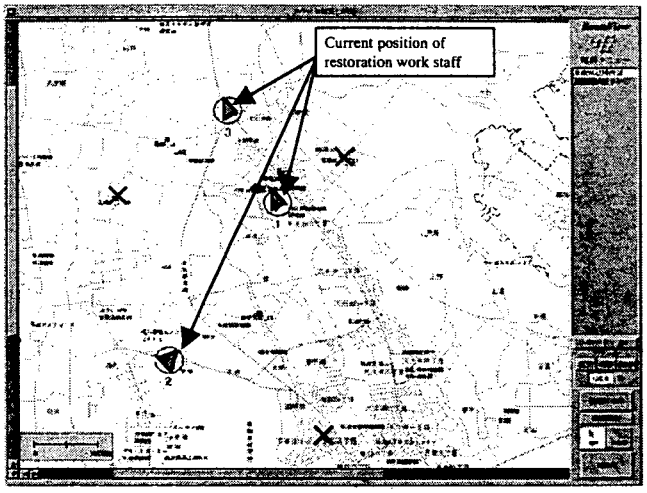


Fig.15 Arrangement of Restoration Work

4.2.5 OFFERING INFORMATION ON WEB

It is possible to refer map information using general browser software by converting data form of the digital map of this system. The map data will be conversed in to general image format (GIF form). The map data can be retrieved by using the space reference data in coordinates and the address, etc. The refuge address, the struck part information etc. could be offered by the map and the text on Web.

5 CLOSING

Based on the experience of the Hyogo-ken Nanbu Earthquake, NTT have been working on a new measure to achieve communication service endure against disaster. While the importance of the information and communication continue to increase, NTT will continue developing various disaster countermeasure systems to present services and to accomplish the obligation even under disastrous situation.

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MANAGING UTILITY EARTHQUAKE RISK

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Electric power and natural gas utilities in California, Japan, and other countries have gained a clear understanding of the seismic risks they and their customers face. Severe urban earthquakes in 1989 and 1994 (California), 1995 (Japan), and 1999 (Turkey and Taiwan) have

- damaged utility systems
- disrupted customer use of utility services—due to damage to the utility or to the customer's facility—causing a loss of utility revenue
- caused delays in resumption of pre-earthquake levels of commerce due to delays in utility recovery

As a result of these experiences, utilities in areas of high seismic hazard are motivated to implement programs to systematically reduce earthquake risk, including such activities as improving emergency response, replacing or retrofitting vulnerable facilities, and implementing stringent seismic criteria for new construction.

Intensifying these efforts to reduce seismic risk, utilities also are responding to major changes in their business environment caused by

- a demand for greater reliability and quality of electric power and natural gas service by utility customers, particularly those in high-technology-based businesses
- the increased operational efficiency inherent when customers seek lower utility prices as utility operations open to marketplace competition
- the greater levels of public safety now expected and required by public officials and government oversight agencies
- the new engineering standards and guidelines based on utility performance goals, not design codes.

The impact of these four factors creates a significant challenge for each utility to determine the operational priorities and rate of investment needed to address the earthquake hazard faced by the utility. Each utility is unique in terms of its network of facilities and lines required to meet customer-service needs, the seismic vulnerabilities of its network, and the exposure to earthquakes in its service territory. Because of these

unique attributes, decisions on managing earthquake risks also are unique to each utility; however, the basic information needed to support the decision process is similar for all utilities in high seismic areas.

During the decade since the 1989 Loma Prieta earthquake, PG&E has been conducting a major seismic risk management program. The goals of this program are to protect life safety, to limit loss of property, and to enable rapid restoration of utility service following an earthquake. Early in the program, the decisions were straightforward: the highest priority was given to retrofitting or replacing the weakest structures and equipment, in the areas having the greatest hazard. Once the most obvious retrofits were completed, decisions on prioritizing and performing additional retrofits or taking alternate actions became increasingly more difficult because

- the expected earthquake performance of the remaining facilities and systems was difficult to estimate accurately
- determining the acceptable levels of performance involved complex technical and policy aspects
- critical information needed for the earthquake risk management effort to be cost effective was not available

For example, an appropriate performance goal may be to have a 95 percent confidence of being able to restore electric service within 24 hours after an earthquake that has at least a 10 percent chance of occurring in the next 50 years. This form of goal statement explicitly includes the recognition that there is some low likelihood of not reaching the goal. The critical information needed to make informed decisions toward this goal is a probabilistic evaluation of the seismic performance of the electric system. Similar performance goals can be developed for gas systems.

In some cases, it may be more cost effective to provide additional redundancy to the system, and accept failures of some components rather than retrofitting to avoid failure of every component. The most cost-effective mitigation approach may be identified by evaluating the seismic performance of the system due to various scenario earthquakes, as follows:

1. Develop a set of scenario earthquakes and their associated probability of occurring.
2. For each scenario earthquake, compute the ground motion and ground deformation at each facility location. To capture the randomness in ground motion and ground deformation for a given scenario, consider multiple realizations of each scenario.
3. For each facility, estimate the damage states due to the given scenario using fragility curves. To capture the randomness in the damage for a given level of ground motion or ground deformation, consider multiple realizations of the damage state at each facility.
4. For the given set of damage states, evaluate the performance of the gas or electric system.

5. Combine the probability of the ground motion and ground deformation, and damage states to obtain the probability of the computed system performance for the scenario.
6. Combine the probabilities of the scenarios with the probabilities of the system performance for each scenario to obtain the overall probability of the system performance.

With this information, a utility can develop a cost-effective seismic risk management plan. Unfortunately, the data, models, and methods needed to implement this approach are not yet available or lack sufficient accuracy. Beginning in 1996, PG&E initiated a multi-year, utility-directed applied research program to address these needs. When completed, the results of this research will allow expenditures to be targeted to the facilities and equipment that most benefit company goals, and avoid or reduce expenditures that are extraneous to the system performance goals.

Without this information, a utility may simply decide to replace or retrofit all facilities and equipment that are considered vulnerable to earthquakes, regardless of where it is located. This type of broad-brush approach may achieve the performance goal, but it is not cost effective because many of the retrofits may not be necessary to reach the performance goal.

Avoiding unnecessary earthquake-preparation expenses is expected to save PG&E more than $20 million per year for the next ten years, out of a projected budget of about $100†million per year. PG&E research expenditures to date are about $9.9 million; additional funds come from co-funding of some projects by the California Energy Commission and the California Department of Transportation. The current planned scope of work for the next three years is about $13 million.

As major utilities perform major seismic improvement programs over the coming years, there is a potential for similar cost savings due to avoiding unneeded seismic retrofits. Because PG&E and other utilities face many of the same issues in conducting a seismic retrofit program, all can benefit by leveraging their research funds in a cooperative, utility-directed seismic research program.

Development of SUPREME

Yoshihisa SHIMIZU[1)]

ABSTRACT

In order to achieve a more sophisticated real-time system of disaster mitigation, Tokyo Gas Co., Ltd., commenced preparation of what will be the world's most extensive ultra-high-density real-time seismic motion monitoring and disaster mitigation system in January 1998. Known as "SUPREME," the system employs the New SI (spectrum intensity) sensor and a district regulator remote surveillance system installed at about 3,600 locations in its supply area, which measures about 3,100 square kilometers. The New SI sensors utilize ultra-small acceleration pickups made with micromachining technology as well as central processing units (CPUs) and random access memory (RAM) units, and constitute a new kind of seismometer that is both high-performance and low-cost. They are capable of measuring SI and ground acceleration, recording six earthquake wave-form acceleration trends on three (XYZ) axes, detecting liquefaction based on knowledge of the changes in acceleration waves, and control of regulators by means of settings for SI or acceleration. Tokyo Gas intends to harness the system for high-precision estimates of damage and detection of liquefaction in real time, and for investigation of seismic shaking amplication at various points based on wave-forms for small and medium earthquakes.

KEYWORDS: Real-time, Damage estimation, Damage mitigation, Earthquake monitoring, Liquefaction detection method, Gas, Signal

1. INTRODUCTION

Tokyo Gas Co., Ltd. supplies gas to customers in metropolitan Tokyo area -- one of the world's most densely populated urban areas, and a major center of political, cultural and economic activity. We regard it as part of our responsibility to society as a gas supplier to assure safety even in the event of a major earthquake. Such preparations have long been an important concern of Tokyo Gas, and a range of hardware and software solutions is in place, including both the hardware of gas supply facilities and the software such as regulations or manuals relating to emergency response and efficiency of restoration work.

On 17 January 1995, an earthquake with a magnitude of 7.2 occurred directly under the Hanshin-Awajishima area of Japan. It resulted in unprecedented damage, especially in the city of Kobe, and subsequently became known as the "Great Hanshin Earthquake." As shown in Table 1, it also caused considerable damage to city gas supply facilities, and particularly low-pressure pipelines. The results reconfirmed the immensity of the threat posed by earthquakes and also underscored the importance of emergency response systems for gas supply facilities in the event of an earthquake [Gas Industry Earthquake Countermeasures Study Report, 1996].

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Table 1: Damage to gas facilities in the Great Hanshin Earthquake

Item	Details
1. Damage to pipelines	Medium-pressure pipelines 106 cases of leakage Low-pressure pipelines 26,459 cases of leakage
2. Number of cases of supply suspension	About 860,000
3. Number of days required for complete resumption	85 days

The Great Hanshin Earthquake provided graphic proof of how difficult it is to gather information on damage immediately after an earthquake, in spite of the crucial importance of obtaining such information. As a means of resolving this difficulty, systems for real-time estimation of earthquake damage are being planned or constructed by several agencies. To the same end, Tokyo Gas launched development of the Seismic Information Gathering & Network Alert System (SIGNAL) [Shimizu, 1997] in 1986 and put it into operation in June 1994, about six months prior to the Great Hanshin Earthquake. With a view to achieving a higher level of safety in the event of major earthquakes, it began constructing another system in January 1998 for SUPer-dense REal-time Monitoring of Earthquakes (SUPREME). Based on installation of roughly 3,600 new seismometers (New SI sensors) over its supply area of roughly 3,100 square kilometers, the new system will feature the most intensive seismic monitoring of any in the world.

2. DEVELOPMENT OF THE NEW SI SENSORS

Micro-machining technology has made possible the adoption of ultra small acceleration pickups (manufactured by Sumitomo Precision Products Co., Ltd.), and the availability of low-cost, high performance CPU and RAM devices have resulted in the joint development together with Yamatake Co., Ltd. of a New SI sensor (see figure 1), which features high precision and high performance at a low price. The features are as follows:

2.1 Both Control and Measurement Functions, and Accommodation of Telemeter Equipment

The New SI sensors employ a voltageless relay contact point output for regulator shutoff, analog output of SI values and acceleration data for measurement, and an alarm (contact point output) for liquefaction. The analog output is of a highly general-purpose nature; it has an operational range of 4 - 20 mA to accommodate various kinds of telemeter equipment.

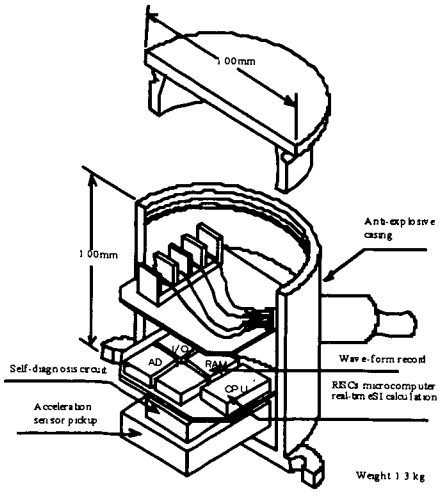


Figure 1: New SI sensor

The sensors are capable of measuring acceleration from plus 2,000 Gal to minus 2,000 Gal, and with a precision of less than plus or minus 5 percent. Moreover, the setting for issuance of alerts can be changed (in addition, the SI and acceleration settings can be selected as desired).

2.2 Wave-form Data Storage

The New SI sensors are also equipped for storage of the earthquake wave-form data to permit their use in the formulation of disaster mitigation countermeasures and in related research. The data are stored on an internal memory together with header information for items such as six earthquake wave-forms on the X, Y, and Z axes, (listed beginning with the highest SI value) and the dates of occurrence. The sensors have a recording data sampling time of 1/100th of a second, a resolution of 1/8th of a Gal, and a wave-form recording duration of 50 seconds (from plus to minus 25 seconds) per seismic wave, centered around the wave with the highest SI value. Figure 2 shows the acceleration wave-form data actually stored for an earthquake which struck in the southern part of Ibaraki prefecture on 14 January 1998.

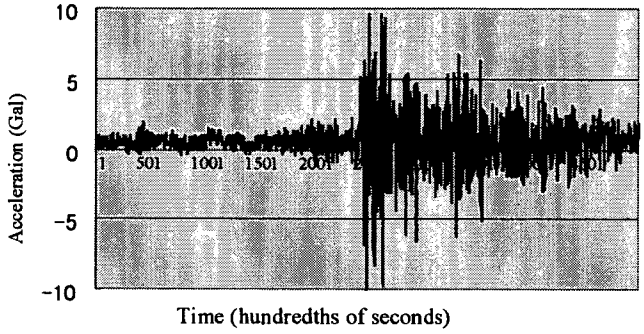


Figure 2: Seismic data, 1998/1/14 (Konan, Minato ward)

2.3 Self-diagnosis

The SI units are equipped with a constantly available self-diagnostic function in the interest of more reliable action. In the event of abnormality, the situation can be promptly apprehended by abnormal output to the tele-metering device.

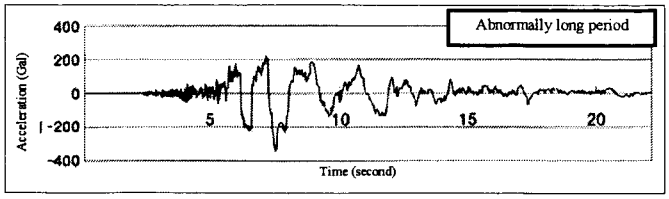
2.4 Liquefaction Judgment

Data on ground liquefaction are extremely important for estimating damage. Conventionally, the acquisition of such data has required large-scale boring. The New SI sensors make a judgment on the presence or absence of liquefaction from the changes in the acceleration wave-forms, and therefore make it extremely simple to apprehend ground liquefaction. As shown in Figure 3, the wave-form period for Port Island, where ground liquefaction occurred in the Great Hanshin Earthquake, is clearly longer than that for the Kobe Marine Meteorological Station.

The New SI sensors judge that ground liquefaction has occurred when the four conditions shown below have been met in respect of acceleration (A max), SI value, estimated displacement (D; $2SI^2/A$ max) [Towhata, Park, Orense and Kano, 1996], and estimated period (T), based on the change in seismic wave-form. The estimated period is equated with the time interval as defined by zero-cross, i.e., the time required for the wave-form trend measured by the sensor to cross the zero line.

(I) Amax > 100 gal
(II) SI value > 20 kine
(III) D > 10 cm
(IV) T > 2 sec

Recorded at Port Island (where severe liquefaction occurred)



Recorded at the Kobe Marine Meteorological Station
(no liquefaction)

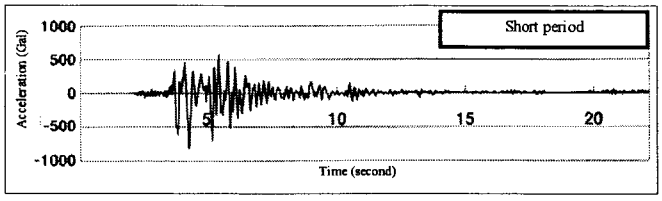


Figure 3: Seismic wave-forms for the Great Hanshin Earthquake

Figure 4 shows the results of the analysis of wave-forms and liquefaction judgment in the case of 70 past earthquakes. Among these 70 earthquakes, those which actually caused liquefaction were as follows (with areas of liquefaction noted in parentheses): the Central Sea of Japan Earthquake (Aomori, Hachirogata, and the Tsugaru Bridge), the Great Hanshin Earthquake (Amagasaki, Kobe harbor, Port Island, and the East Kobe Bridge), Superstition Hill (Wildlife) [Matasovic and Vucetic, 1993], and the Niigata Earthquake (Kawagishi-cho). Use of this newly developed measurement technique will enable determination of liquefaction in real time with an accuracy approaching 100 percent.

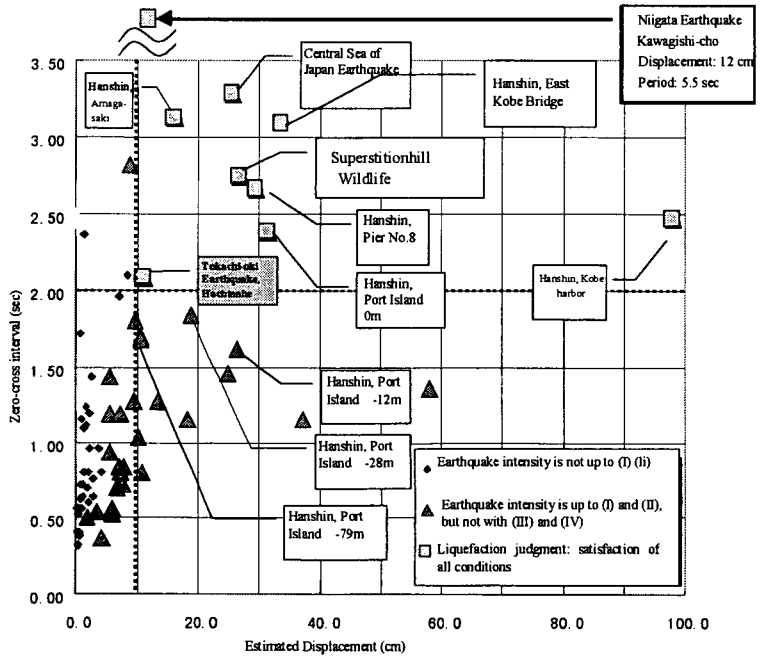


Figure 4: Results of liquefaction judgment

3. DEVELOPMENT OF THE SUPER HIGH-DENSITY REALTIME DISASTER MITIGATION SYSTEM (SUPREME)

3.1 Outline of the Super High-density Real-time Disaster Mitigation System (SUPREME)

Since the Great Hanshin Earthquake, numerous agencies have constructed systems for high-density monitoring of seismic motion and real-time damage estimation. Tokyo Gas is already operating the Seismic Information Gathering & Network Alert System (SIGNAL) based on installation of seismometers at 331 locations (see Figure 5). To raise the level of safety from disasters even higher, it embarked on construction of what will be the world's most extensive system for SUPer-dense REal-time Monitoring of Earthquakes (SUPREME) through installation of about 3,600 seismometers (New SI sensors) over its supply area, which measures about 3,100 square kilometers, beginning in January 1998. Figure 6 shows the distribution when all of the New SI sensors have been installed.

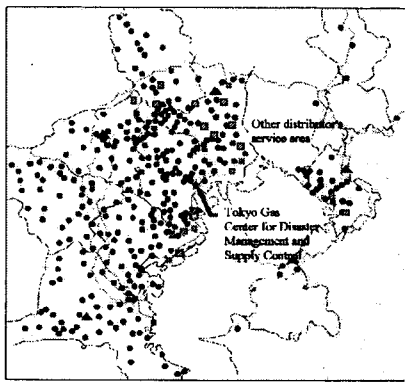


Figure 5: SI sensors in SIGNAL

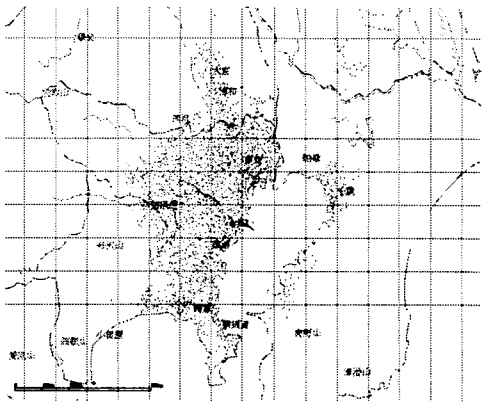


Figure 6: New SI sensors in SUPREME

Figure 7 shows the structure of the super high-density real-time disaster mitigation system. Tokyo Gas is currently taking the opportunity presented by replacement of the former SI regulator shutoff sensors to install the New SI sensors and district regulator remote monitoring system (DCX) in about 3,600 district regulators. The linkage of this equipment with the command center through communications circuits will enable observation, and remote monitoring at the center, of various control items at the roughly 3,600 points in the supply area of roughly 3,100 square kilometers (for an average of one point every 0.9 square kilometers). These items include the SI value, PGA, pressure, regulator shut-off status, and liquefaction alert data.

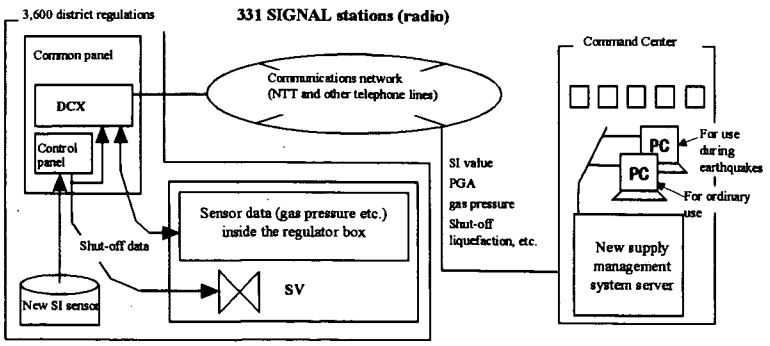


Figure 7: Composition of SUPREME

3.2 Approach to System Utilization

- The SI values, which are measured in ultra high density, and the GIS, which includes information on gas pipelines, soil and geography of the gas supply area, are used to make highly accurate estimations of the damage caused by an earthquake.

- Analysis of the yearly wave-form data on small and medium earthquakes in combination with GIS data will make it possible to determine the seismic shaking amplication at each of the roughly 3,600 points. Such information can be reflected in zoning plans and assist optimization of the setting of values for automatic shutoff of district regulators.

- In the event of a major earthquake, the system will not only automatically shut off the district regulators but also enable the command center to confirm the operation of the shutoff equipment. This will contribute to a more prompt and sure response to emergency situations.

- It is possible to monitor the gas pressure during critical events at approximately 3,600 points. Losses in gas pressure during an earthquake are indications of potential damage, and can be used to make early estimates of the extent of damage. Not only can realtime estimates of damage to major facilities be made, but a system is now being developed for the swift and accurate detection of actual damage.

- Detailed, realtime detection of liquefaction allows highly accurate estimates of damage, and the rapid execution of emergency measures

3.3 Release of Seismic Data

Data from 31 of the major points in the SIGNAL earthquake monitoring network are transmitted to Nippon Hoso Kyokai (NHK) and other mass media organs as well as public administrative institutions such as the Tokyo Metropolitan Government. Beginning in September 1996, it was decided to release data from all 331 SIGNAL points through Internet within a very short time after occurrence in the case of earthquakes with a magnitude of 3 or more, in order to contribute to emergency response and research by numerous institutions (see Table 2). In addition, Tokyo Gas is promoting the sharing of data and research results with governmental bodies that are taking active approaches to real-time disaster mitigation. The transmission of data from the 331 SIGNAL points to the Yokohama municipal government beginning in 1998 is a part of this policy.

Table 2: Release of SIGNAL data through Internet

- Objective
  - Promotion of research for disaster mitigation through sharing of seismic data
  - Active use for initial mobilization
- Items of data release (for earthquakes occurring within the service area and having a magnitude of at least 3)
  - Earthquake name, time of occurrence, and epicenter
  - Location of the seismometer (name of location, latitude, and longitude)
  - SI value and maximum acceleration
- URL
  http//www.toyko-gas.co.jp

  Posted at the bottom of the Tokyo Gas web site

The new SUPREME real-time disaster mitigation system will record wave-form data (six earthquake wave-forms on three axes, listed from the highest SI value) for small and medium earthquakes at some 3,600 points. Earthquake wave-forms entail an immense load of data which cannot be collected in real time. However, the company plans to release data stored by CD-ROM once a year.

4. CONCLUSION

Real-time disaster mitigation came to the fore in the aftermath of the Great Hanshin Earthquake, and systems for real-time monitoring of seismic motion and damage estimation have since been installed or planned by many agencies. In SIGNAL, Tokyo Gas constructed one of the first systems of this type, and was commended for its foresight with selection for the 1996 Award for Civil Engineering and Development given by the Japan Society of Civil Engineering. In order to raise the level of safety from disasters even higher, Tokyo Gas began construction of a new SUPREME system for disaster mitigation based on installation of roughly 3,600 New SI sensors and a DCX system for remote monitoring of district regulators in January 1998.

It is hoped that the future will bring a sharing of seismic and geophysical data obtained from the systems of Tokyo Gas (i.e., the SUPREME disaster mitigation system and SIGNAL) and the systems of other agencies, the promotion of related research by numerous institutions, and a sharing of the research results by all concerned.

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Session V: Crisis Management- Urgent Response Works and Restoration (4)

- On the UrEDAS- its Development and Application for Early Warning and Rapid Information against Destructive Earthquakes, *Yutaka Nakamura (System and Data Research co. ltd.)*
- Geospatial Systems for Natural Disaster Planning and Recovery, *William Roper (U.S. Army TEC)*
- Framework for Efficient Gathering of Earthquake Damage Information, *Shinsaku Zama* (NRIFD), Masafumi Hosokawa*

On the UrEDAS - its Development and Application for Early Warning and Rapid Information against Destructive Earthquakes

Yutaka NAKAMURA

ABSTRACT

Recently many destructive earthquakes occurred in various place and caused serious number of casualties as well as damage on social infrastructures. The damages to residence often cause human loss. It is important to make countermeasures against earthquake disaster on the assumption that residences are frequently collapsed by earthquake. From this point of view, early warning and rapid information are very important countermeasures against destructive earthquakes. This paper describes the development and the application of the UrEDAS, Urgent Earthquake Detection and Alarm System, which is unique system under actual use for P wave alarm for automatic systems.

KEYWORDS: Earthquake warning system, UrEDAS, quick-response system, hazard estimation

1. INTRODUCTION

Earthquake disaster countermeasures are based in principle to know both characteristics of earthquake motions and resisting power of structures against the earthquake motions. Earthquake damage occurs when earthquake power exceeds the resisting power or durability of the structures, including natural slopes. Disaster can be prevented if we can find weak points of structures beforehand and execute effective countermeasures in advance. Thus, it is really important to assume a few kinds of earthquakes that may attack the area and to clarify the weak points of structures by estimating the expected earthquake damage. However, practically it is impossible to reinforce all estimated weak points before the earthquake.
Thus, the following two points become indispensable for the earthquake disaster prevention,

1) Estimating the present anti-seismic durability of existing structures,
2) Preparing back-up countermeasures to avoid an unexpected hazardous situation.

The second item is a co-seismic countermeasure and it asks real-time response. It is necessary to grasp the change of durability degree in time by measuring it with appropriate intervals for the first item.

2. CONCEPT OF EARTHQUAKE EARLY WARNING

Since the second half of the 1950s, simple alarm seismometers had been installed along the railway in Japan by Japanese National Railways. Along the Tokaido Shinkansen, which started its operation in October 1964, the same alarm seismometers were also installed. A local earthquake (M6.1) near Shizuoka in April 1965 signaled the urgency to prepare an automatic

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train stop system using more reliable alarm seismometers. However, though the newly adopted alarm seismometer issues only an alarm when seismic acceleration exceeds a pre-set threshold, it can not give the experienced final maximum acceleration. When Tohoku Shinkansen was opened in 1982, the alarm seismometer was developed to set several alarm acceleration levels and indicate the maximum acceleration value with a paper-print as well as to give analog waveform records. Since then, similar alarm seismometers have been installed for the conventional Japan Railways (JR) lines and other Shinkansen lines. Now alarm seismometers are installed more than four hundred. The alarm seismometers are at present installed every 40~50 km along the conventional lines of JR and every about 20 km along the Shinkansen lines. The alarm seismometer is installed on the ground surface and set to issue when horizontal acceleration exceeds preset threshold. The alarm is issued generally after S wave arrival. If we set the threshold level lower, the seismic motion can be detected earlier. However, it easily responds to many environmental noises due to human activities such as traffic vibrations and industries and the number of false alarm may increase. Conventional alarm seismometer includes following two problems,

1) Alarm is issued too late to give enough time for the useful countermeasures,
2) False alarm is frequently issued by a harmless small earthquake.

The above problems are based on the basic idea to issue an alarm, when seismic motion exceeds the pre-set threshold. Thus the problems can not be solved even when we use quantities other than the acceleration.
In order to realize the early detection of an earthquake, following two methods will be discussed,

1) To detect the earthquake near the epicentral area, which is named as "Front detection",
2) To detect the earthquake by initial P wave, which is named as "P wave detection".

The idea of "Front detection" is explained in Fig. 1. The earthquake must be detected as early as possible because this idea realize the early warning using difference of transmission velocities, electric communication (=300,000 km/s) and seismic wave (≅8 km/s). For this purpose, seismometers must be installed near the source. This idea was first published in the San Francisco Daily Evening Bulletin, 3. Nov. 1868, by J.D.Cooper, M.D. in San Francisco (Nakamura and Tucker, 1988). He described about the necessity of automation of the early warning system and the problem of false alarm as well as the importance of public education for the warning. However, the technical level of those days could not realize his idea in practice. After about 100 years, in 1972, Dr. Motohiko Hakuno (the emeritus professor, Univ. of Tokyo) and others proposed the same idea for Tokyo instead of San Francisco. Then

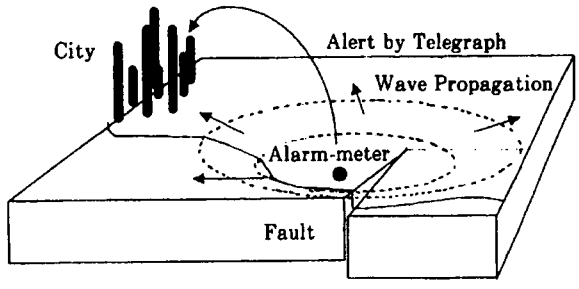


Fig. 1 The idea of "Front detection"

Japanese National Railways (JNR) paid strong interest in this concept to prepare against unexpected situations of railways due to strong earthquakes and promoted the research and development for this project. Thus JNR completed this idea as the Coastline Detection System for the Tohoku Shinkansen in 1982 (Nakamura and Saito, 1982). After about ten years, the Mexico City Seismic Alert System, almost the same as the JNR Coastline Detection System, was installed in 1991 (Espinosa-Aranda, *et al.*, 1995).

Fig. 2 shows the timing of the alarms in relation to the seismic motion schematically. Conventional alarm seismometers detect earthquake motion when the main motion arrival (S wave alarm). An alarm can be issued earlier if we detect the earthquake by P wave. However, P wave alarm is not so easy if it issues an alarm merely when the earthquake motion exceeds a certain pre-set trigger level. Because of the lower trigger level, detection can be done earlier, but false alarm occurs very often.

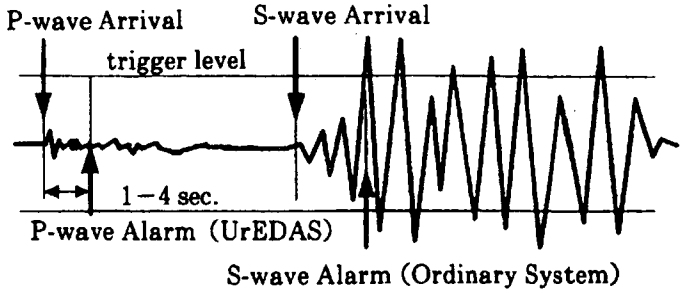


Fig. 2 the timing of the alarms

In order to examine new alarm methods, past cases of earthquake railway damage are plotted in a diagram, taking earthquake magnitude in horizontal axis and epicentral distance in vertical axis as in Fig. 3. It clearly shows that damage occurs for M>5.5 and damaged areas are confined within a certain distance range around the epicenter. For example, earthquakes with M6, M7 and M8 give damage within epicentral distances 12 km, 60 km and 300 km respectively. If we could estimate the earthquake magnitude and epicenter location with depth rapidly, the area to be alarmed is clearly shown by M-Δ diagram in Fig. 3 and reasonable alarm can be issued immediately after the earthquake. This new alarm is referred to as M-Δ Alarm.

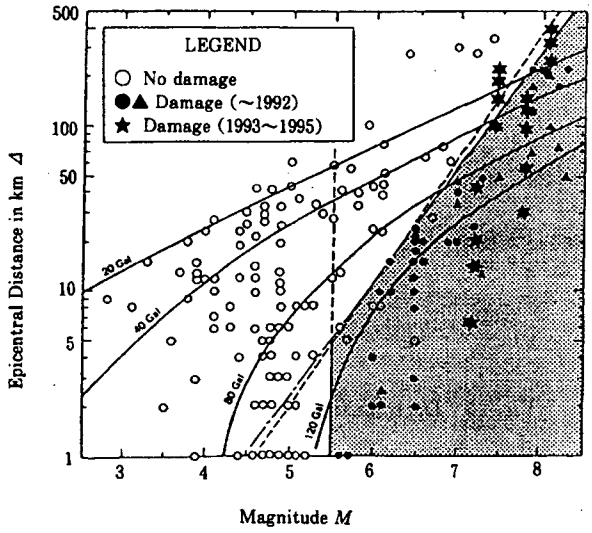


Fig.3 M-Δ Diagram

Today there are two types of earthquake early warning system with P wave detection. The first one is called UrEDAS. After the detection of P wave, UrEDAS estimates earthquake parameters as magnitude, distance, depth etc, and issues the alarm within 3 seconds to the 200 km area if necessary. And the latter system called Compact UrEDAS, detects the earthquake with the P wave and gives alarm to a 20 km area, just after 1 second of the P wave detection. The method to issue P wave alarm of Compact UrEDAS will be mentioned later.

3. DEVELOPMENT OF UrEDAS

The task of UrEDAS is to estimate the magnitude of an 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, UrEDAS does not have to transmit the observed waveform in real-time to a remote processing center and thus the system can be considerably simplified.

Epicentral Azimuth

Of the seismic wave motions, the first one that reaches the observation point is P wave, and in this case, the direction of seismic motion and wave propagation coincides. Therefore, the epicentral azimuth can be estimated from the direction of the initial motion projected on the horizontal plane.

Fig. 4 compares the epicentral azimuth estimated by the local network of Tohoku University or the national network of the Japan Meteorological Agency (JMA) and that by the proposed method using the data of a single UrEDAS observation point. They coincide within ±20 degrees.

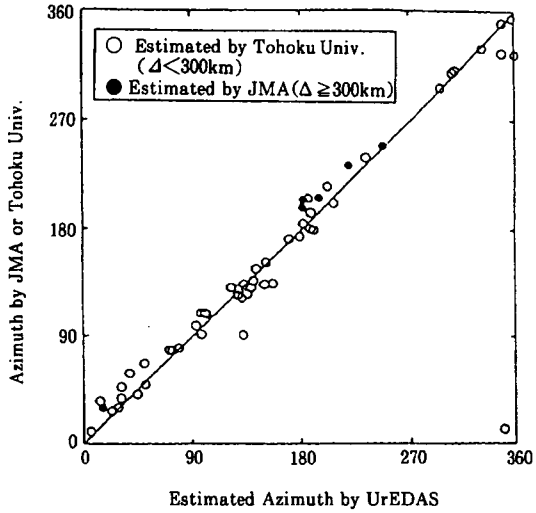


Fig. 4 Comparison of Azimuth

Magnitude of Earthquake

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 magnitude. Therefore, the magnitude of an earthquake can be predicted from the predominant period of the initial motion.

Fig. 5 shows a comparison between the initial motion periods automatically read by the UrEDAS and the magnitude given by JMA. The values of magnitude estimated by UrEDAS are almost within ±0.5 relatively to the magnitude estimated by JMA.

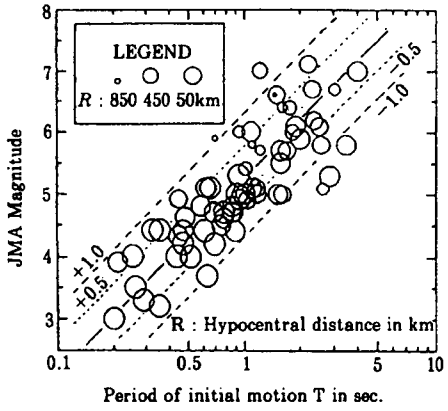


Fig. 5 comparison between the magnitude and periods

Hypocentral Distance

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 and the magnitude of the earthquake can be estimated from the period of the initial motion, the hypocentral distance can be estimated from this information. Although the accuracy of estimating the hypocentral distance in this way is not high (a half to twice), more accurate estimation by using the duration of preliminary tremors is possible after the arrival of the principal motion.

Identification of P wave and S waves

The process mentioned above is based on the premise that the detected seismic motion is P wave. Identification whether P wave or 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 one (tentative value: vertical motion is predominant), it can be considered as P wave, and if the ratio V/H is less than one (tentative value: horizontal motion is predominant), it can be considered as S wave (see Fig. 6).

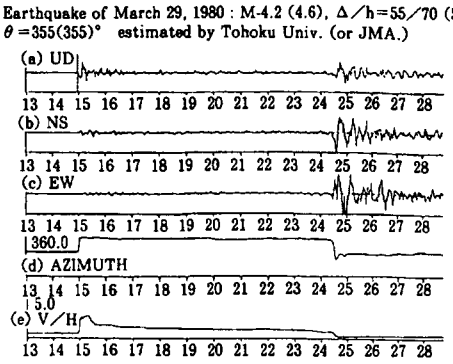


Fig. 6 Identification P wave and S wave

Estimation of Epicentral Distance and Depth

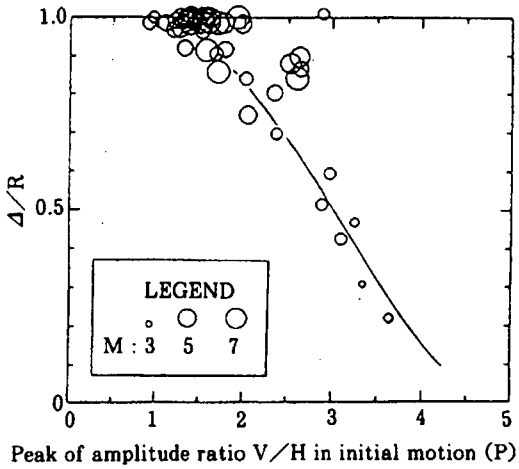


Fig. 8 Relationship between V/H and Δ/R

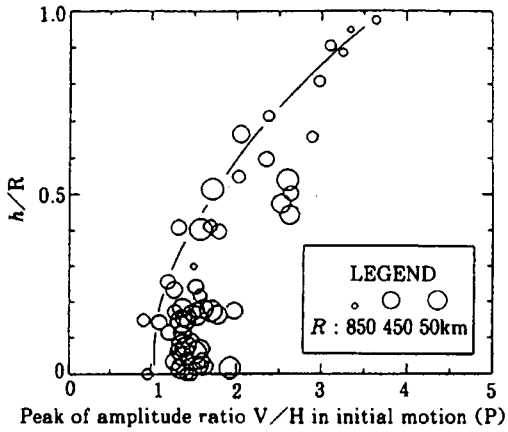


Fig. 9 Relationship between V/H and h/R

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. Figs. 7 and 8 show the relations of V/H to Δ/R, and to h/R respectively. By means of Figs. 7 and 8, Δ and h can be estimated from V/H and R.

Examples of Earthquake Monitoring by UrEDAS

UrEDAS worked in both time of the Northridge Earthquake, 17 January 1994, and the Hyogo-Ken-Nanbu Earthquake, 17 January 1995.

During the first 24 hours after the Northridge Earthquake, UrEDAS detected about 700 aftershocks of which their magnitudes and locations of hypocenter were automatically determined as shown in Fig. 9. All detected earthquakes of Pasadena UrEDAS were indicated graphically in the office room of Seismological Laboratory of Caltech immediately after each event. In addition, Pasadena UrEDAS information was sent to CUBE and referred as useful

data.

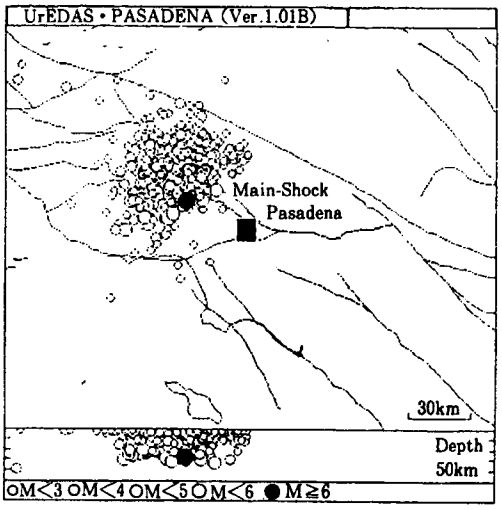


Fig. 9 detected earthquakes of Pasadena UrEDAS

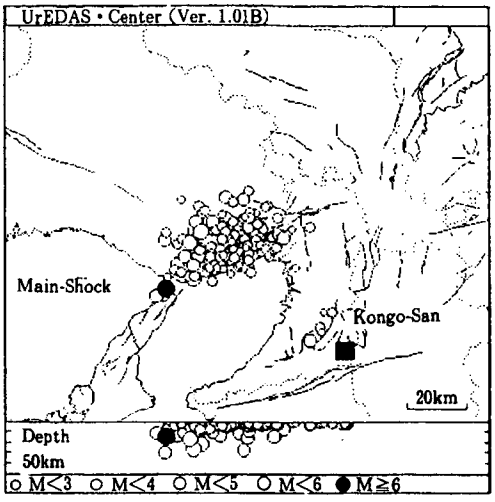


Fig. 10 result of monitoring the Hyogo-Ken-Nanbu Earthquake and its aftershocks

Fig. 10 shows the result of monitoring the Hyogo-Ken-Nanbu Earthquake sequence before 30 Jan. 1995 at UrEDAS Kongo-San station, the nearest station to the epicenter. Although this figure based on the data of only one UrEDAS station, aftershock activity was almost correctly traced. The Hyogo-Ken-Nanbu Earthquake occurred just beneath the San'yo Shinkansen line and alarm seismometers along the line have responded to the event. The recorded seismograms showed that strong seismic motions arrived successively at the alarm seismometers installed every 20 km along the line and each seismometer issued alarm within a few seconds one by one. All Tokaido UrEDAS, except the one station at Gozaisho, judged the Hyogo-Ken-Nanbu Earthquake as harmless for the Tokaido Shinkansen, which terminates at Shin-Osaka and did not issue the alarm. But, even granted that a P wave alarm was issued from the Kongo-San UrEDAS, this alarm and alarms from the seismometers along the line would probably reach almost simultaneously. It suggests that the alarm seismometers along the Shinkansen line functioned as expected.

4. NEW CONCEPT OF P WAVE ALARM FOR Compact UrEDAS

The earthquake damage is strongly related to the power of earthquake motion.
Power can be expressed as in equation (1),

$$\begin{aligned} Power &= Force \times Velocity \\ &= Mass \times Acceleration \times Velocity \end{aligned} \qquad (1)$$

Two parameters named DI (Damage Intensity), PI (P wave index) are introduced for damage estimation and for early warning. DI function is also considered as an inner product of acceleration and velocity vectors and considered to be related with damage, same as K value. DI function relation with acceleration and velocity can be simply written as,

$$DI = \log |\alpha \cdot \nu| \qquad (2)$$

where α is acceleration vector(in Gal = cm/sec^2) and ν is velocity vector (in mkine = 1/1000 cm/sec). DI function is practically calculated as a sum of products of acceleration and velocity for three components. Then DI value is defined as a maximum value of DI function after the S wave arrival.

A predominant circular frequency of earthquake motion ($\omega = 2\pi/T$) can be found from the ratio of α/ν, and a period T can be expressed as $T = 2\pi\nu/\alpha$. Therefore, $\nu = \alpha T/(2\pi)$. Substituting this into equation (2), DI function can be expressed as,

$$DI = \log [\alpha^2 T/(2\pi)] = 2\log\alpha + \log T - \log(2\pi) \qquad (3)$$

Figure 11 shows the change of DI as a function of time. When P wave arrives, DI increases drastically. PI is defined as maximum DI within t second after the P wave detection. This value is suggested to be used for P wave alarm. In this study, preset time t is taken as 1 second. Value of t can increase maximum up to PS time. After this, DI continues to increase slowly until the S wave arrival. After the arrival of S wave, it reaches to its maximum level that is called as DI value. This value can be related with damage and Instrumental Seismic Intensity of Japan Meteorological Agency (I_{JMA}).

I_{JMA} can be determined only after the earthquake terminated, on the other hand, DI value has a very important practical advantage, since it can be calculated in real-time soon after the P wave arrival. This can be concluded as, with the continuous observation of DI, earthquake alarm can be issued efficiently and damage can be estimated precisely.

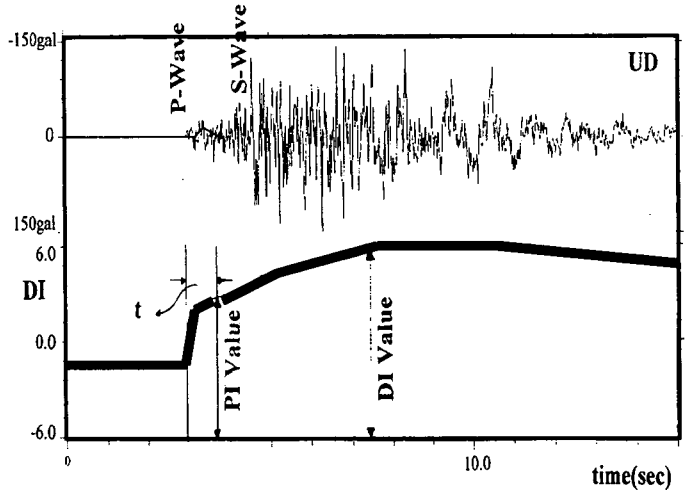


Figure 11 Change of DI as a function of time

Application to real earthquake records

Application of the method was made to the K-Net data, recorded at three stations from 1996 to 1997. These stations were selected as sample, since they recorded earthquakes with I_{JMA} up to

VI. Fig. 12 shows the distribution of the DI value and PI. In case of setting maximum acceleration at 40 Gal and 80 Gal, PI trigger level vary between 2-2.5 in present study. PI is promising for the future early warning systems.

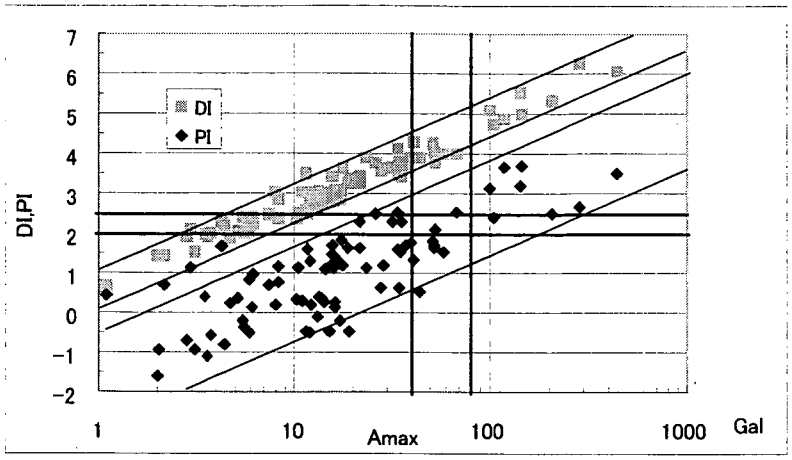
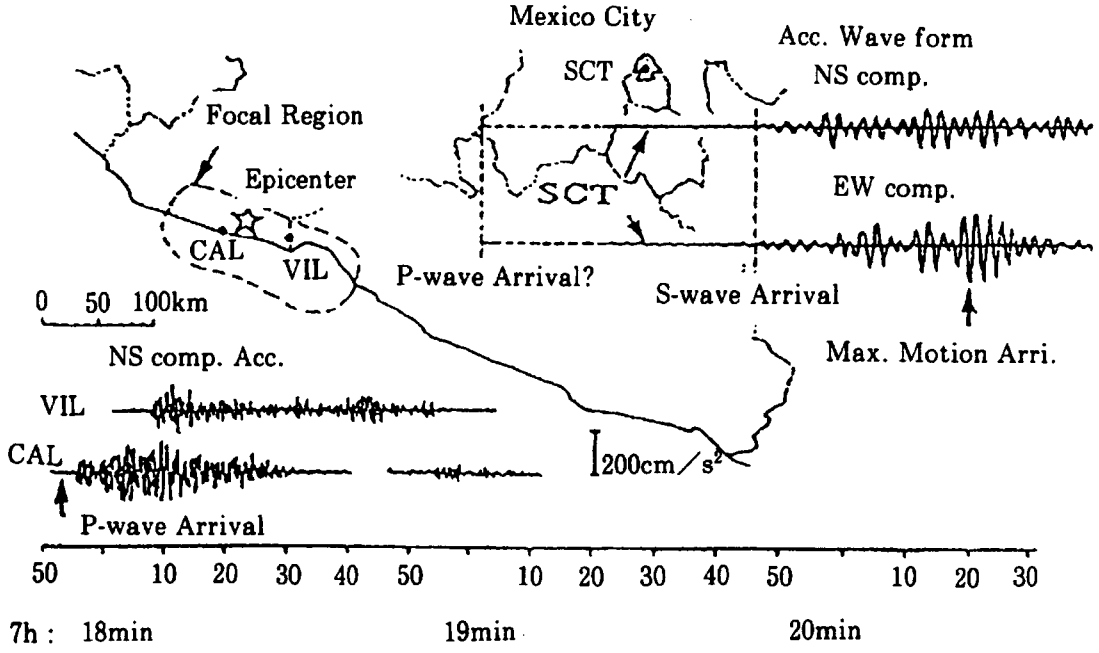


Figure 12 Application of the method to the K-Net data

5. TIME MARGIN OF UrEDAS AND ITS EFFECT FOR DISASTER PREVENTION

Fig. 13 shows a model of UrEDAS installed along the pacific coast of Mexico. This figure shows that the P wave of the 1985 Michoacan Earthquake reaches Mexico City one minute after



7 a.m. of September 19, 1985 (Local time)

Fig. 13 UrEDAS simulation oMichoacan Earthquake

the UrEDAS alarm and the main strong motion, which causes damage, arrives there after another one minute later. Namely there is two minutes margin time for Mexico City, and even if UrEDAS is installed only in Mexico City, still there is one minute margin. This margin time expected to UrEDAS in Mexico City is nearly equal to that of the Mexico City Seismic Alert System consisting of seismometers along the pacific coast of Mexico. People can move 100 m or over per one minute. UrEDAS can decrease human damage, by utilizing this one minute margin time. UrEDAS can recommend adequate refuge reaction, use of anti-shelter in high rise building floor, etc during the margin time between the UrEDAS alarm and strong seismic motions.

UrEDAS gives a prompt first alarm within a few seconds and provides more exact information about one minute after it detects the event. It is not only useful for the safeguard of train and automobile transportation, but also expected to be applied widely for the different disaster prevention such as trigger of active control devices. For example, UrEDAS can apply for building, control of elevator of high-rise building, earthquake countermeasures of chemical plant and nuclear power plant, tsunami warning for the harbor and coastal publics, early response of fire-fighting, preparedness of hospitals, etc.

Another example is mentioned for the 17 August 1999 Izmit Earthquake (See Fig. 14). If Compact UrEDAS were installed in Izmit above 15 km from the hypocenter, it could give the alarm after one second before the destructive waves arrive to the city. It is quite short time because the earthquake occurred just under the city, but it shows it is still possible to be an alarm even for the event as close as this. If UrEDAS was in Istanbul, considering of 100 km epicentral distance, it could give the alarm more than 10 sec before the destructive waves arrived at the city. It seems that 10 seconds is short, but it is still enough for the automatic shutdown of gas or electricity supplement. If UrEDAS were in Izmit, it could give the alarm 6 sec. before the P wave arrives to the Istanbul (which means it can give the alarm before the earthquake waves arrive to the city), destructive waves come 14 sec. after this alarm. It means that 20 sec. is a time enough to decide countermeasures.

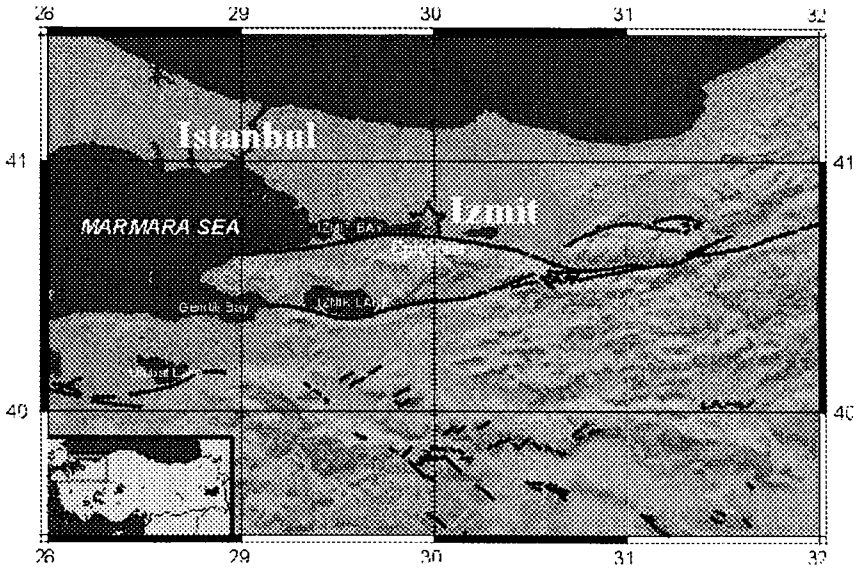


Fig. 14 1999 Izmit Earthquake

6. APPLICATIONS

UrEDAS is a uniquely practical system and it was the first real-time earthquake disaster prevention system in the world.

In 1983, a prototype system using a personal computer with basic function of UrEDAS was completed. Since 1984, test observations with this prototype system were executed in Miyako, near pacific coast of the Tohoku District, and some other places. Then an UrEDAS network for Tokyo Metropolitan Area consisting of five UrEDAS stations was established in 1988-1989 by the subsidy of the Ministry of Transportation. In March 1988, four UrEDAS stations were also installed for the Seikan Under-Sea Tunnel between Honshu and Hokkaido as a part of its earthquake disaster prevention system. The Tokaido Shinkansen UrEDAS at Omaezaki, Shizuoka Prefecture, started limited operation in September 1990. And in March 1992, Tokaido Shinkansen UrEDAS started operation with fourteen UrEDAS stations surrounding the Tokaido Shinkansen line realizing the P wave alarm (M-Δ Alarm). Between 1992 and 1997, About 50 user were delivered UrEDAS earthquake information via facsimile within four minutes after earthquake detection. This information was automatically derived from Tokyo Metropolitan UrEDAS as a map located the epicenter.

In September 1992, an UrEDAS network with one station and one data collecting center was installed in California Institute of Technology (Caltech) of Pasadena, California as a joint research project of Prof. H. Kanamori of Caltech and Railway Technical Research Institute (RTRI). This Pasadena UrEDAS observed the Northridge Earthquake, 17 January 1994, and its aftershocks mentioned before. This Caltech-RTRI Project terminated in August 1999. Renewal Project will start under cooperation of researchers of Caltech and SDR.

After 17th August 1999 Izmit earthquake, from September of 1999, for the test, Istanbul UrEDAS was installed Kandilli observatory of Earthquake Research Institute with cooperation of Prof. Mustafa Erdik, Bosporus University. It requires some tuning work but after the installation, this system detected one of the biggest aftershock M=5.8 of the Izmit earthquake as M=5.9 and made possible to check the performance of the system.

UrEDAS gives location, depth and magnitude of the earthquake in order to estimate the impending damage promptly. To know the earthquake dimension, data at many observation points are usually used. However, considering the complexity of multi-station systems and weakness of network systems, UrEDAS adopted the single station principle for the alarming.

By monitoring the earthquake motions of a single observation point in real-time, an UrEDAS detects initial P wave motion, estimates epicenter azimuth and magnitude, calculates epicentral distance and focal depth as the first inference within about three seconds after detecting P wave. This is the actual function of UrEDAS in practical use for Tokaido Shinkansen since March 1992. With respect to the locations of epicenter and the UrEDAS station, the alarm eventually reaches the target area before the destructive wave arrival. UrEDAS issues the first alarm information just 3 - 4 sec after P wave arrival and sends out the second information after arrival of S wave.

Even in case of using plural UrEDAS, individual UrEDAS estimates the earthquake elements separately and sends necessary alarm by individual judgment. Information of earthquake elements decided by each individual UrEDAS is collected in the UrEDAS center and synthesized into final earthquake elements with higher accuracy. For example, the Center System of Tokaido UrEDAS automatically outputs a Re-Operation Procedure Recommendation Sheet of countermeasures for the alarmed earthquake within two minutes after P wave arrived at the first UrEDAS station.

Ordinary centralized alarm system loses its total function when its center equipment is once destroyed. On the contrary, UrEDAS is a completely autonomous and dispersed system, and even for a destructive earthquake, its system function is not lost function simultaneously. Even when main earthquake motions destroy an UrEDAS, it has already issued the alarm and necessary information has been already communicated to the necessary areas.

In addition, UrEDAS responds to big earthquakes far from the railroads, while conventional alarm seismometer works against local strong earthquakes just beneath the line and both systems compensate their roles with each other. Recently, conventional alarm seismometers are started to replace for Compact UrEDAS. At present, in October 1999, SDR have installed 19 sets of UrEDAS and 62 sets of Compact UrEDAS in Japan for customer's practical use and several overseas UrEDAS was installed or will be installed for joint research with SDR (see Fig. 15).

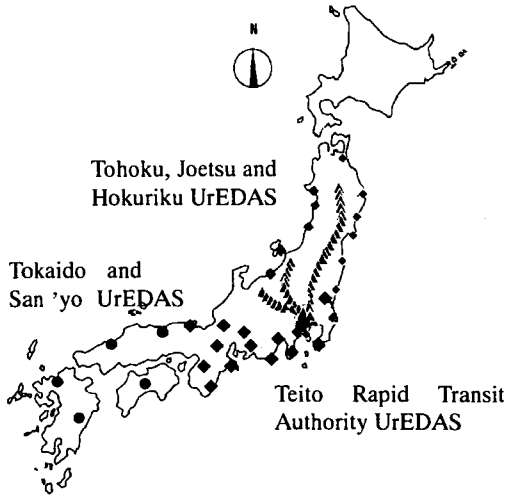


Fig. 15 UrEDAS networks

7. RESULT OF UrEDAS OPERATION ON TOKAIDO SHINKANSEN

The earthquake warning system for Tokaido Shinkansen consists of the 25 conventional alarm seismometers which respond to the strong shocks near the line and the 14 UrEDAS stations which responds to the big earthquakes far from the line. Table 1 shows the issued alarm since

Table 1 Operation Results of UrEDAS and Ordinary Alarms for Tokaido Shinkansen between '92 and '98

Period	Number of Issued UrEDAS Alarm		Number of Issued Ordinary Alarm		Total Number
	Total Num.	M-? :M>4.5 in '92, M>5.5 in other years	PGA>40Gal with 5Hz LPF	Total Num.	
March - December, '92	10	◎●●○○○○○○○	□	1	11
January - December, '93	4	◎◎○○	□□□	3	7
January - December, '94	1	⊙	□□□	4	4
January - December, '95	2	○ ⊙	□□□□□	6	7
January - December, '96	0		□□□	3	3
January - December, '97	1	⊙	□□□□	5	5
January - August, '98	1	○	□	1	2

○ : UrEDAS Alarm M>4.5 ⊙ : UrEDAS Alarm M> 5.5 □ : Ordinary Alarm

◎ : UrEDAS False Alarm caused by coda wave after the distant big earthquake

● : UrEDAS False Alarm caused by electromagnetic noise , lightning and etc

UrEDAS started operation in March 1992. Ordinary alarms were issued few times a year in average. Since around 1993, relatively big earthquakes occurred frequently in Japan, and especially in 1995, many small shocks occurred near the Tokaido Shinkansen line. In 1992, when UrEDAS was first used, alarms were issued rather frequently, because the UrEDAS was operated to issue alarms for relatively small earthquakes with M>4.5, in order to confirm the function of UrEDAS. But the number of alarms decreased and the expected function was realized after the alarm target considered M>5.5.

Until 1993, strong Electro-magnetic noise given to the seismometer out-put due to lightning near the UrEDAS station gave false alarms twice and seismic coda waves of distant large earthquakes gave other false alarms three times. After these false alarm events, software of the UrEDAS were improved and since then, no false alarm has been issued, although several times lightning near the UrEDAS station and distant big earthquakes occurred. The recovery times of 2-5 hours of the train operation due to the previous reopening procedures have been reduced to 15-60 minutes. It suggests UrEDAS is useful not only for the rapid warning but also very effective for the rapid recovery after the warning.

Fig. 16 shows the comparison between the final earthquake magnitudes of JMA and UrEDAS instant magnitude estimated within 4 seconds. This figure shows the UrEDAS instant magnitudes coincide with the magnitudes estimated by authorities within −0.5~+1.0 (±0.7) errors except in the distant stations for the deep earthquake. Fig. 17 shows the comparison between unified UrEDAS final magnitudes and instant magnitudes of JMA or more accurate magnitudes estimated by other authority. This figure show the UrEDAS final magnitudes coincide with the more accurate magnitudes estimated by authorities within ±0.5 errors. The instant magnitudes of JMA and the more accurate magnitudes estimated by authorities differ by a maximum 0.8 and UrEDAS instant magnitudes determined by a single station information can be said to have enough accuracy.

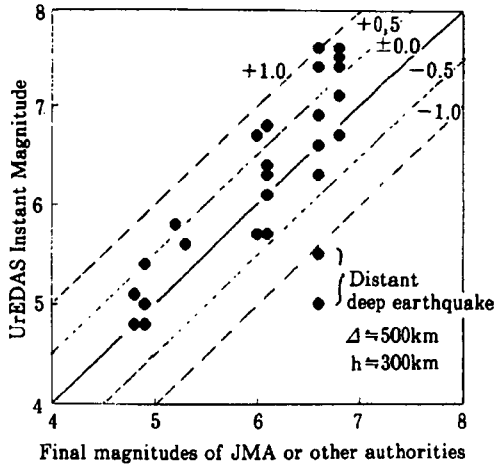


Fig. 16 Comparison the instant magnitude of UrEDAS and other authority

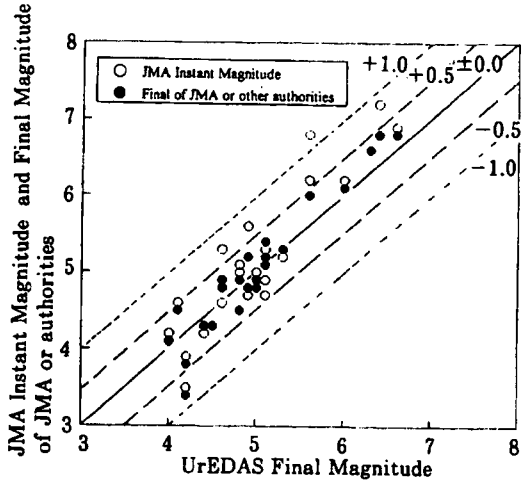


Fig. 17 Comparison the final magnitude of UrEDAS and other authority

8. CONCLUDING REMARKS

UrEDAS can issue P wave alarm before the destructive earthquake motion. If the margin time

is short, it is desirable to examine countermeasures from various viewpoints.
UrEDAS in present issue alarm only for automatic system as train operation. Author believes that UrEDAS will be useful for persons educated beforehand.

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GEOSPATIAL SYSTEMS FOR NATURAL DISASTER PLANNING AND RECOVERY

William E. Roper[1]

ABSTRACT

Natural disasters have a major impact, globally and within the United States (U.S.) causing injury and loss of life, as well as economic losses. To better address disaster response needs, a task force has been established to leverage technological capabilities to improve disaster management. Geospatial analysis is one of these important capabilities. A sample of geospatial technologies applicable to disaster management are presented. These include: 3-D visualization, hyperspectral imagery, LIDAR, use of spectral libraries, digital multispectral video, radar imaging systems, photogeologic analysis and geographic information systems. The application of these Geospatial technologies in support efforts to hurricane Floyd in the United States and Hurricane Mitch in Central America are presented.

KEY WORDS: Disaster management; mapping; hyperspectral; geospatial library; LIDAR, radar imaging; fluorescence; GIS; photogeologic analysis; GPS; satellite sensors; shaded relief; 3-D fly through.

1. INTRODUCTION

Natural disasters are a constant threat to mankind on a global scale. Global disaster costs are continuing to rise. Annual global economic costs related to disaster events average $440 billion per year (World Disaster Report, 1996) with floods being the major cause (Figure 1). In the U.S., the number of lives lost due to natural disasters has been decreasing over the last several deceased, largely because of advances in disaster indication and warning capabilities. In terms of damage to property, however, the trend is reversed. For the period 1992-1996, the average cost of natural disasters in the U.S. has been $54.3 billion, with hurricanes and earthquakes tied as the leading cause (Figure 2). These rising costs are the combined result of increased urbanization, particularly in high-risk coastal areas, and the increased complexity and size of our infrastructure.

The loss of life and property continues to rise in many regions of the world because of these events. One example is the Bangladesh weather event of 1970, when a tropical cyclone slammed into its delta region killing 300,000 people (Tobin and Montz, 1997). The crop losses were estimated at $63 million, and more than 280,000 cattle were drown (Burton, Kates, and White, 1993). The rich delta soil is an agricultural resource that still draws people to settle there, therefore a recurrence of this type of weather event could likely pose a similar disaster.

This paper will focus on geospatial analysis and some of the specific developments in this rapidly changing area that can assist the disaster manager. There has been significant capability growth in the geospatial areas of remote sensing, spectral analysis, global positioning systems (GPS), geographic information systems (GIS), and modeling and simulation techniques (Roper, 1997). Each adds important value in characterizing infrastructure, risk areas, disaster zones, and control points that are essential to rapid deployment of scarce resources in the most effective manner. Examples of geospatial applications on recent hurricanes are the east coast of the United States and in Central America are presented in the paper.

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2. GEOSPATIAL RESEARCH COMMUNITY INVOLVEMENT

The flow of disaster related information can be conceptually shown as a seven step process as shown in Figure 3. The geospatial research community may have a role in each of these steps, depending on the particular disaster situation.

This could include assistance in defining the problem through current image analysis. Assistance in determining collection and analysis methodologies assists in defining the requirement. A key area of support is providing supporting data in the form of maps, imagery, and spectral information.

An even more important support area is data exploitation. This includes the processing of digital data, image integration, feature classification and attribution, classification output, accuracy assessments, and post-processing operations. It is most technically challenging step in process. The decision support phase includes geospatial visualization, merged data analysis, and specialized decision support products. This involves the synthesis of data types in order is generate data layers (such as, soils, vegetation, terrain) along with models and simulation techniques that use the various data layers.

It is during this phase that the concept of virtual forums could take place. These forums would allow expert input from multiple locations to be jointly focused on problem solving for the disaster situation. Within the geospatial community this could include virtual fly-through support showing the impacts of possible decisions on the natural environment, and on the population, including those with special needs. It also could include analysis of changing situational information, and image-based change detection and analysis.

In the final two phases, tailored map products and GIS overlay information can be used a integral parts of directives and guidance to disaster managers in the field. These specific products could be maps delineating evacuation routes, area identification for damage assessments, or point locations for water distribution.

The geospatial research community has typically been interdisciplinary, including the natural sciences, engineering, architecture, land use planning, photogrametry, etc. However, in the disaster management arena, broader interdisciplinary teaming will be required. This could include public policy and health specialists at the Federal, state, and local level. It may include other medical specialists, police, National Guard, and communications experts.

The greatest potential for loss reduction is during the mitigation phase (Disaster Information Task Force Report, 1997), when communities can be made more disaster resistant. The largest share of costs, however, are directed toward the recovery phase, where good mitigation principles also need to be put into practice rather than just rebuilding to be impacted by a similar disaster in the future. Geospatial products and location specific tools developed during the response phase of the disaster may be excellent vehicles for planning and implementing effective mitigation.

3. GEOSPATIAL TECHNOLOGY OPPORTUNITIES

There are a number of new and evolving technologies and capabilities in the geospatial area that have application to disaster management. Some of these techniques assess and present data in new and innovative ways. Others are possible today because of new sensor and data processing capabilities.

3.1 Drawland Visualization

Drawland is one of the software programs used to support terrain visualization research. It was developed by the U.S. Army Topographic Engineering Center (TEC) and continues to be refined and used in research and operational applications. TEC has recently entered into a cooperative research and development agreement with ERDAS Corporation to make Drawland available commercially as part of the ERDAS Imagine software program.

Drawland's main input is digital terrain evaluation data (DTED). Which can load the program into memory directly from CD-ROM. The user can specify the geographic area to be loaded. Given the southwest corner and the size of the cell, Drawland searches for the appropriate files and can combine data from several files to produce a 3-D terrain scene. A sample scene over a mountainous valley terrain is shown in Figure 4. A digital fly-through of this geospatial database will be presented during the oral presentation. Drawland has been used to visualize imagery from a variety of sources to include: Landsat, SPOT, high-altitude aerial photography, and Interferrometric Synthetic Aperture Radar (IFSAR). It also can use data from commonly used commercial software for disaster management support, such as ArcInfo, ArcView, and ERDAS Imagine. Drawland can drape raster data over digital terrain evaluation data within minutes to create the appearance of a 3-D map.

In the interactive or flight mode, the terrain is displayed as a reduced resolution polygon surface. Users can adjust the resolution and vary the rendering mode to suit their purpose (e.g., wire frame for speed, photo texture for realism). Coordinates, altitude above Mean Sea Level, distance above ground, yaw, pitch, and roll, are displayed for the viewpoint or for a model. The software also provides mission planning tools, such as masked area depiction, line-of-sight calculations, and flight path design, and can include unit symbols or polygon models of objects based on ground locations. All of these tools could be tailored to the particular disaster management situation and requirements.

During flight mode, the movement of the user's viewpoint can be recorded, as can the movement of any selected model that is being controlled. The animation can be recorded one frame at a time to a VCR tape or various digital movie formats. Model movements also can be played back in real time.

3.2 Hyperspectral Imagery

Hyperspectral remote sensing combined imaging and spectroscopy in a single system that includes data sets and processing methods. Hyperspectral data sets are generally composed of about 100 to 200, or more, spectral bands of relatively narrow bandwidths (5-10mm). The spectral range of interest of these data sets usually encompasses the portion of the spectrum dealing with reflected energy from the visible to the short-wave infrared (0.4 to 2.5 um). Hyperspectral airborne sensors can image ground materials in many bands of relatively high spectral resolution in a digital mode (Samuel Barr, 1997). Figure 5 illustrates this as applied to the Jet Propulsion Laboratory's Airborne Visible Infrared Imaging Spectrometer (AVIRIS) sensor. If a stack of picture elements (pixels) of a single target were extracted from the data set and plotted out as a function of wavelength (Figure 6), and average spectrum of all of the materials in the pixel would result. Because of the 3-D nature of these data sets, they are generally referred to as image cubes as depicted in Figure 7.

The large amount of data in the hyperspectral image cube may provide an important new tool in disaster management. However, there is still much to learn about the practical application of this technology. An example application, the mosaic image of Landsat Thematic Mapper data and AVIRIS data of a potion of the Bighorn Basin, northeast of Worland, WY, U.S., is shown in Figure 8. The image illustrates the synergy between large area coverage by satellite sensors and targeted airborne imaging hyperspectral data. The background image is a roughly 20 by 30 km portion of a Landsat Thematic Mapper color composite of bands 3,2,1 (true color), saturation-enhanced to contrast with the AVIRIS overlay. North is shown toward the bottom of the page. The 3-D hyperspectral image cube demonstrates the high spectral resolution nature of the AVIRIS data, which has 224 bands covering the spectral range of 0.4 – 2.5 um at 10nm resolution. The AVIRIS cub face is a true color composite using bands 31,19, and 10 (0.66 um, 0.55 um, and 0.45 um). The cube sides represent color-coded reflectance spectra for the pixels along the edges of the image. The color scheme of black, blue, green, yellow, red, and white indicates increasing reflectance (ENVI internet home page, 1998). These data are used together in a hierarchical strategy in

this application for geologic mapping and exploration using Landsat to provide an overview and to locate targets for more detailed study. The hyperspectral data are used for mineral species identification and abundance mapping, and field mapping and field spectroscopy for verification. Similar analysis of this kind of geospatial data might be used to identify earthquake, landslide, or soil liquefaction potential in the mitigation phase of disaster management. It is important to note that the commercialization of hyperspectral systems will soon make these data widely available. Commercial aircraft systems are in use today, and several satellite systems are planned for deployment in the next several years.

4.3 Spectral Library Database Program

The ever increasing amount of data and spectral information that is in current databases, and the future flood of data from hyperspectral sensors, will require a more usable spectral database library for more effective interpretation and development of products. The possibility of an open cross platform web-based spectral library is a very powerful concept. It could provide an invaluable tool for future spectral related research, and greatly reduce the time and resources necessary to produce useful products from spectral data. The design of such a library would require careful assessment of user needs, minimum data characterization requirements, and easy input and access controls.

TEC currently has more than 5000 spectral signatures, as well as signatures from other organizations in its existing database catalogue. These include visible-near infrared, fluorescence and thermal spectra obtained from field , laboratory and imagery. These data are being organized and characterized into an interactive library structure. The initial design concept is shown in Figure 9. Upon completion, the library is intended to have multiple scientific tools for viewing spectral data and performing numerical and statistical analysis. The distributed system will house the database and scientific tools on different servers and possibly different platforms. The system structure will be transparent to the user who will access the data over the Internet via a web browser or similar interface. A prototype of the computer metadata display and spectral signature is shown in Figures 10. This is an activity where we will be seeking broad collaborative partnerships to build a comprehensive and useful spectral data library.

4.4 Digital Multispectral Video

Digital Multispectral Video (DMSV) is an immerging technology that has strong potential application to disaster response and mitigation activities, as well as many other site characterization applications. The DMSV is an airborne instrument that acquires high spatial and temporal resolution multispectral (visible to near infrared) imagery. This technology is very useful for accurately characterizing complex tidal, atmospheric, geologic, anthropogenic induced change, and geometric events that would be difficult to measure with other systems.

The surface characterization application of DMSV, shown in figures 11 and 12, illustrates the system's tuning ability for detection of whether shoreline or aquatic vegetation are predominate in an environmental monitoring application. In Figure 11 the location and density of shoreline vegetation is very evident, but only the presence or absence of aquatic vegetation is observable using the 0.75, 0.66, and 0.55 micrometer bands. If a band combination of 0.77, 0.75, and 0.55 micrometers is used, the density of aquatic vegetation can be observed (Figure 12).

The DMSV system is comprised of four charged coupled device (CCD) cameras with 12-mm focal length lenses, a ruggedized 486 PC, 32 Mb of RAM, a 500 Mb hard disk, and a 4-Mb AT frame-grabber board. Each of the four cameras were fitted with a 25-nm band pass interference filter. These filters were centered at 450-nm, 550-nm, 650-nm, and 750-nm, respectively. The four bands are captured simultaneously and stored on internal RAM. Each 8-bit, 740 by 578 pixel four-bands frame is a little over 1.7 Mb in size, which allows for the collection of 17 frames before the data must be transferred to the PC hard drive.

4.5 Radar Systems

The technology is rapidly emerging to produce flood plain maps of greatly improved accuracy at lower cost than is possible with the traditional, less accurate, methods. To facilitate the transfer of these technologies, NASA, FEMA, and the U.S. Army Corps of Engineers have established a partnership. The partnership is conducting a cooperative technology demonstration to evaluate the potential for use of high-accuracy, high resolution digital topographic and image-based information products to re-map flood plains in the U.S.

The emphasis for the U.S. Army Topographic Engineering Center (TEC) in the project is on the use of Interferometric Synthetic Aperture Radar (IFSAR), Light Detection and Ranging (LIDAR), and National Technical Means (NTM) data to develop highly accurate geospatial information to support flood plain mapping and FEMA's future map modernization objectives. These data will be used singularly and in combination to perform improvements in derived elevation accuracy values and feature characterization completeness.

The state of the art in exploiting interferometric synthetic aperture radar (IFSAR) for terrain information is advancing rapidly, and provides significant potential for use in flood plain, mapping, and flood crisis support operations, as well as other situations. Unlike conventional SAR imagery, IFSAR data permits the generation of rectified SAR images co-registered with an accurate terrain elevation file. This imagery can have an absolute geographic accuracy of 3 meters RMS or less. The rapidity with which IFSAR data can be collected and processed over wide areas, and the all-weather, day-night capability offers significant potential for providing direct support to crisis situations as well as enhancing the performance of spectrally based assistance (Roper, 1998). In addition, IFSAR terrain elevations can be employed to rectify hyperspectral and other imagery, allowing for the registration of radar and hyperspectral imagery in the ground plane thus providing an improved rapid digital elevation model (DEM) product (Figure 14).

The Interferometric Synthetic Aperture Radar for Elevations (IFSARE), was a joint industry-government program between TEC, NASA, JPL, and the Environmental Research Institute of Michigan (ERIM). This research effort resulted in the fabrication of an interferometric radar system integrated with a GPS internal navigation system which was mounted on a Learjet 36A. The National Aeronautics and Space Administration joined with the Jet Propulsion Laboratory in California to develop the processing software and the ground-processing environment. This software and ground processing capability has now been transitioned to Intermap Technologies Company and is available now for commercial applications (Roper, 1999).

This effort represents a convergence of technology development by a large number of investigators and a pressing need for low cost, fine resolution, highly accurate terrain elevations for a wide variety of applications. It is critically dependent on recently devised Global Positioning System (GPS) capabilities and the advent of high-speed data processing capabilities.

It is anticipated that significant IFSAR data collections will occur in the next few years. Ongoing activities within the Topographic Engineering Center are focused on quantifying the performance of IFSAR techniques. Additional work will also be one for demonstrating the capability to merge radar and LIDAR data.

TEC has been actively involved with the development of a capability to create maps from IFSAR with a minimum of human intervention. Automated algorithms operate on the IFSAR data files to extract land use classification, DEM generation, and bald earth estimations. Hydrology, elevated structures, power lines, and road network data layers can also be automatically extracted. TEC continues to enhance these automated algorithms to assess flood

plain soil roughness and extend structure identification capabilities. A series of map products will be produced with IFSAR-based technology for selected test areas(figure 13).

The state-of-the-art in exploiting interferometric synthetic aperture radar (IFSAR) for terrain information is advancing rapidly, and provides significant potential for use in crisis support operations. Unlike conventional SAR imagery, IFSAR data permits the generation of rectified SAR images co-registered with an accurate terrain elevation file. In addition, this imagery can have an absolute geographic accuracy of 3m RMS or less. The rapidity with which IFSAR data can be collected and processed over wide areas, and in all-weather, day-night capability, offers significant potential for providing direct support to crisis situations, as well as enhancing the performance of spectrally-based assistance. In addition, IFSAR terrain elevations can be employed to rectify hyperspectral imagery, allowing for the registration of radar and hypespectral imagery in the ground plane, thus providing an improved database for the extraction of topographic information.

The contractor for this program, titled Interferometric Synthetic Aperture Radar for Elevations (IFSARE), was the Environmental Research Institute of Michigan (ERIM). Their efforts resulted in the fabrication of an interferometric radar system integrated with a GPS internal navigation system, which was mounted on a Learjet 36A. The National Aeronautic and Space Administration jointed with the Jet Propulsion Laboratory in California to develop the processing software and the ground-processing environment. This software and ground processing capability has now been transitioned to the Intermap Technologies Company, and is available for commercial applications.

This effort represents a convergence of technology developed by a large number of investigators, only a few of whom are referenced above, and a pressing need for low cost, fine resolution, highly accurate terrain elevations for a wide variety of applications. It is critically dependent on recently devised GPS capabilities and the advent of high-speed data processing capabilities.

In summary, the IFSARE system for collecting digital elevation map information, at low cost, is just now becoming available for application to problems such as disaster responses. It is anticipated that significant IFSAR data collections will occur in the next few years. Ongoing activities within TEC are focused quantifying the performance of IFSAR techniques. Additional work will be done for demonstrating the capability to merge radar and hyperspectral data. There is significant potential for application of IFSAR data in all four phases of disaster management.

4.6 LIDAR Systems

LIDAR-topographic-mapping systems have considerable promise for producing high-resolution digital elevation models (DEMs). Satellite communications and GPS navigation systems are critical parts of LIDAR mapping systems. TEC has acquired multiple LIDAR-topographic- mapping data for the purpose of producing high-resolution DEMs. These will be evaluated and the results used to help develop criteria for future applications for flood plain mapping.

However, processing of raw LIDAR data into useful and reliable DEMs is not yet mature. For example, unless exceptional effort is made to produce accurate LIDAR calibration, significant merging artifacts, and their associated errors, can occur. Another example is with merging artifacts that can presently be found in HARC data.

Merging artifacts in LIDAR data are generally due to miss-calibration of the LIDAR sensor or residual GPS errors. Both kinds of errors can be described by mathematical models and corrected. Because data within overlap regions should match, the parameters of the mathematical models can be calculated. Subsequently, the data can be adjusted so that the errors are minimized. Least-squares estimation techniques have proven to be efficient, accurate, and reliable for this purpose. The overall process is a least-squares model-based merging.

TEC is currently analyzing the LIDAR data sets from the FEMA-sponsored LIDAR collection in the Lakewood community, Los Angeles, California. This effort will undertake to develop appropriate mathematical models of merging errors. This LIDAR data set will be further developed to establish an automatic processing methodology, based on least-squares model-based merging, for adjusting the data to minimize merging errors. Sample collection images from Lakewood, California, are shown in Figures 14 and 15. There are clear differences in the sample images. Also, because of the high resolution, the data bases are time dependent.

The LIDAR collection plan for the Lakewood, California, area includes a number of collection actions and products (Jorgensen, 1998). These include:

* Multiple LIDAR collections
* Long cross-flights over the AR zone
* Small mosaic area
* LIDAR-derived DEM at 3-meter postings
* X, Y, Z data from each LIDAR return
* LIDAR used to improve vertical accuracy of products

Airborne LIDAR systems are capable of precise platform-to-ground ranging that produce decimeter-level height accuracy and meter-level post spacing topographic information of the surface. Some systems are capable of return pulse waveform digitization which provide precise ground surface AND vegetation height and volume measurements. Laser altimeter measurements are acquired along profiles or swaths up to a few hundred meters wide using small aircraft. These swaths could replace channel cross-sections (currently obtained via costly ground-based surveys) required by flood backwater models, which are used to predict flood plain extent.

4.7 Photogeologic Analysis

Historical Photogeologic Analysis using Aerial Photography allows mapping of terrain features, such as fractures or the surface expression of these fractures, which are called lineaments. Fractures in the bedrock are important to identify because they often serve as contaminate conduits. They are the "doorways" that allow surface contamination to enter the ground water system. Changes in land use and land cover often obscure the surface expression of these fractures in the underlying bedrock.

Additionally, knowledge of the location, direction, and length of fractures significantly improves the speed and results of costly Geophysical Studies by correct alignment of their survey track planning. Also, surveys that, for lack of good planning input, do run parallel to fractures often produce erroneous data.

In an area of Karst terrain, photogeologic analysis identification of historical sinkhole depressions can be used. The features also frequently "disappear" with changes in Land Use and Land Cover. Like fractures, sinkholes serve as a direct contaminates conduit for connecting the surface with the ground water system.

Photogeologic analysis can be applied to the identification of historic seismic shear zones, and to the geo-positioning of these features onto current maps and GIS products. Such products could be used in all phases of disaster management. Identifying physical changes to the terrain that have occurred in the past through photo-geometric analysis can be very useful in environmental cleanup, disaster response etc. An example is shown in figure 16 of pit burial operations in the 1950s. Figure 17 identifies the location of the site geo-referenced on imagery of the current dense jungle condition of the terrain. This can be a very useful planning tool and result project cost savings.

5. HURRICANE MITCH STORM TRACK AND CHARACTERISTICS

Hurricane Mitch, the strongest October hurricane ever recorded, formed in the southwest Caribbean sea from a tropical wave about 360 miles south of Kingston, Jamica, late on October 21. The system initially moved slowly westward and intensified to a tropical storm (AcuWeather, 1999). Mitch then moved slowly northward. Its course changed to north-northwestward on the 23rd and 24th while gradually gaining strength. Early October 24, Mitch became a hurricane. Later that day, as it turned towards the west, Mitch began to intensify rapidly. In about 24 hours, its central pressure dropped 52 MB to 924 MB by the afternoon of October 25. Further strengthening took place and the central pressure reached a minimum of 905 MB about 40 miles southeast of Swan Island on the afternoon of October 26. This pressure is the fourth lowest ever recorded in an Atlantic hurricane this century. It is tied with Hurricane Camille in 1969. This is also the lowest pressure ever observed in an October hurricane in the Atlantic Basin. At its peak, the maximum winds were estimated to be 180 mph, a strong Category 5 hurricane.

After passing over Swan Island, Mitch began to gradually weaken on October 27 while moving slowly west, then southwest toward the Bay Islands off the coast of Honduras. The center passed very near the Island of Guanaja wreaking havoc there. From mid-day on the 27th to early on the 29th, the minimum central pressure rose 59 MB. The center of the hurricane meandered near the north coast of Honduras from late on the 27th through the 28th before making landfall during the morning of the 29th about 70 miles east of LaCeiba with 100 mph winds. Mitch moved southward over Honduras, weakening to a tropical storm early on the 30th. Mitch moved slowly over Honduras and Guatemala on September 30-31, gradually weakening to a depression. The storm generated torrential rains over portions of Honduras and Nicaragua where the associated floods were devastating. Some heavy rains also occurred in neighboring countries. Figure 18 shows rain bands associated with Mitch.

Although Mitch originally dissipated near the Guatemala/Southeast Mexico border Sunday afternoon, November 1, the remnants continued to produce locally heavy rainfall over portions of Central America and eastern Mexico for the next couple of days. On November 3, a low-level circulation became evident in the eastern Bay of Campeche and an Air Force Reserve reconnaissance aircraft investigating the system reported tropical storm-force winds and a 99-MB central pressure. Mitch had regenerated into a tropical storm on the afternoon of the 3rd while located about 55 miles west-southwest of Campeche, Mexico. Mitch weakened to a depression early on the 4th as it moved inland over the northwest Yucatan Peninsula. The center re-emerged over the south central Gulf of Mexico by mid-morning on the 4th regaining tropical storm strength. Mitch began to accelerate to the northeast as it became involved with frontal zone moving through the aster Gulf of Mexico. Mitch made landfall on the morning of the 5th in southwest Florida near Naples with maximum sustained winds near 60 mph. By mid-afternoon of the 5th, Mitch moved offshore of south Florida and became extratropical. Figure 19 shows the storm track of Hurricane Mitch.

6. GEOSPATIAL SUPPORT OF MITCH RECOVERY ACTIVITIES

6.1 Initial Emergency Response Efforts

U.S. military forces were some of the first international support units on the ground conducting recovery operations. As a result, a number of requirements for geospatial products were identified early in the operations (Operations Summary, January 1999). In support of these requests, maps, country studies, water areal appraisals and other available materials were collected and provided to the U.S. Army Corps of Engineers (USACE) Operations Center for use in immediate recovery operations, planning any additional deployments and future reconstruction efforts. Separate requests for ground water resource data were received from support elements of the Second Mare Expeditionary Force and two Air Force Red

Horse Squadrons (well drilling units) in Honduras. Maps and water areal appraisals were provided to two Marine Expeditionary Forces. Water detection data was also provided to the Air Force Unit.
Initial analytical activities focused on assessing road and bridge damage in Honduras. Satellite imagery was reviewed and road and bridge assessment data were tabulated and served over the communication links. These data were keyed to a regional map, provided by the National Imagery and Mapping Agency (NIMA), to which a grid was added as an orientation aid for the user (Figure 20). Photo maps of the Soto Cano Air Base and a slide area along the Chaluteca River in Tegucigalpa were also prepared and provided to the Army Corps of Engineering Operations Center. The 30th Engineer Battalion, also in Honduras, requested specific Digital Topographic Data, and loan of high-capacity hard drives to process data. The Topographic Engineering Center imbedded current imagery data on the affected areas onto 14 CDs and provided them to the 30th Engineers. These CDs contained landsat and Spot imagery.

6.2 Joint Government and Private Sector Support

A cooperative effort of U.S. Government agencies and the private sector developed a Digital Atlas of Central America to assist in recovery efforts and planning for reconstruction. The geographic information system (GIS) based product provided a framework for displaying and organizing information in multiple layers useful to those responding to the disaster. Figure 21 is a sample product showing the path of Hurricane Mitch over a map with country boundaries and terrain elevation color coding (Digital Atlas, January 1999).

6.3 Geospatial Technology Applications

For the initial reconstruction phase, a number of geospatial products are needed to enhance planning and project execution (Heam, February 1999). Virtually all activities associated with the reconstruction effort required large-scale (high resolution) base maps showing topography, drainage, and the location of roads, bridges, and massive sediment deposits from the flooded Rio Choluteca Rier within the city limits is of particular concern with the fast approaching rainy season. Also a major landslide during Mitch has left a large area of unstable ground immediately above the city. Figure 22 is an airborne image of the landslide area, and Figure 23 is a GIS layered data base illustrating the area of unstable earth (Digital Atlas, 1999).
Because of the vulnerability of the city of Tegucigalpa to additional flooding and landslides during the upcoming rainy season and the limited time available to put protection measures in place; the majority of the effort in developing this action plans was placed on short-term solutions to the flooding and landslides are conceptual at this time and will require substantial data gathering and engineering analysis to determine the most cost effective solutions. The study would involve sending a two-man team to Tegucigalpa for a period of 30 days to gather information. Topographic maps and existing sewer system plans would be reviewed. The service area and potential locations of the treatment plant should be addressed on this initial site visit. After making the site visit, the report should be prepared. The report should provide a plan showing the preliminary layout of the sewage collection system, pumping station locations, and location/alternate locations for the treatment plant. The report would address alternate treatment plant processes and the reason for selecting a particular process. The report would be coordinated with the city officials and three design review meetings would be held at Tegucigalpa. It is estimated that the report would take 12 months to prepare.

6.4 Summary of Lessons From Hurricane Mitch

Hurricane Mitch was a natural disaster of epic proportion to Central America. The recovery and reconstruction efforts have also been of a magnitude not encountered before in that region. For the first time in a major disaster, extensive application of geospatial technology was used to assist in all phases of the recovery. A digital atlas and Geographic Information System was created for the impacted area to form a framework to integrate new data information over time in a systematic manner. Satellite, aircraft,

and ground information sources were used to collect data and information to support the recovery activities. A variety of products were successfully generated tailored to user needs in the field and higher level decision-makers in the recovery effort.

7. CLIMATE SYSTEM OF HURRICANE FLOYD

On September 07, 1999, a tropical depression formed in the central Atlantic Ocean east of the Windward Islands. One day later, the storm became a tropical storm and was given the name "Floyd". With steady movement to the west-northwest, Floyd became a hurricane three days later on September 10th. Continued intensification to a strong Saffir - Simpson Category 4 hurricane with winds of 155 mph. and a low-pressure center of 921 Mb. developed by mid day on the 13th. Floyd maintained this intensity for almost 48 hours before land effects slowly caused this system to weaken (figure 24).

By the morning of the 15th, winds had decreased to 120 mph. By this point, however, the real story was not the wind-induced damage but the rain induced flooding. The North Carolina flood plain region associated with the Tar River was hard hit. In this region alone, more than 10,000 people were forced into shelters, with more than 3,600 homes destroyed, and 12,000 others damaged by flood waters that submerged buildings in over 16 feet of murky, contaminated water. As the storm rapidly weakened on the 17th and 18th, the damage and loss of life was already extensive. The path of Hurricane Floyd is shown in figure 25. The Appalachian mountain chain interacted with, now, tropical storm Floyd so that it rapidly lost its remaining tropical characteristics. The last advisory was issued on the 18th with flooding the chief concern for almost another week throughout the central eastern seaboard region.

8. IMPACTS OF HURRICAN FLOYD

North Carolina was the single worst hit state. There were also significant impacts in Florida, Georgia, and Virginia. The primary damage was from flood waters. Because of the low level terrain along the coast the water had no place to move and caused extensive flooding that lingered for over three weeks in some areas.

The storm and accompanying floods destroyed as many as 1,600 homes in North Carolina and damaged another 30,000, leaving more than 10,000 people in shelters (Figure 26). Floyd came ashore near Cape Fear on September 16th. Authorities blame the storm for at least 46 deaths in the state; crop and livestock losses are expected to exceed $1 billion, and the overall tab may top the $6 billion in damage left behind by Hurricane Fran in 1996. In all, Floyd killed 74 in a rampage that stretched from the Bahamas to New England. States provided some emergency housing in the major flooding areas. Housing sites included Rocky Mount and Tarboro, two North Carolina cities hit hard by the flooding (figure 27).

8.1 Recovery Centers Set Up

Disaster recovery centers were set up across the state to help flood victims cope with the enormous losses. The centers allow victims to meet with federal, state and local agencies on anything from discussing insurance claims to signing up for food stamps. But relief workers warned that the shock of losing everything – homes, clothes, scrapbooks, heirlooms – will have long term effects on the people most severely impacted form Floyd. "It's really going to hit home when they go back and see what's left," Federal Emergency Management Agency spokesman Rudy Hernandez said. Arlen Holt, spokesman for hard-hit Pitt County, added: "We've gone from the initial hurricane and flooding to the aftermath of picking up the pieces. A lot of people in the rural communities have lost everything." Emergency officials concentrated their initial efforts on helping flood victims find temporary shelter and signing them up for food stamps.

8.2 Public Health Dangers

Residents were urged to wear boots, gloves and other heavy protective gear while trudging through the thick slosh. Flood victims also were told to watch out for snakes, colonies of ants and other creatures lurking in homes. In addition, septic systems were washed away in many areas, contaminating water supplied. State officials said people should not use their wells until the water is tested. Residents of cities where the water supply was contaminated were being told to boil water and to drink only bottled water if possible.

State emergency officials said flies breeding in more than 50,000 hog carcasses and 1 million dead chickens could spread disease. Caskets from cemeteries were washed away by the floodwaters. North Carolina transportation officials said they believed as many as 1,000 roads had been damaged. The State Department of Transportation has found damage to about 700 roads, and another 300 remain partially covered by floodwaters.

8.3 Pollution Discharge Into Pamlico Sound

A brown freshwater plume containing human and animal waste flowed into North Carolina's coastal estuaries following the passage of Hurricane Floyd. It sits atop the salt water, robbing the salt water of oxygen from surface air and reducing its salinity. Both ingredients are essential for aquatic life. "What were seeing is an ecological event on the catastrophic scale," said Hans Paerl, a marine scientist at the University of North Carolina at Chapel Hill. Floyd dumped 20 inches of rain on eastern North Carolina on September 16th killing at least 48 people as it flooded hog lagoons and sewer plants, homes and cars. The resulting sludge is flowing from the Neuse and Tar Rivers into Pamlico Sound, the nations second-largest estuary, and from the Cape Fear River near Wilmington into the Atlantic. The largest affected area is a 350-square-mile expanse of Pamlico Sound and part of adjacent Core Sound. Very low low oxygen levels in the bottom waters of Pamlico Sound – 1 milligram per liter, compared to the normal 7 milligrams have been reported. While fisherman have to avoid the dead zone, they still have been able to catch fish and shrimp in areas not affected by the dirty water. Initial testing showed the catch was safe to eat.

The situation in Pamlico Sound, an estuary second in size only to Chesapeake Bay, especially concerns scientists because pollutants won't readily be flushed into the ocean. The Pamlico has just three inlets to the Atlantic, and most of the sound's water leaves via evaporation. "The sound is acting like a giant bathtub," Paerl said. Making matters worse is that the pollutants become more concentrated as water evaporates. Off the Cape Fear coast, the runoff is at least 40 feet deep and covers 300 square miles. It has been described as a brown ocean right now. Cape Fear has never experienced plummeting oxygen levels of this magnitude because of its rapid water flow. But the current brown color of the water is indicative of a large amount of nutrients that could eventually feed algae blooms that us up oxygen and kill fish.

9 GEOSPATIAL PRODUCTS FOR FLOYD RECOVERY

In addition to the operations center situational map products one of the other products developed was in response to requests for help from Franklin Virginia where sever flooding was occurring. A response planning map product was developed that used remotely sensed data to overlay the precise location of inundation areas in and around the city as shown in Figure 28. Because of the magnitude of the recovery effort this provided a very useful planning tool that helped organize recovery efforts.

Some efforts were also undertaken to predict flood area based on anticipated water level at gauge stations on some of North Carolina's rivers. The Tar River was of particular interest. Five sites were selected and projected gauge elevations were projected onto digital terrain elevation models for that area of North Carolina. At each station three products were produced. A graph of recorded maximum flows for that

gauge site, a plot on the digital terrain elevation model of estimated flood area for various gauge readings and a current eight day gauge record (figure 29).

10 CONCLUSION

The opportunity to leverage technology in the geospatial area to assist in disaster management has never been greater. There are many tools and processes currently in use that have not been applied to assist in disaster management. Examples include the application of hyperspectral sensor data, use of digital multispectral video, and geospatial 3-D fly-through analysis. All of these capabilities could support and enhance the information available to the disaster management decision-maker.

There are exciting changes expected to occur during the next few years in the few years in the geospatial community. New aircraft and space-based sensor systems are planned that will revolutionize the spectral and spatial resolution of data available for commercial applications. There will be challenges, particularly in the data processing and management area, because of the extremely large spectral databases these new sensors will generate.

The spectral library project also provides an opportunity to expand cooperatively our global understanding of the vegetative and geologic spectral makeup of the earth. The baseline data from this effort would be invaluable in conducting change analysis assessments following a natural disaster, such as an earthquake or hurricane. Using some of the analysis tools described earlier, the analysts and decision-makers could virtually walk into the disaster situation. Other spectral technologies, such as fluorescence, could be used to precisely locate very small underground gas and oil leaks remotely.

Within the next decade, there may be the ability to better harness geospatial analysis capabilities to help reach the vision for the cooperative exchange of timely, relevant information useful during all phases of disaster management—to save lives and reduce economic loss.

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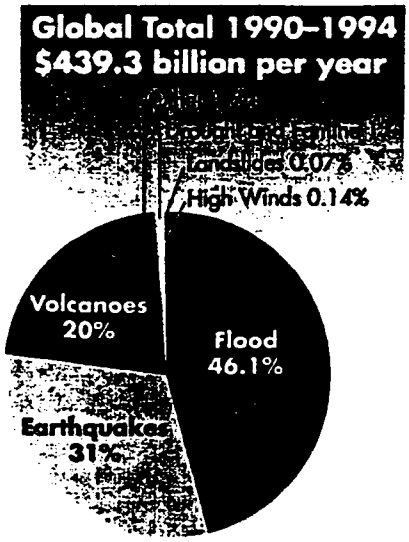


Figure 1: Global Natural Disaster Costs

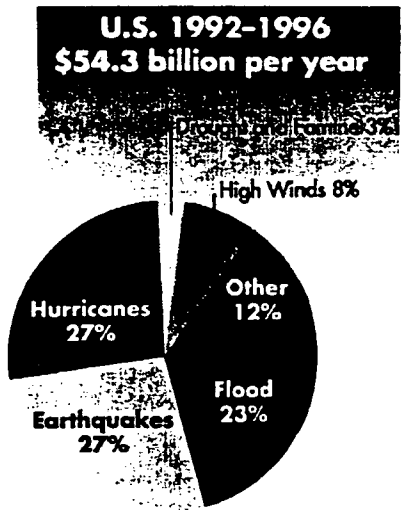


Figure 2:US Natural Disaster Costs

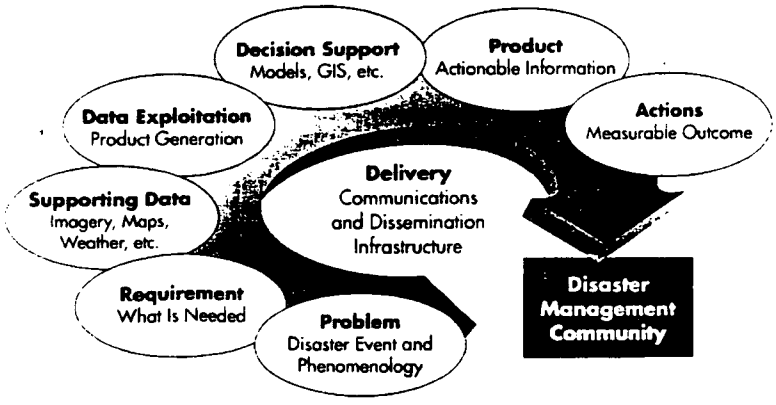


Figure 3: Elements of Disaster Management

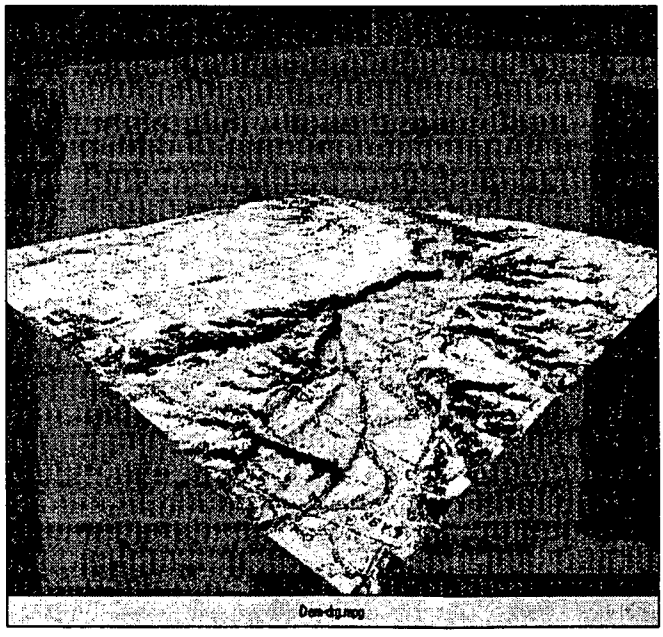


Figure 4: Draw-Land Visualization

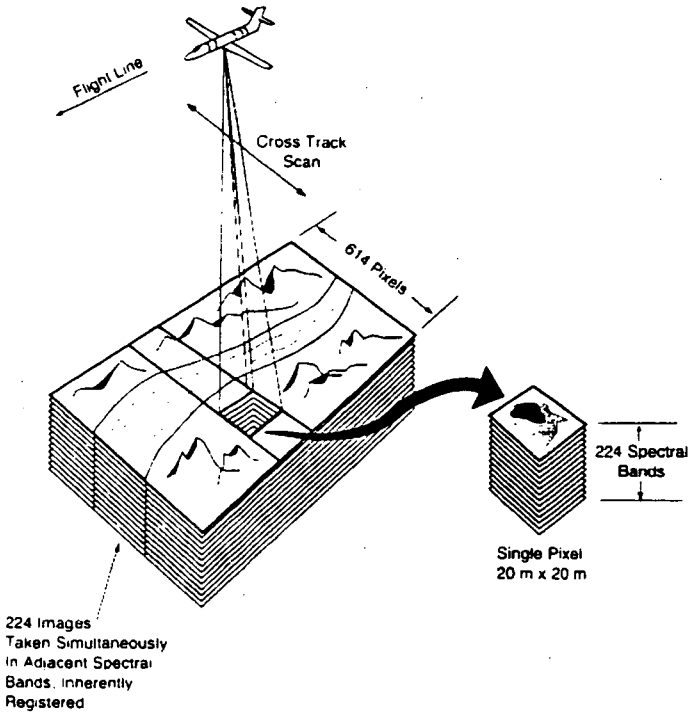


Figure 5: AVIRIS Hyperspectral System

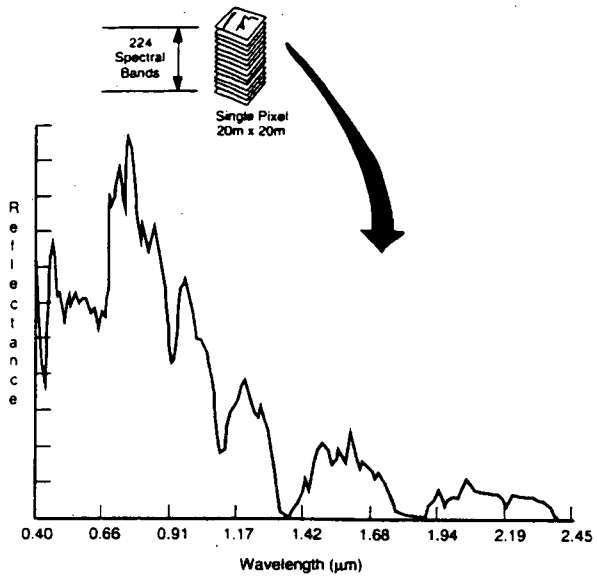


Figure 6: Spectral Distribution

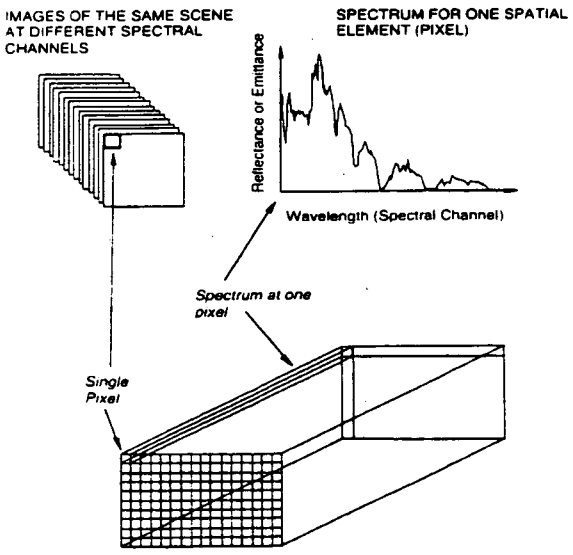


Figure 7: Image Cub



Figure 8: Thematic Mapper & AVIRIS

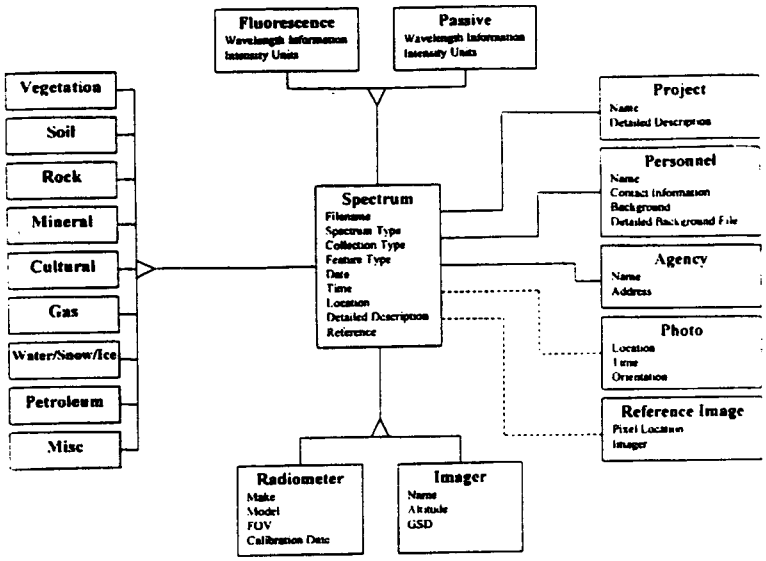


Figure 9: Spectral Library Framework

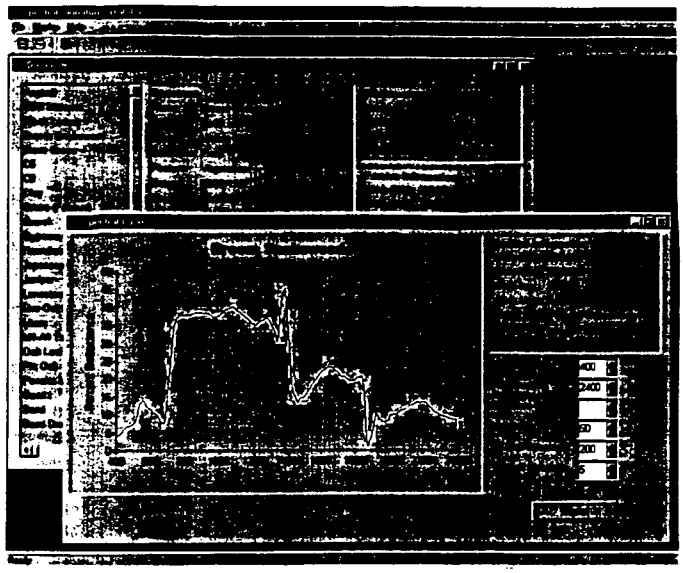


Figure 10: Prototype Display



Figure 11: Multispectral Video



Figure 12 Multispectral Video



Figure 13: IFSAR Image Sacramento Valley



Figure 14: LIDAR Lakewood California



Figure 15: LIDAR Image Lakewood 24hr Later



Figure 16: Historic Disposal Pit



Figure 17: Current Landscape of Pit



Figure 18: Hurricane Mitch Rain Bands



Figure 19: Storm Track of Mitch

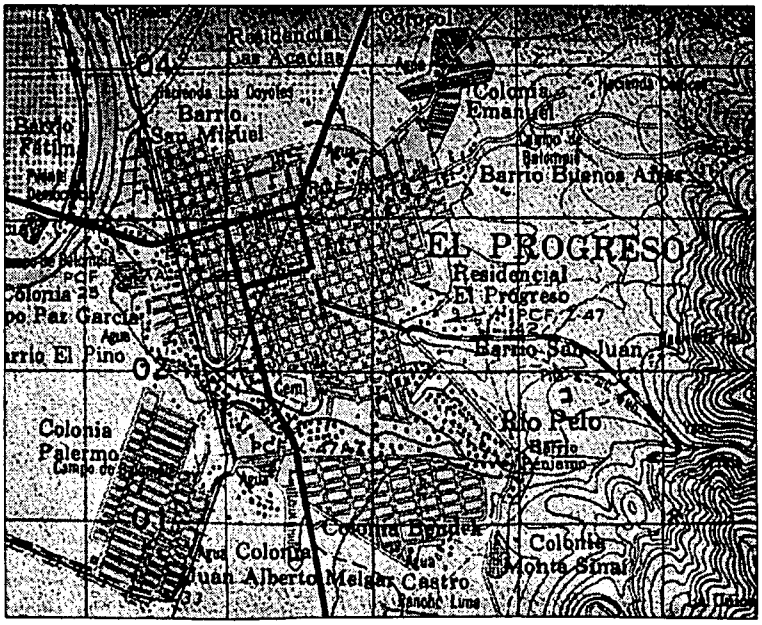


Figure 20: Planning Map product

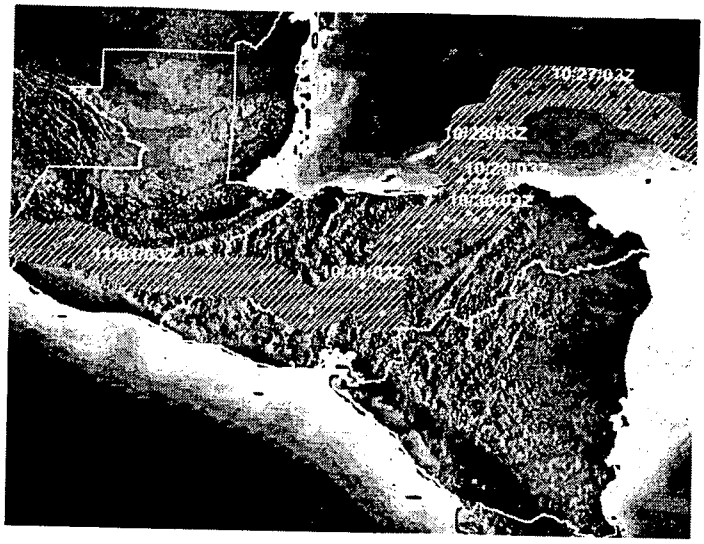


Figure 21: Overlay of Mitch's Route



Figure 22: Image of Landslide Area

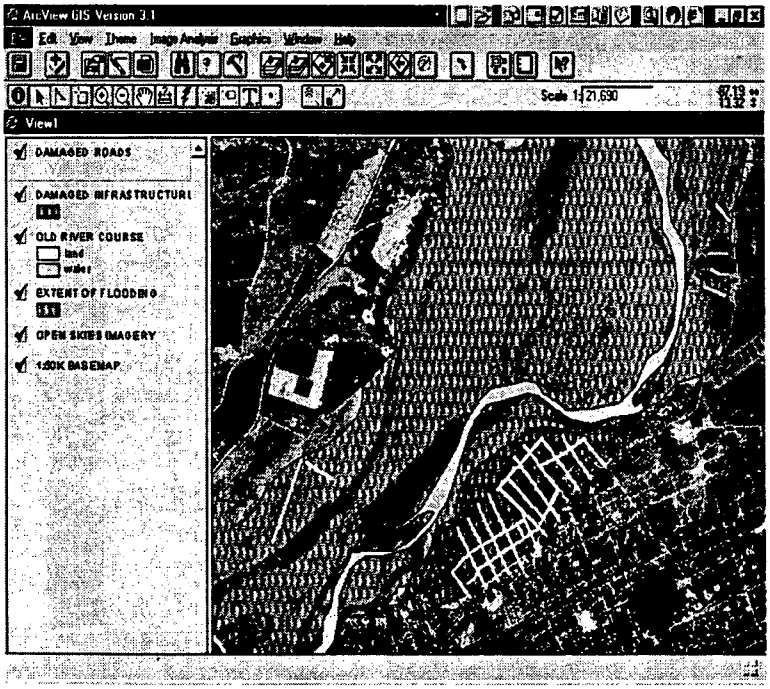


Figure 23: GIS Overlay of Landslide Area

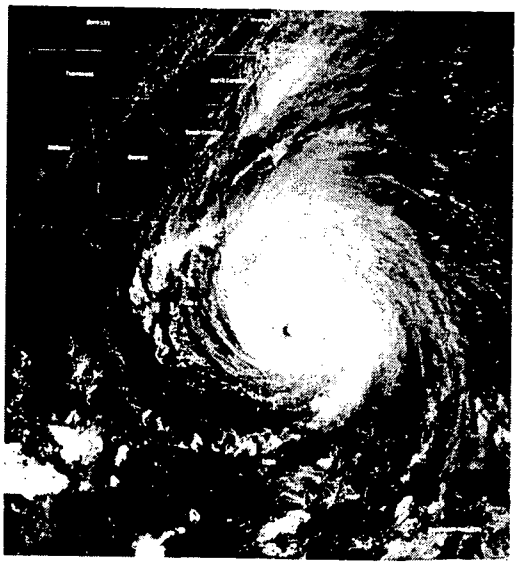


Figure 24: Hurricane Floyd Image

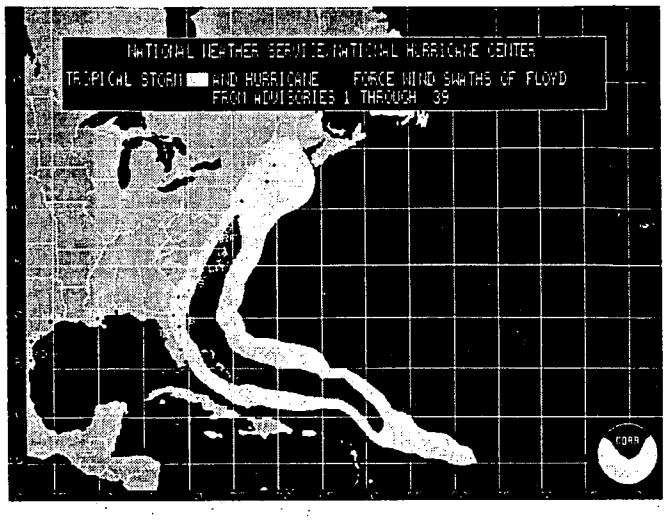


Figure 25: Storm Path of Floyd

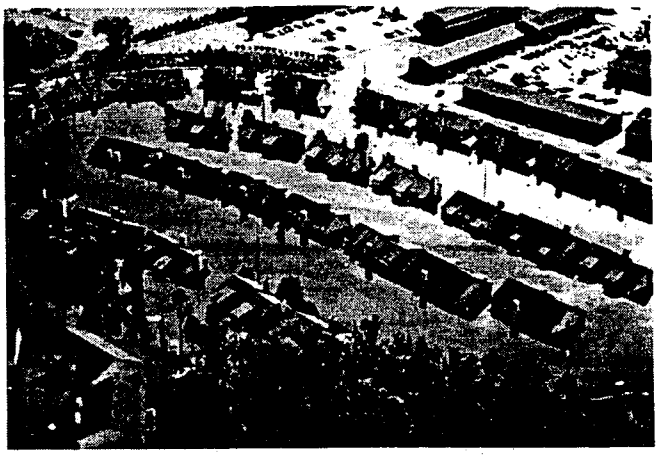


Figure 26: Flooding in North Carolina



Figure 27: Temporary Housing Site



Figure 28: Franklin VA Flood Map

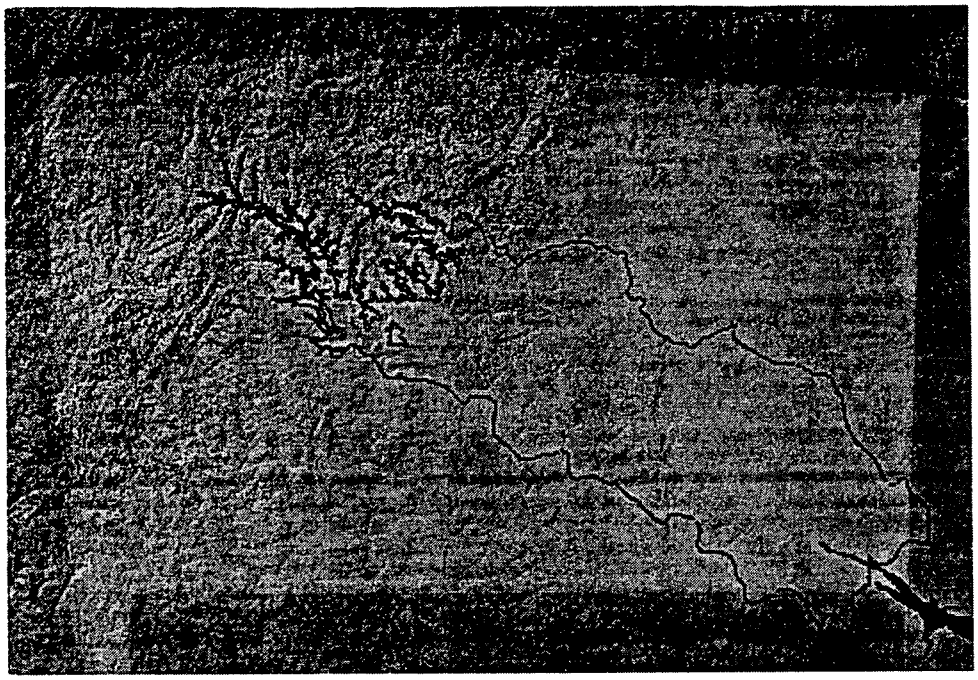


Figure 29: Tar River Flood Model

FRAMEWORK FOR EFFICIENT GATHERING OF EARTHQUAKE DAMAGE INFORMATION

ZAMA Shinsaku[1] and HOSOKAWA Masafumi[2]

ABSTRACT

For effective and adequate emergence responses just after an earthquake, it is necessary for a municipality to grasp accurate damage information at an early stage. We learned through interviews and questionnaires concerning the damage information collection in the 1995 Hyogo-ken Nanbu earthquake that the difficulty of securing a sufficient number of disaster prevention personnel and a reliable means of telecommunications and the absence of information gathering and analysis systems are the main factors in the difficulty of obtaining vital damage information.

On the basis of this result, we propose a framework designed to efficiently gather damage information to ensure a speedy and appropriate disaster prevention response in the aftermath of a major earthquake. Furthermore, the partial development of a concrete system to actualize the framework is also explained.

KEY WORDS: Damage Information, Earthquake Damage Estimation System, Information Gathering Tool, Telecommunication, Network, GIS, Hyogoken Nanbu Earthquake

1. INTRODUCTION

It is a basis to grasp the earthquake damage quickly and precisely, in order to conduct an urgent/emergency response effectively. Importance of rapid establishment of initial measures was pointed out as one of the lessons learned from the experience of the Hyogo-ken Nanbu earthquake.

In this paper, we firstly show the situation of earthquake damage information collection in municipalities after the Hyogo-ken Nanbu earthquake. Secondly, based on this result, we propose a framework for efficient gathering of earthquake damage information. Finally, we describe the partial realization of the effective collection and transmission system in concrete.

2. DAMAGE INFORMATION COLLECTION AFTER THE 1995 HYOGO-KEN NANBU EARTHQUAKE[1]

Fig.1 shows the time variation of the number of deaths grasped by the local government. The whole number of deaths was almost grasped on that day in Itami City, Takaraduka City, and Hokudan Town in Awaji Island. On the other hand, it was hard to grasp the situation for Kobe City, Osaka City, and Nishinomiya City. Situation in Ashiya City lies between the above two cases. Then, we investigated reasons for such differences through the questionnaires and the interviews.

The investigation items are as follows:

(1) Damage of local government office, where a disaster countermeasure headquarters was established,
(2) Situation of the aggregation of staff,
(3) Situation of telephones and electrical use etc.,
(4) Use situation of disaster public-address radio,
(5) System and means for the disaster information collection, and so on.

A summary of the results is as follows:

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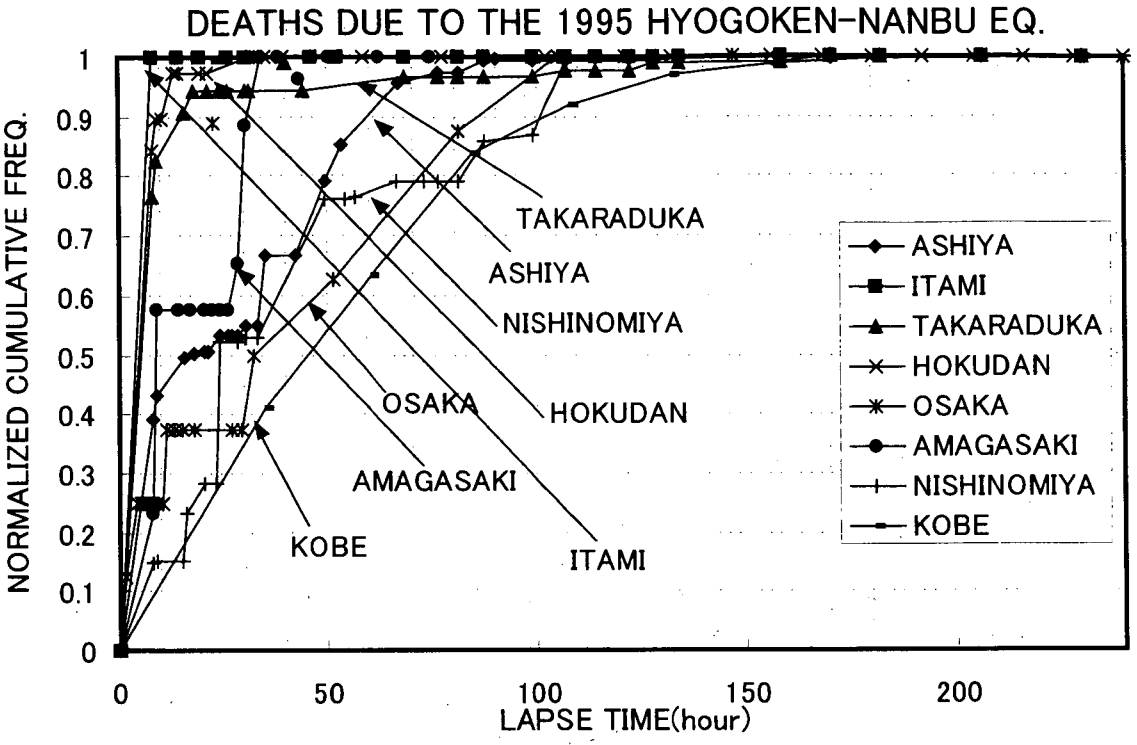


Fig.1 Normalized cumulative frequency for the number of deaths grasped at municipalities damaged by the 1995 Hyogo-ken Nanbu earthquake.

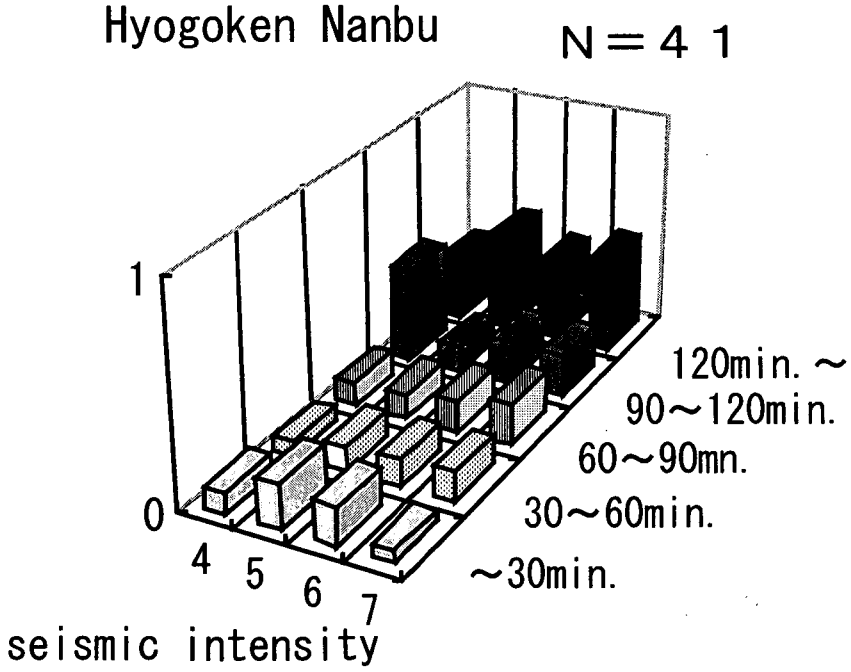


Fig.2 Time needed for emergency summons of staffs in municipalities after the 1995 Hyogo-ken Nanbu earthquake vs. seismic intensity.

At the enormously damaged municipalities, the personnel were overwhelmingly short of hands to collect damage information, local government offices were almost damaged, telephones could not be used, and summoning personnel was difficult as shown in **Fig.2**. Since the trend becomes stronger as the damage becomes heavier, we can say that the seismic intensity is a good index of difficulty in collecting damage information. On the other hand, at the area with a high potential of the disaster prevention, even if the seismic intensity is very high, the emergence response could be quickly taken. This is clear in the case of Hokudan Town. The situation of Kobe City will be considered to be in the antipodes to the one of Hokudan. Town

In the area that the information communication means such as the disaster public-address radio etc. are provided with, it seems to be possible to conduct efficient collection activities greatly. However, since they communicate with sound or papers in general, it needs great labor and time to handle a lot of information. For example, the personnel of the disaster prevention in Kushiro City in the 1993 Kushiro-oki earthquake, where the damage was only two deaths and 29 collapsed houses, had been processing damage information with little dormancy time for about one week after the earthquake. It is supposed that the situation was more severe for the Hyogo-ken Nanbu earthquake. Therefore, some information collection means or the others are needed, in which the easy processing information should be taken into consideration.

3. QANTITIZATION OF DAMAGE INFORMATION COLLECTING PROCESS[2)]

Now, we suppose that the main factors of the time difference in the damage collection process as shown in **Fig.1** are the damage degree and the disaster prevention potential, or the degree of urbanizing in the area. The distribution in **Fig.1** can be approximately expressed with the Weibull distribution as follows, using three coefficients.

$$F(t) = 1 - \exp(-a(t-c)^b) \quad (1)$$

Where, t is the lapsed time from the origin time of the earthquake. Minimizing the square summation of the difference between $F(t)$ and the actual distribution by changing the values of three coefficients, gives the best fitted curve. In most area, a and c are about 50 and 0, respectively. Even if a and c are fixed to these values, there are not large difference compared with the best fitted case. Then, we pay attention to the b-value only.

Taking the building damage percentage (R) as the index showing the degree of damage, and the population (P) as the index indicating the urbanization, b-value can be expressed by the regression equation as follows.

$$b = 3.747 - 0.591\log(P) - 1.294\log(R) \quad (2)$$

The correlation coefficient is quite high (0.854). Here, we excluded Osaka's data, because the situation of Osaka was considered as very different from the other area. Equation (2) shows that it takes much time for the area with many population and heavy damage to collect the damage information, because the b-value corresponds to the steepness of rise shape of the distribution. This equation is useful for predicting whole round number from the limited actual number of the damage just after the earthquake, by replacing the damage percentage with the measured seismic intensity.

An important conclusion of this section shows that the less population there is, the more quickly the damage information can be collected. This connects with construction of a framework in space for an effective information collection in the next section.

4. FRAMEWORK FOR EFFECTIVE DAMAGE INFORMATION COLLECTION BY MUNICIPALITY

It is considered from the interviews and the questionnaire to the municipalities that the factors, which

influence the collection activities of the damage information, are the intensity of ground motions, a

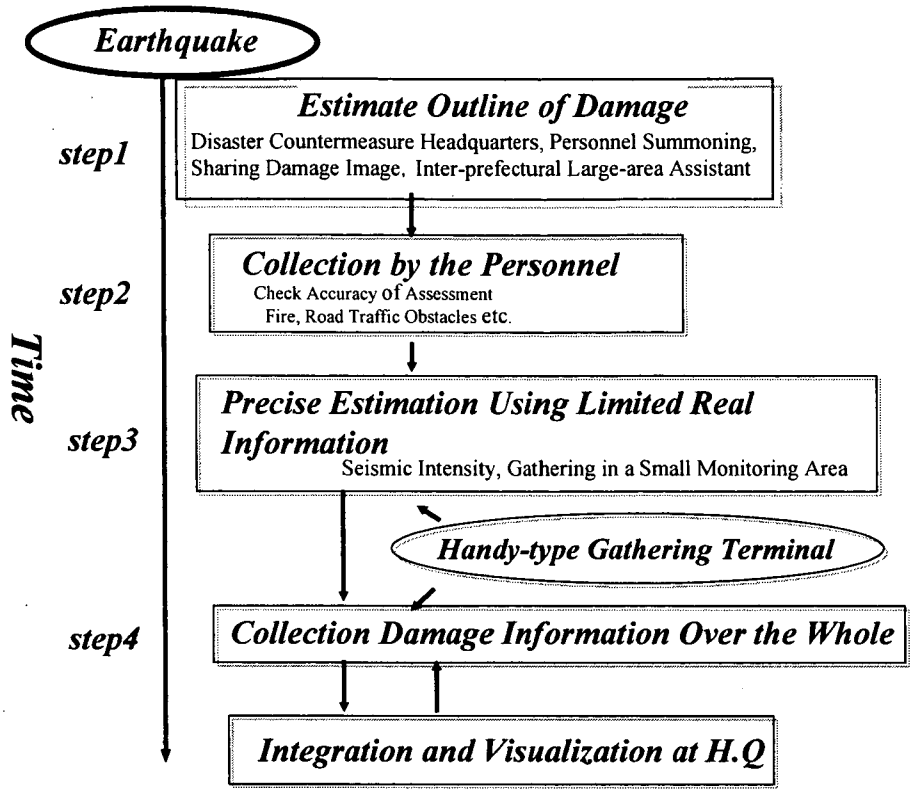


Fig.3 Framework in time for effective damage information collection.

population, and the information collection/communication/processing means. Considering these keywords, we propose a framework for the effective damage information collection as follows.

4.1 FRAMEWORK IN TIME

We propose a framework in time as shown in **Fig.3** and explain the each step as follows:

Step 1: In the immediate aftermath of an earthquake, it is anticipated that the grasp of the damage is quite difficult because disaster prevention staffs cannot assemble to their stations due to intensive damage over a wide area. Under these circumstances, municipalities are required to swiftly set up a disaster countermeasure headquarters and to make a quick judgement of whether or not a request for wide area assistance should be made, and to share an image of damage by staffs. In order to assist such a judgement, it is effective to roughly estimate the earthquake damage for a wide area in real time.

Step 2: Within one or two hours after an earthquake, most staff members, if not all, should be able to assemble to their stations. It is vital for these staff members to gather information on their way to their respective stations. This observation will enable rough verification of the estimation accuracy referred to in step 1, so that the image of the damage more accurately can reflect the reality. The priority of information gathering should be given to factual information on fires and road blockages, etc. which have a direct bearing on urgent fire-fighting and other activities. Naturally, the information is useful, provided by cameras on the high-position, helicopters and inhabitants or by telephone, etc.

Step 3: Even if damage information begins to arrive successively, it is still difficult to integrate all of the useful information to establish a complete image of the damage in a municipality. A limited number of staff members are, therefore, mobilized to gather damage information on pre-determined areas. Once amage information on such areas has been accurately gathered, comparing the actual information on the

predetermined areas and the results of the above-mentioned damage estimation can make a more accurate

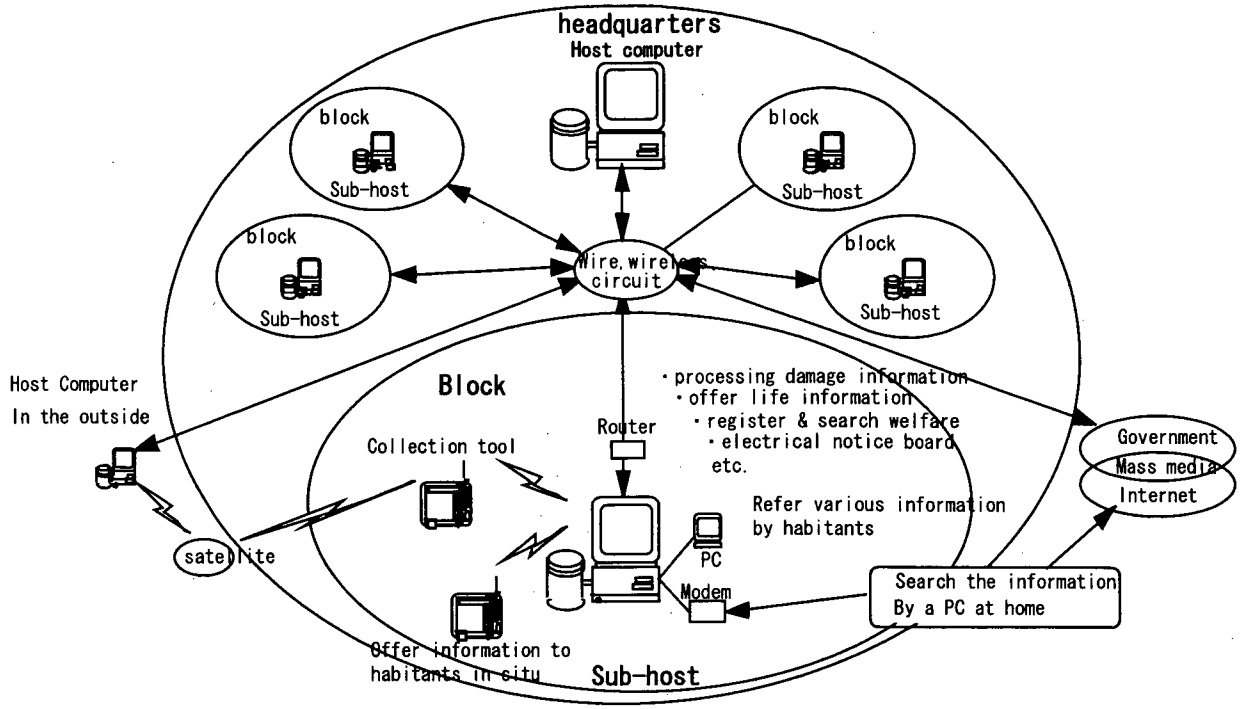


Fig.4 Framework in space for the effective collection and transmission of the earthquake disaster information.

estimate of the damage in a municipality.

Step 4: Efforts are now made to gather accurate information on the actual damage even if some time is required. Here, the prospect of efficient analysis of the gathered information should be taken into consideration in the method employed to gather such information. If the preparation of rehabilitation measures is included in the scope of analysis, it is useful to indicate damage sites and contents using GIS. As one of such means, a mobile computer equipped with the GPS system and a municipal map will be available to gather damage information as digital values. It is natural to use this tool in the previous stage, that is, in collection damage information in a limited or monitoring area.

4.2 FRAMEWORK IN SPACE

Even if the system described in 4.1 is introduced, the early establishment of a total picture of the damage is difficult in a highly urbanized municipality with a large population. Based on the earlier result that the gathering of damage information can be quickly achieved in a municipality with a smaller population, it is proposed that damage information should be gathered and analyzed within each small area as shown in **Fig.4**.

In fact, Shimizu City in Shizuoka Prefecture where will be extensively damaged in the hypothetical Tokai earthquake, divided the city into 19 blocks, and uses city halls and other public facilities as communal disaster prevention bases to conduct emergence responses including damage information collection.

The introduction of this type of self-supporting and dispersive system is expected to quickly gather important information on each block. The information obtained at these communal disaster prevention bases is transmitted to the disaster prevention headquarters, which in turn feeds back integrated information over a wider area to the communal disaster prevention bases. In this way, inhabitants can obtain not only a full picture of the damage at nearby communal disaster prevention bases, but also

various information needed in lives after an earthquake from the disaster prevention headquarters.
This spatial information gathering system is only viable if there are communication links between disaster sites and the fire defense headquarters and between communal disaster prevention bases and the disaster prevention headquarters. Particularly important is communication between disaster sites and the fire defense headquarters or communal disaster prevention bases. Because of the narrow radio band used, this communication could face the serious problem of congestion, preventing effective communication. Thus, a new communication system is necessary to solve this problem.

5. CONCRETE GATHERING AND TRANSMISSION MEASURES OF EARTHQUAKE DAMAGE INFORMATION

Here, we introduce the partially developed system for the efficient collection and transmission of earthquake damage information to realize the framework.

5.1 SIMPLIFIED EARTHQUAKE DAMAGE ESTIMATION SYSTEM[3)]

We have developed a system as shown in **Fig.5** that can give us an image of earthquake damage just after an earthquake, needed at the 1st step in the above-mentioned framework.
The characteristics are as follows:
① It is possible to estimate the number of deaths, fires, and collapsed wooden houses,
② It can be used for the whole country,
③ Used data are Digital National Land Information and National Census Data,
④ The necessary equipment is a Windows machine,
⑤ Time needed in estimating damage in a prefecture is about 10 sec, and so on.
It is already used in more than 1,500 municipalities etc. as of June 1999.

5.2 RAPID GATHERING TOOL[1)]

In the rich cities such as Tokyo, Yokohama etc., cameras on the high-position and helicopters are used in order to collect the earthquake damage just after an earthquake. However, the obtained information will not be detailed, and it is difficult to use these in a small town owing mainly to economical situation.
On the other hand, it is needed to know precisely location and contents of damage for emergency responses. For this purpose, staffs in a municipality will organize information collection teams. In the case, damage information including location should be digitalized so that they can be easily processed and displayed on the map. Visualization of the damage situation will lead to exact and quick responses and smooth restoration as well as reconstruction measures.
From such viewpoint, we have developed a tool shown in **Fig.6** that staffs in a municipality, fire fighting staffs, and leaders in an area can easily input damage information such as place, time, damage item, extent and so on at damaged sites. Main features of the tool are as follows:
① Handy type.
② Detailed map (1/2500) of all area within a city, in which each house can be discriminated, is displayed.
③ Position information can be acquired by GPS and coordinates of a map.
④ Damage location (latitude, longitude) is automatically inputted.
⑤ Damage item and its extent can be inputted easily, and be displayed on the map.
⑥ It has a communication function and the data can be transmitted to a host computer.
⑦ Since it can receive the integrated data from a host computer, staffs can know the damage over the whole.
For staffs collecting information in a part of the city, the function of ⑦ is very important, because they can know their own situation in all over the city, and can also evacuate inhabitants to a safe place.

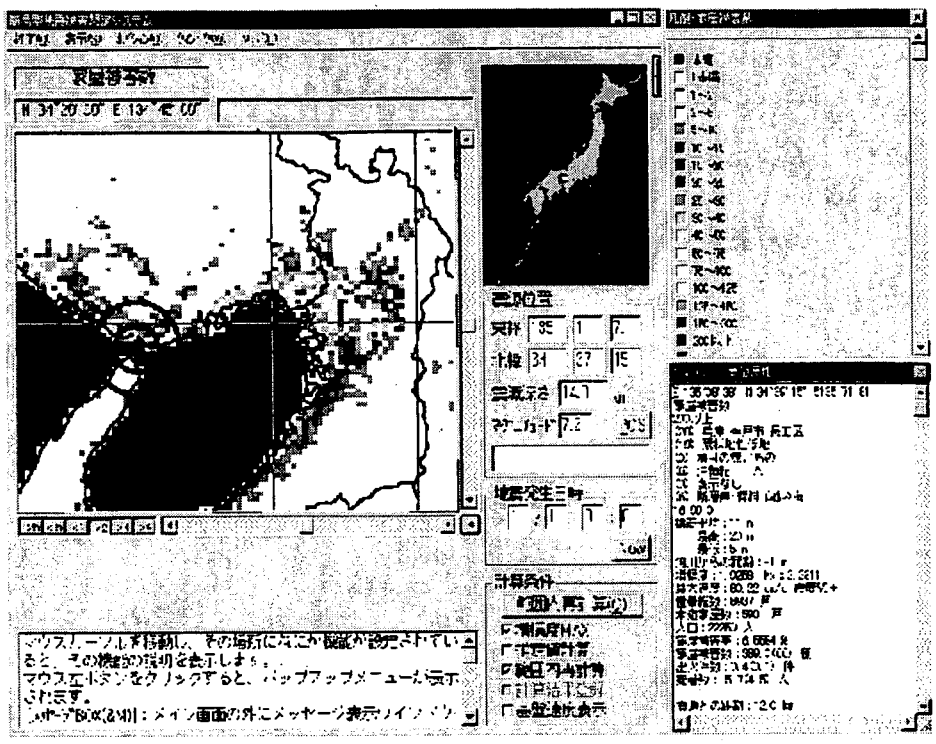


Fig.5 Simplified earthquake damage estimation system.

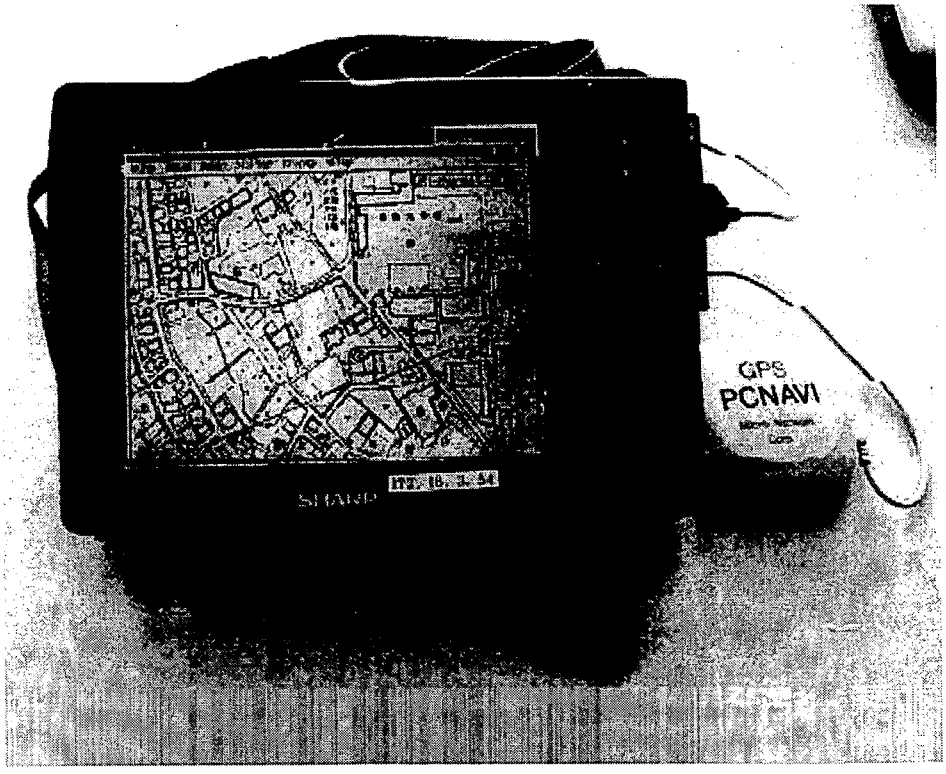


Fig.6 Handy-type collection and communication terminal of earthquake disaster information.

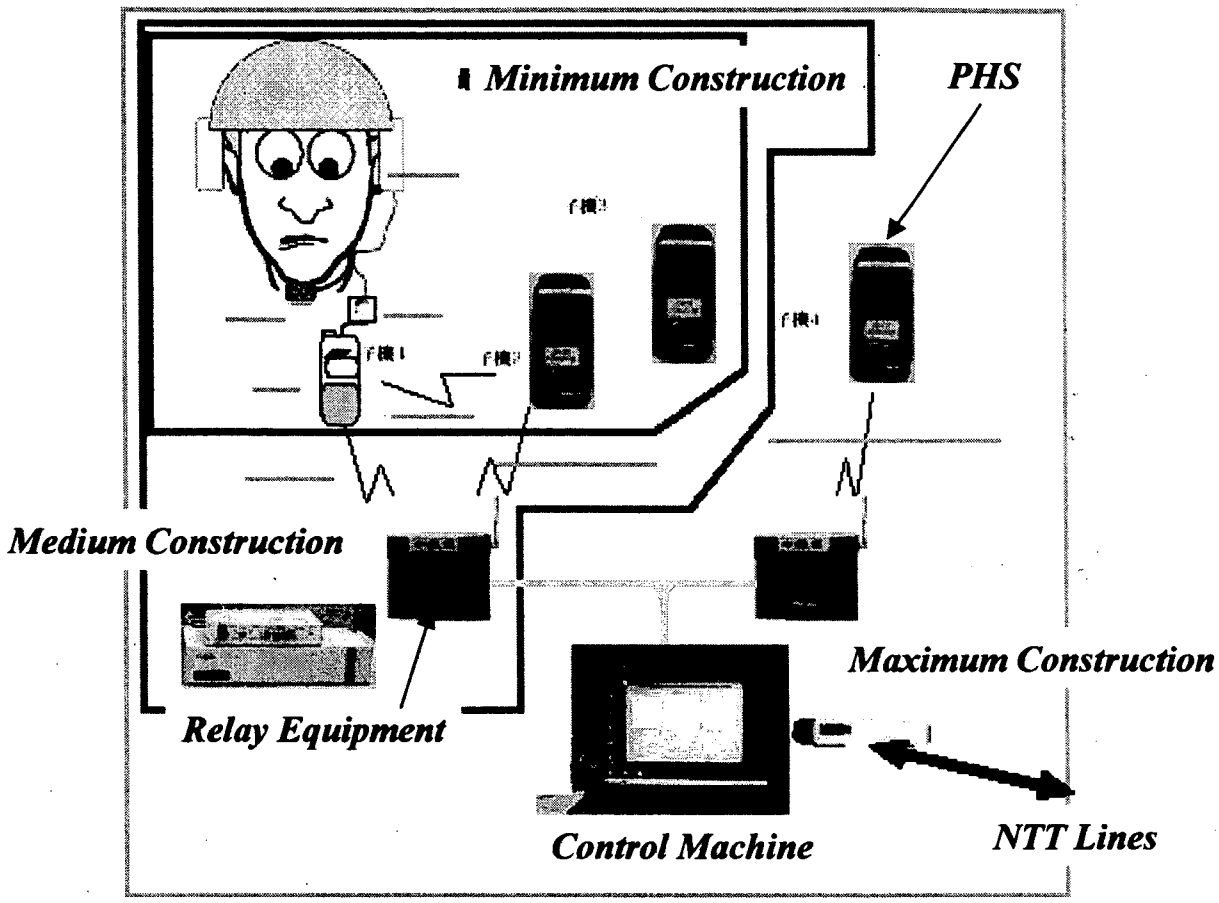


Fig.7 Component of FiReCOS

5.3 FIRECOS[4)]

As mentioned above, it is very important to communicate 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 firemen to communicate smoothly among them at a disaster site, as shown in **Fig.7**. FiReCOS is a high performance and portable radio equipment using PHS (personal handy phone system).

Since both the digital wireless communication technology and multi-channel access system are adopted, it can considerably reduce both radio interference and congestion. Therefore, it can be used as the basis for a communication network. Furthermore, because of the adoption of the standard TCP/IP (Transmission Control Protocol/Internet Protocol) used in the computer networking technology as the base technology, it can be easily connected to the national level Fire-D Net described below. In addition, the distribution of information to the mass media and so on through the Internet should reduce the bad influence of newsgathering activities on disaster prevention activities.

5.4 FIRE D-NET PLAN[5)]

Fire and Disaster Management Agency (FDMA) is responsible for transmitting disaster information from local government to the Cabinet in the large earthquake. FDMA has been constructing the tele-communications network, where telephones and facsimiles play the central role. Since the capacity

and speed of transmission is limited and people at both ends of this network consisting of multiple stages is necessary as shown in **Fig.8**, the network is insufficient in order to smoothly collect damage information when a large earthquake occurs. Recently FDMA planned to a new computer network, provisionally called the Fire-D Net, as shown in **Fig.9**. Since the network serves national, prefectural and municipal governments, including the fire defense headquarters, each organization can directly access to an arbitrary one. Functions of this network are expected as follows.

① automatically detect large-scale disaster relief activities using the number of calls to the emergency number, the number of fire-fighting and other vehicles mobilized and information on the seismic intensity, etc.,

② automatically inform the neighboring fire defense headquarters, prefectural government offices and FDMA,

③ collect the type and conditions of the disaster in addition to information on the geography and water availability etc. of the area in question,

The information on the actual disaster sites must be stored in the server at the headquarters. This can be performed by transmitting the information through the FiReCOS.

5.5 GIS FOR DISASTER PREVENTION[6)]

In order to share the various data through the Fire-D Net, the data items and their formats must be standardized, as well as base map. FDMA established the Study Group on GIS for Disaster Prevention in fiscal 1998 to examine how to share the various data among fire defense headquarters. The Study Group determined the common items, their attributes and formats needed in preparing a wide-area assistance. For example, items are water supply, hospital, hazardous materials facility, and refuge, etc. as static data, and fire, death, collapsed house, and damaged road, etc. as dynamic data.

Furthermore, experiments on sharing the data among seven fire departments were conducted using NTT (Nippon Telegraph and Telephone Corporation) lines. Time needed in collecting data from a fire department close to the hypothetical disaster site, visualization by GIS, recognition of regional characteristics and situation of disaster at the site etc. were examined. Although results are not always satisfied, establishing the Fire-D Net as well as GIS for disaster prevention is expected to smoothly transmit the disaster information to the Cabinet and also to reinforce a wide area assistance system, if the radio-based communication system with high speed and large capacity transmission is established.

6. CLOSING REMARKS

Gathered information is not worthy unless it is actually used for disaster prevention and other purpose. The consolidation of both hardware and software in the manner described above will contribute to not only the early gathering of damage information but also to (i) further assisting the activities of public disaster prevention organizations in terms of the real-time prediction of the spread of fire based on real information, judgement of the effective mobilization of the fire-fighting capability and appropriate deployment of reinforcements from other areas, (ii) providing urgent disaster prevention and other types of information related to the daily lives of inhabitants, (iii) providing information to the mass media and (iv) preparing relief and rehabilitation measures. In the coming years, it will be necessary to make efforts to realize the framework to efficiently gather damage information and to verify the usefulness of such a framework, and to ensure the safety of inhabitants.

ACKNOWLEDGEMENTS

We wish to thank personnel in municipalities for cooperation in the interviews and questionnaires, and also thank Mr. Teramura, Head of Disaster Prevention Information Section in FDMA, who willingly permitted introducing Fire-D Net Plan and GIS for disaster prevention, and Dr. Matsubara, Head of Alarm and Communication Section in our institute, who permitted introducing FiReCOS. A part of this study was supported by the budget from Promotion of Science and Technology.

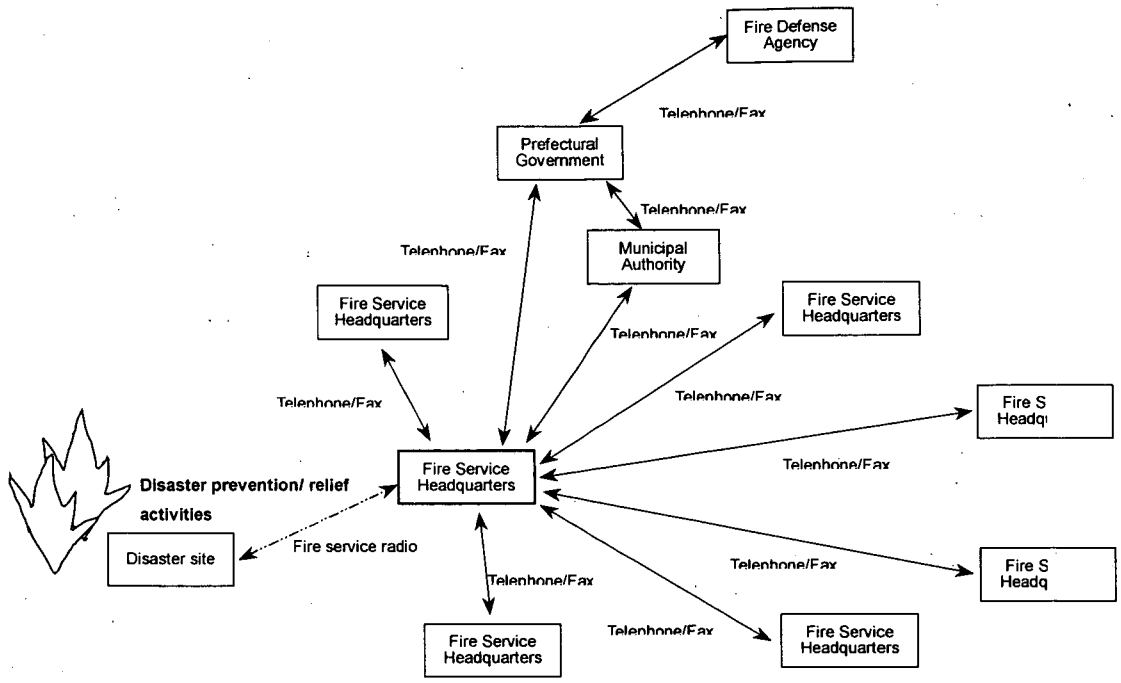


Fig.8 Current Communication Network

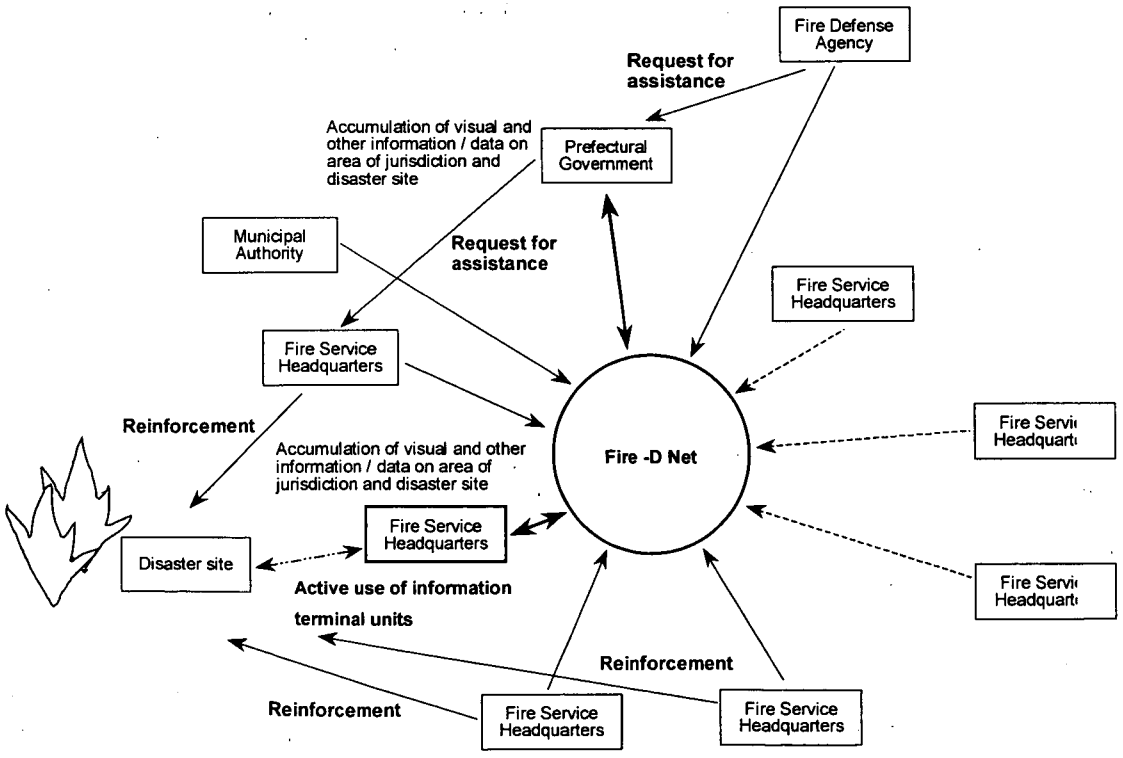


Fig.9 Fire-D Net for Smooth Implementation of Wide Area Assistance

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Session VI: System Issues and Advanced Technologies

- Draft Manual for Seismic Information System Development, *Tomofumi Nozaki* (PWRI), Hideki Sugita, Yasushi Ohtani*
- GEONET (GPS Earth Observation Network) Monitoring Crustal Deformation of Japan, *Tetsuro Imakiire*(GSI), Kazuo Tajima, Shujiro Nishi*

Draft Manual for Seismic Information System Development

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ABSTRACT

When large earthquake occurs, organizations in charge of civil infrastructure must investigate the damage of facilities that exist over wide area and analyze the information to make proper decision to secure and restore the function of facilities. Considering the importance of the civil infrastructures, information of damage and decision making regarding the facilities needs to be managed promptly after an earthquake. Recent technologies to process the information are incredibly advanced and those are promising for the elemental technologies of the seismic information systems (SIS). However, as such technologies are usually developed only in the respective professional field, the users encounter problems. For example, the performance of some technologies is not sufficient for earthquake response activities, or the data may not be able to be shared between different systems. Being aware of such problems, Public Works Research Institute (PWRI) has developed a guideline to develop SIS. This paper introduces outline of the "Draft Manual for Seismic Information System Development". The manual includes general idea of SIS development concept and the references to elemental technologies, which helps personnel in charge of developing SIS who is not necessarily professionals of information technology.

KEY WORDS: Earthquake, Disaster Prevention, Information System

1. INTRODUCTION

When a large earthquake occurs, earthquake response system encounter such difficulties as below.

- Earthquake usually occurs without any sign, and the damage is caused immediately after it.
- Numbers of facilities in extensive area are damaged at a time.
- They must cope with large number of sites that need efficient restoration works.
- There are reciprocal relation of damages and restoration works of complex urban systems.

On the other hand, recent progress of advanced technologies such as information technology and space

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development are thought to be efficient tools to solve the problems. These technologies include,

- wide area precise inspection by satellite image data,
- easy positioning by using portable GPS devices,
- flexible display and analysis of geographical data by GIS and
- computer network and distributed system by small-sized information devices.

By combining those technologies, the problems which earthquake response system encounter can be efficiently solved. In reality, many organizations apply PCs and other information devices for earthquake disaster prevention.

However, as those advanced technologies are developed only by the professionals of respective fields, their performance may not agree with the requirements of earthquake disaster response activities. For example, satellite images may not be precise to detect damage of facilities, or maneuverability of the GIS is too complex for the emergency actions. Besides those problems regarding each technology, other problems may exist due to framework of the information system. For example, sometimes the same kinds of data set are stored to different computer systems redundantly. In addition, once a huge system is constructed, it needs much amount of cost to extend or revise it. In other words, there are many possible problems and losses when SIS is constructed applying highly sophisticated technologies without considering requirement of the users.

However, it does not mean those technologies are irrelevant as long as they are combined in proper manner. Being aware of this issue, PWRI has tried to compose a guideline to develop an efficient SIS. In this paper, the brief contents of the "Draft Manual for Seismic Information System Development" are introduced. In the chapter two, the structure of the manual is briefly stated with key issues. From chapter three to six, each key issue corresponding to the manual contents is introduced.

2. STRUCTURE OF MANUAL

2.1 Overview

Aiming to support development of an efficient SIS, the manual contains important topics, namely, planning and development concepts of user-oriented and flexible SIS, and a list of state-of-the-art of technologies as a reference for the system planners. The topics are arranged in corresponding chapters as shown in Figure 2.1. Note that the numbers of chapter are not of this paper but of the manual. The contents are shown in the Appendix.

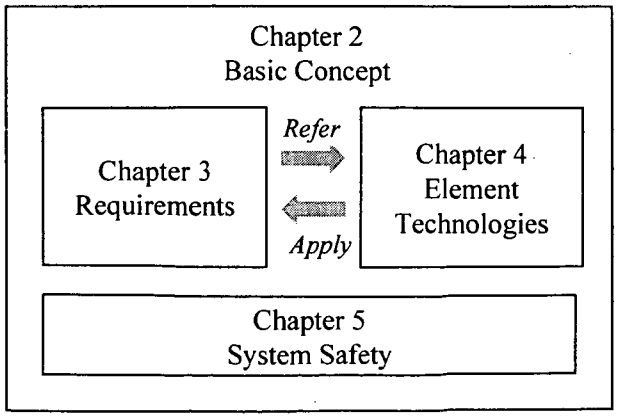


Fig. 2.1 Structure of Manual

2.2 Key Issues

Brief statements of the key topics in Figure 2.1 are as follows. The detailed explanations are in the chapter three to six of this paper.

(1) Basic Concept of SIS Development

The basic concept of SIS development includes (i) planning concept for user-oriented SIS and (ii) that for flexible SIS, (iii) consideration of system interface and (iv) application of SIS in the normal state. These issues are fundamentals for SIS that satisfies requirements for earthquake disaster response systems, and they are stated in the chapter two of the manual. While the concept mainly aims to initial development of SIS, they can be applied to improvement of existing SIS with careful consideration.

(2) Earthquake Disaster Response Activities and Requirements for SIS

Based on the statement in the concept of SIS, an example of investigation to understand requirements of SIS is shown in the chapter three of the manual.

(3) Review of Element Technologies for SIS

After requirements and structure of SIS is determined, planners must investigate proper technologies to realize the functions of SIS. As SIS includes both advanced information technology and earthquake engineering technology, the planners need their comprehensive list. The manual provides an inventory of current advanced technologies of both fields in the chapter three.

(4) Consideration of Safety of SIS

Because SIS is supposed to be used in an earthquake situation, it must be well prepared for a disastrous condition. Therefore, planners must consider safety of devices, facilities and data related to SIS against earthquakes. Besides the safety, security must be established and maintained because SIS is developed as a network system. The peripheral technologies and methodologies for SIS are introduced in the last chapter of the manual.

3. BASIC CONCEPT OF SIS DEVELOPMENT

3.1 General

When one tries to develop an efficient SIS, there are several problems. First, advanced information systems are usually developed mainly from a viewpoint of information technology professionals who do not necessarily know the activities of earthquake disaster response system. As a result, sometimes personnel in the response system encounter insufficiency of system performances such as accuracy, speed and capacity while some other performances exceed their aims. There can be another problems in the progressive information technology. For an example, once SIS is developed as a large host-terminal system, it cannot be revised easily. For another example, data may not be shared easily between different systems which are separately developed, or even it may be difficult to exchange data between different versions of the same application because of frequent revision. Thus, in the first part of the manual, several

suggestions are stated to develop efficient and flexible SIS that meet with the requirements of the earthquake disaster response system.

3.2 Objective Oriented Concept

To develop SIS which satisfies requirements of an earthquake disaster response system, SIS should not be thought simply as an integration of devices and application software. Rather, it is suggested that the system should be developed based on the earthquake response activities and the information dealt with in the activities. To accomplish this objective, following three steps are needed.

- to investigate and organize response activities of the earthquake disaster response system
- to investigate information dealt with in the activities
- to clarify the requirements of functions of the SIS to efficiently deal with the information

Charts, tables and even the analytical method such as the systems analysis are necessary to perform the tasks above. Although the manual does not show the detailed methods, a simple example of such an examination is expressed in another chapter.

3.3 Flexibility

SIS deals with many kinds of data of daily maintenance in addition to the emergency information after the earthquake. Therefore, it needs to be able to access almost any information regarding the facility management. One of the solution of such data sharing system is servers with highly integrated functions and clients that browse the result of servers' functions (Figure 3.1), However, it has disadvantages such as inflexibility, bottleneck and concentration of risk against earthquakes. Especially, SIS must be flexible from the viewpoint of expandability because it utilizes rapidly changing advanced technologies. The better solution to cope with this problem is a distributed data sharing system (Figure 3.2). In such system, the data are stored in each server for specific function and they are utilized by arbitrary client through the common interfaces.

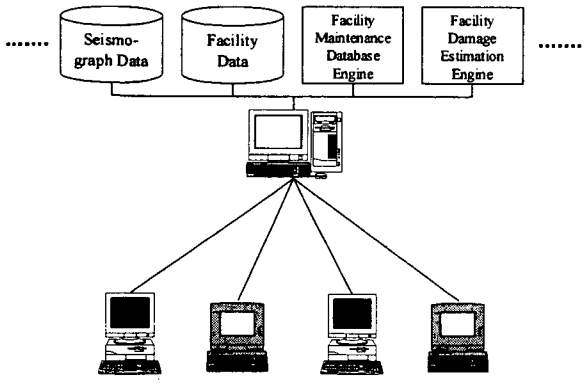


Fig. 3.1 Data Sharing System

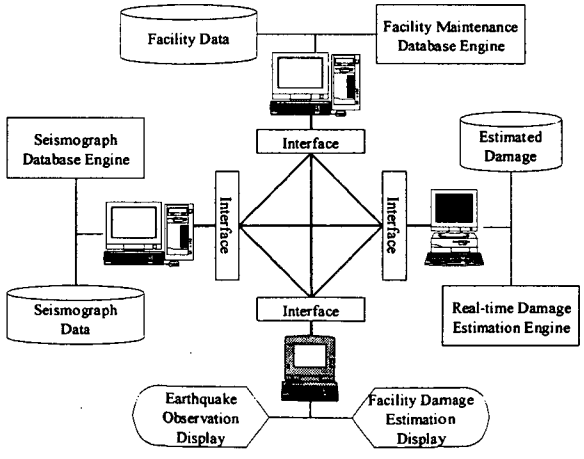


Fig. 3.2 Distributed Data Sharing System

To realize the true distributed data sharing system, the structure and the formant of the data dealt with by SIS must be identified and clearly described. An image of data structure that can include the attributes and relationships is shown in Figure 3.3. Once the structure is defined and clarified, the information can be interpreted to any format. If the format is well defined, arbitrarily added subsystem can access the information regardless with the types of operating systems and applications.

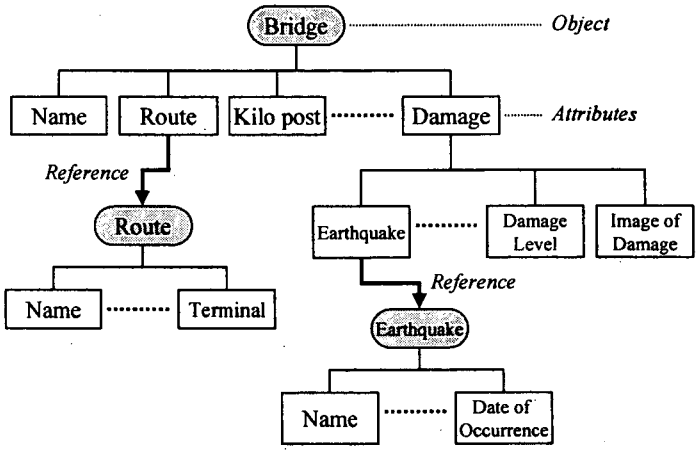


Fig. 3.3 Image of Data Structure

3.4 Others

Other issues concerning the feasibility and the usability of SIS - for example, the standardized interfaces that lead to better manipulation and use of the system in the normal situation to be accustomed to it - are explained.

4. COUNTER-EARTHQUAKE ACTIVITIES AND INFORMATION

4.1 General

To develop an efficient SIS, the activities of the earthquake disaster response system and the information dealt with need to be investigated. In the manual, an example of such investigation in which response activities are divided into four phases is shown. For each phase, the activities are specified, and the information needed for each activity and the functions of system to deal with the information are listed.

4.2 Earthquake Disaster Response Phases

Assuming an earthquake disaster response for civil infrastructures, following four phases are listed.

- Emergency response phase
- Temporary restoration phase
- Complete restoration phase
- Response system support phase

In the emergency response phase, overall rough damage inspection is performed. Temporary measures without heavy equipments are taken occasionally. Temporary restoration phase includes the damage inspection, decision making and activities for the restoration. Complete restoration phase is similar to the temporary restoration phase, while it requires more close inspection and complete restoration of damaged facilities. Response system support phase is different from other three phases, which concerns overall response activities from the start to the end. For example, it includes ensuring safety of the personnel and management of resources to maintain the response system.

4.3 Activities, Information and System Requirements for Each Phase

For each phase, the response activities are itemized. For example the emergency response phase includes four activities, namely, (1) setup of earthquake response system, (2) emergency damage inspection, (3) investigation of response planning and (4) emergency response. Each activity requires various kinds of information for its execution, and the functions of SIS to deal with the information are listed. For instance, the activity to setup the earthquake response system includes the following sets of information and the function of SIS.

(A.1) Setup of earthquake response system

(A.1.1) earthquake information -> earthquake detecting function [4.3.1]

(A.1.2) facility damage information -> damage detecting function [4.3.2, 4.3.3]

(A.1.3) startup trigger information -> emergency call function [4.4.1]

The numbers in the brackets indicate the section numbers of the manual where the technologies corresponding to the functions are explained. Details of those technologies are explained in the chapter four of the manual. The chapter three exemplifies that once the planner analyzes the activities, information and the required functions, he/she can distinguish the appropriate technologies applicable for SIS by referring the corresponding sections.

5. TECHNOLOGIES APPLICABLE FOR SIS

5.1 General

Usually, the personnel of the earthquake disaster response system who plan to develop SIS are not the professionals of the information technologies. Besides, because of the characteristic of SIS, it does not only include the general information technology but also applies the specific technologies regarding the earthquake disaster prevention. Thus, the planners in the response system and the information technology professionals must share the both kinds of knowledge.

In the chapter four "Element Technologies for SIS" of the manual, numbers of technology that can be applied to SIS are introduced. The planner of SIS can refer them to find the technologies suitable for the function of SIS which he/she has investigated as exemplified before. Also, it can be referred as the handbook to know the state-of-the-art of the technologies for SIS. While the advanced technologies are

often explained separately in respective specific area, this manual collects them so as to be the comprehensive reference for SIS planners. Also, it is intended that the manual be useful for the personnel who are not necessarily the professionals of the information technology to discuss about SIS with the information technicians. The technologies included in this chapter are divided into five categories, namely,

- Common infrastructure technologies,
- Technologies to detect phenomena,
- Technologies for information exchange,
- Technologies for display and analysis,
- Technologies to support decision making

The structures of this chapter with Subcategories are shown in Figure 5.1. Each numbers beside the boxes are not of this article but of the manual.

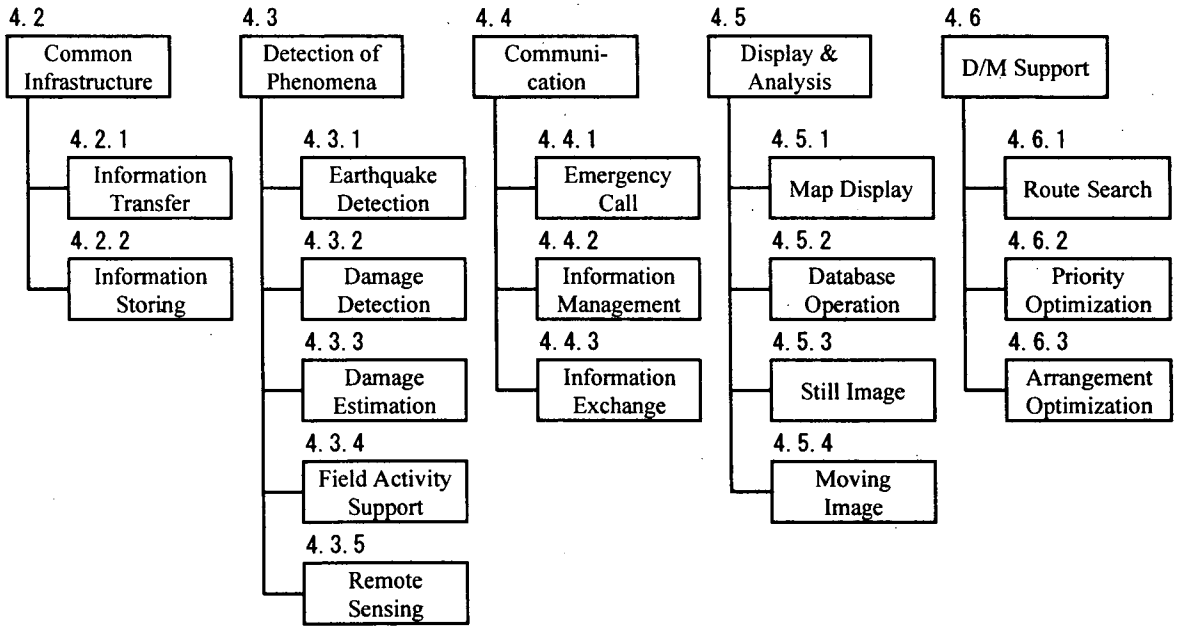


Fig. 5.1 Structure of Manual Chapter 4

5.2 Common Infrastructure Technologies

This section introduces two kinds fundamental and important technology that are common to any SIS: that is, the information transfer technologies and the information storing technologies. In fact, they are fundamental technologies for any kinds of information systems.

The information transfer technologies are the vital for all kinds of information systems, which includes wired/non-wired signal transfer technologies. In the manual, several kinds of those technologies are listed

and compared from such viewpoint as speed, risk and cost.

The Information storing technology section focuses on the storage devices such as hard disk drive (HDD) and magneto-optic disk (MO). Also, this section introduces the brief concept of the relational database (RDB) which is related to the distributed data sharing system. Figure 5.2 shows an image of data shared system with Structured Query Language (SQL) which is generally used to control RDB.

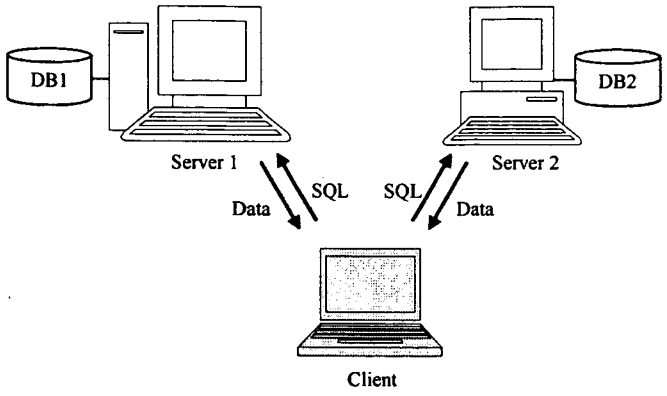


Fig. 5.2 Concept of SQL

5.3 Technologies to Detect Phenomena

Prompt detection of phenomena regarding the earthquake disaster is necessary for the efficient response. This section includes following five kinds of technologies.

- earthquake detection: technology to detect the ground motion of an earthquake by accelerograms that indirectly represents the facility damage
- damage detection: technology to directly detect the damage of facilities caused by the earthquake by utilizing various types of sensors
- damage estimation: technology to estimate the damage of facilities indirectly based on the ground motion data
- field inspection support: combination of technologies to support the field inspection of damage
- remote-sensing: advanced remote sensing technologies from platforms such as an airplane and an artificial satellite

For example, sensors to detect facilities damage should be used properly depending on the distribution of the facilities and the required accuracy. While rough detection of damage of facilities in wide area needs only simple sensors such as the wire sensor, more sophisticated sensors are necessary for accurate detection for important facilities. Figure 5.3 illustrates an image of accurate damage detection for an important bridge.

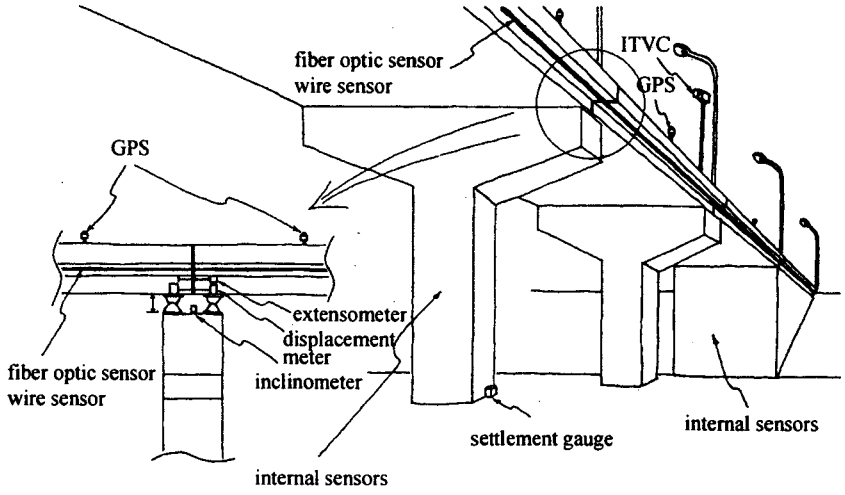


Fig. 5.3 Sensors for Accurate Detection of Important Facility

Figure 5.4 is an example of a real-time damage estimation system for civil infrastructures. The flow of the execution and the display image are from Seismic Assessment Tool for Urgent Response and Notification (SATURN) developed by PWRI. It provides rough estimate of damage on civil infrastructures based on the ground motion data detected by online accelerograms.

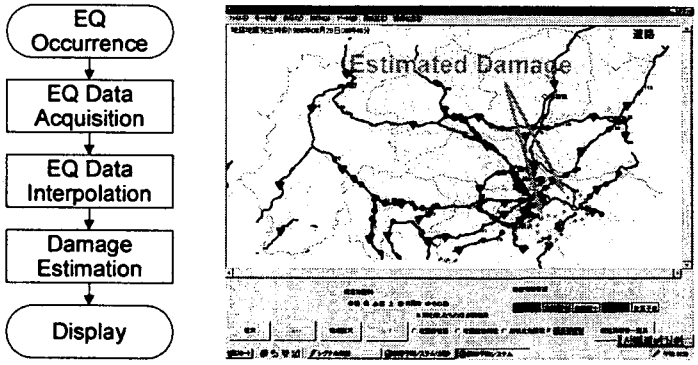


Fig. 5.4 Real-time Damage Estimation

In Figure 5.5, the field inspection support technology is illustrated in which various kinds of advanced technology equipment are utilized. For example, personnel of inspection team can easily understand their position in the damaged area with the help of the global positioning system (GPS) and the geographical information system (GIS). The information about the damage including texts, still images and even moving images can be sent to the response center through the communication technology. The planner can develop such a system with exclusive devices, or he/she can use existing equipments in the market. Recent technology can provide the flexibility of such a way of development of the system, and it

improves the efficiency of the field inspection activities.

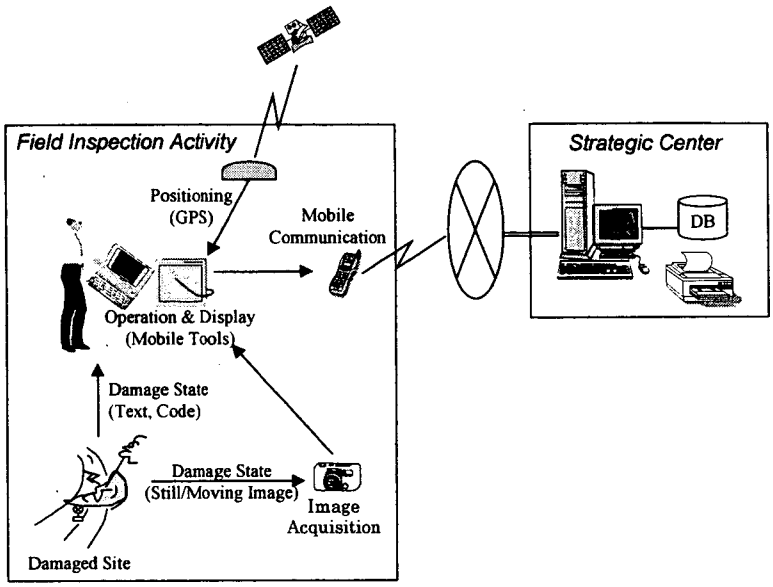


Fig. 5.5 Field Inspection Support

Because of the extension of the earthquake damage, the information in wide area needs to be corrected all at once. Remote-sensing technology can be a candidate for such requirement. The remote-sensing technology consists of two parts, one is a platform and the other is a sensor. There are many kinds of platform: e.g., aircraft and artificial satellite. They are characterized by their height, mobility and stability. As for the sensor technology, it also has various kinds such as an optical sensor, infrared sensor and laser profiler. They are characterized by the ability to detect phenomena, accuracy and influence of weather such as cloud and rain. Simulated images from satellite are shown in Figure 5.6 by changing the accuracy.

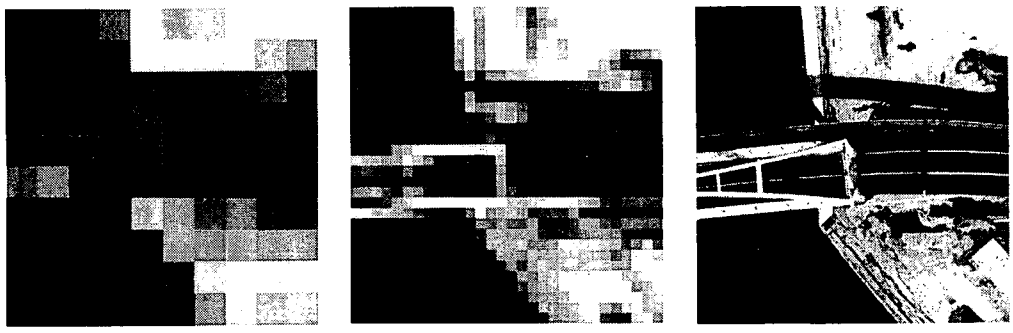


Fig. 5.6 Simulated Remote Sensing Images (Grid Size: 30m, 10m, 1m)

5.4 Technologies for Information Exchange

For the prompt and efficient earthquake response activities, organizations and the personnel need to exchange their information. First, it is vital to note the information for the establishment of the response system to the personnel all at once especially when the earthquake occurs out of office hours. Pager, voice modem and Internet technology can be used. Second, the information stored and corrected need to be managed appropriately. For example, even if the system has the stock data materials for the restoration, they may be meaningless if their volume is not updated timely. Thus, the information management issue is explained here although it is rather a management technique than a pure hardware technology or logical software technology. In the last, the technology that is applicable to exchange information between two different organizations is introduced. It is comparatively the professional issue regarding the network communication technology, however a planner needs to know its concept. Figure 5.7 shows an image of the extranet which utilizes the Internet technology. By applying the extranet, more than one organizations exclusively exchange their information through the Internet which anonymous users access.

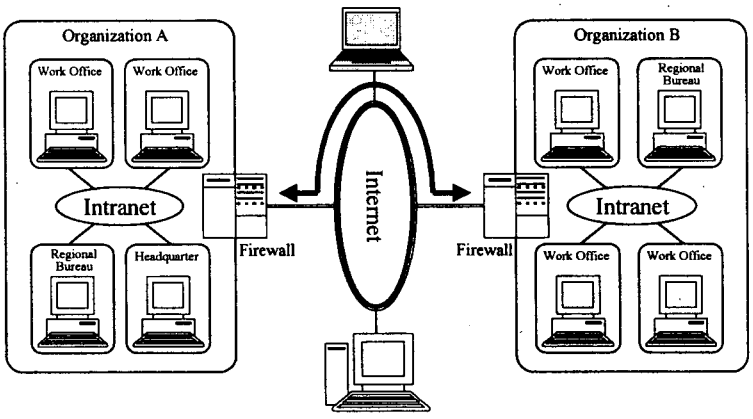


Fig. 5.7 Data Exchange in Internet

5.5 Technologies for Display and Analysis

While the information is gathered and stored, it becomes useful only when they are analyzed and displayed in proper manner. The manual shows recent technologies to display following objects.

- map: display, integration and analysis of data by using GIS
- database: flexible database control by using SQL
- still/moving image: their application and the mechanism

While those technologies are not only for SIS but general for any kinds of information system, their mechanisms are briefly discussed to help planners grasp initial ideas to import them into their SIS. For example, a still image linked with an object in GIS is shown in Figure 5.8. In the manual the mechanisms of each technology is explained conceptually.

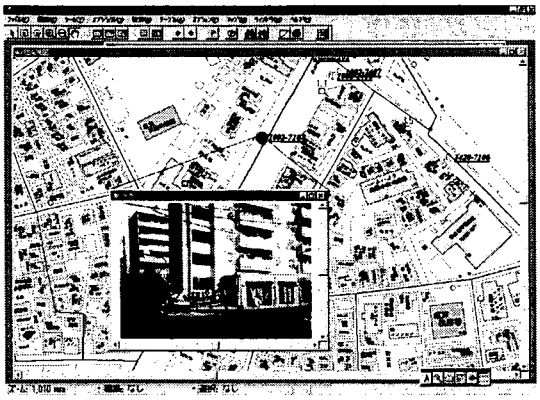


Fig. 5.8 Still Image in GIS

5.6 Technologies to Support Decision Making

While the information of damage state and other phenomena and their analyzed results improve the earthquake response activities, it can be useful if the SIS provides more creative information to support examination on efficient response alternatives. Usually such functions utilize simulation and/or optimizing techniques from many fields. The manual introduces three examples of them as follows.

- Technology to find the shortest route
- Technology to find the most efficient priorities of such activities as emergency restoration
- Technology to find the most optimized pattern of person/material arrangement

Those technologies do not necessarily give the completely exact results, however, the earthquake response team can investigate the appropriate countermeasure by examining the alternatives that the decision making support technologies provide.

6. SAFETY AND SECURITY

6.1 General

Sometimes, the negative surface of the information system is emphasized: e.g., its vulnerability to disaster, security problem and complexity of operation. It may be true if the system is not constructed and maintained properly. To realize the functions of SIS both in the usual and the emergency states, the manual introduces the following important points: that is, safety against earthquake disaster and security as network system.

6.2 Safety against Earthquake Disaster

SIS must be functional under the estimated level of earthquake. On the other hand, the information system devices are weak against such conditions as shock, vibration and irregular temperature which occur in earthquakes. The manual explains following three issues to reduce and manage the risk of SIS against the earthquake.

- Constructing earthquake standing SIS : many points regarding the settings and arrangements of system devices and facilities
- Risk control with distributed SIS : concepts and techniques to keep the redundancy of the system, network line and data against the disaster
- Preparedness to the critical situation in which SIS is not functional : importance of consideration of contingent situation in which the response system must act without sophisticated SIS

Examples of data distribution by using RAID (Redundant Arrays of Inexpensive Disk) technology are shown in Figure 6.1. Here, RAID0 is used to improve the disk access speed and RAID1 is used to improve safety of data. There are other efficient and practical disk system of RAID versions, and the planners can improve the safety of the data by utilizing them.

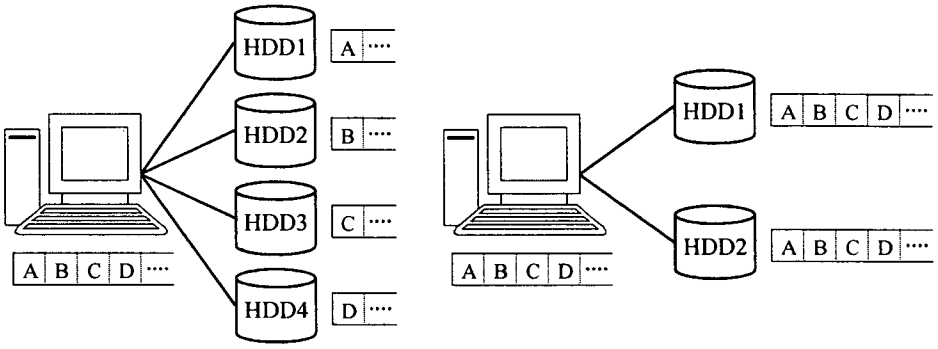


Fig. 6.1 Image of RAID0 and RAID1

6.3 Security

Although the security does not directly related to the efficiency of SIS function, it is an important issue regarding the computer network system. Because the ideal SIS deals with almost all the kinds of data of the earthquake disaster response organization, the data stored and transferred in SIS must be well secured by such technologies as firewall and encryption. In Figure 6.2, an idea of the firewall for a network system is illustrated. Here, the access from out of SIS is denied as long as it is not the reply to a request from SIS.

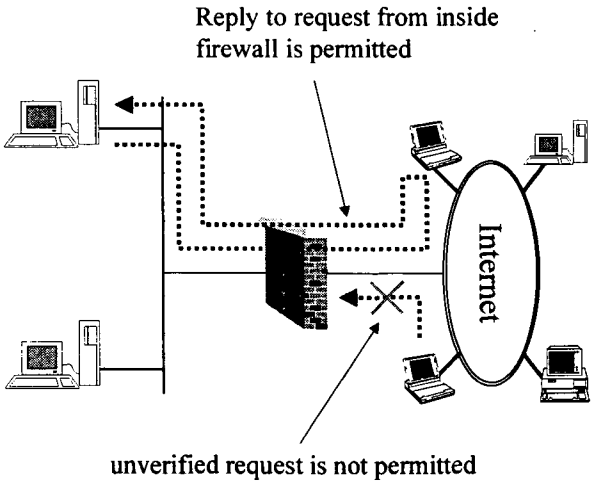


Fig. 6.2 Example of Firewall Policy

On the other hand, strong security occasionally becomes an impediment for the earthquake disaster response activity. An example is a case in which all the limited authorized personnel are not accessible to the system in a disaster. Thus, the manual suggests that both the security and its exception from the point of the earthquake disaster response need to be considered.

7. CONCLUSION

Seismic Information System is one of the most difficult information systems to develop. Because the earthquake response system must deal with many kinds and much amount of information over their own organization, SIS is required to be the most extensive system. Also, it must stand against a disastrous earthquake for its original use. In addition, the planner and user must have the knowledge of earthquake engineering for some of functions of SIS. Thus, planning and developing SIS certainly require comprehensive knowledge of the information technology, earthquake engineering and risk management.

Although there are researches and products for the individual system currently, there have not been guidelines for the comprehensive SIS and they are left to the information technicians. The manual introduced in this paper has been produced aiming to be such a comprehensive but easy-to-use guideline for information technicians, earthquake engineers and earthquake response system planners. As the software and hardware technology progresses in rapid speed, the elemental contents needs to be revised by degrees. By improving the technologies based on another detailed researches regarding each element technologies, actual SIS that helps response systems can be developed.

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APPENDIX

- Brief Contents of the Manual-

1. General
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1.2 Structure
1.3 Definition of Terms

2. Basic Concept of SIS Development

3. Earthquake Disaster Response Activities and Requirements for SIS
3.1 General
3.2 Phases of Earthquake Disaster Response, Information and SIS Requirements
3.2.1 Phases of Earthquake Disaster Response
3.2.2 Emergency Response Phase
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4. Element Technologies for SIS
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5. Safety of SIS
5.1 Disaster Risk Mitigation
5.2 Security

GEONET(GPS Earth Observation Network) monitoring crustal deformation of Japan

Tetsuro IMAKIIRE*, Kazuo TAJIMA, Shujiro NISHI[1])

Abstruct:
GSI established GPS permanent observation station network GEONET covering all over Japanese islands. GEONET is working for the monitoring for crustal deformation. Many information on geodynamics has been obtained by the observation result of GEONET. GSI is going to extend its ability into the GPS data service for surveying and positioning.

Keyword: GPS, crustal deformation, monitoring system

1. GPS survey by GSI

GSI(Geographical Survey Institute) is the governmental agency which is responsible to maintain the geodetic control points network covering Japan. GSI has been carrying out the geodetic survey on the first to third order triangulation points since 19th century. The instruments used for those survey were transits at first, and laser distance meters were used after 1970s. As Japanese islands are tectonically very active regions, crustal deformation caused an unavoidable displacement of control points. Therefore survey on all first order and a part of second geodetic control points has been executed repeatedly to monitor the crustal deformation. The pattern of horizontal deformation which is related to plate motion around the Japanese island was made clear by these survey. Those results were compiled to the "Horizontal Strain of Japan". (GSI, 1996)

Recently GPS was introduced for geodetic survey. GSI started to use GPS for the geodetic survey from 1984 and started continuous GPS observation on the permanent monument from 1993. Though the number of permanent stations was about one hundred points at that time, it has increased to about one thousand points, now. This network, called GEONET, is operating to monitor the everyday crustal deformation of all Japanese islands.

2. Construction of GEONET

The first four permanent GPS observation stations were constructed at Izu peninsula in 1992. In 1993, one hundred and ten GPS stations, including these four stations, network was established in Tokai and Southern Kanto are. This network was called "COSMOS-G2" (COntinuous Strain MOnioring System-with GPS by GSI). The purpose of this network was to monitor the crustal strain of target area. Tokai region is considered as a source region of large earthquake which would occur in near future. Average distance between two neighboring sites was 15km. Receivers set on the sites records every 30 seconds data and those data was downloaded to analysis center at GSI in Tsukuba through analog telephone lines everyday. Observation at the station was carried out only in the night time, and 6 hour data was processed to determine the three dimensional position of each site using broadcast ephemeris.

Another GPS network for geodetic control system was established in 1994. This GPS observation network consisted of one hundred stations covering all over Japan. The average distance between two neighboring stations was about 120km. One of the main purposes of this

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network was to establish a geodetic control points based on space geodesy technique as well as to monitor the crustal deformation. Therefore each observation site equipped one metal marker for survey using traditional survey tools such as distancemeters or transits. This GPS observation network was named "GRAPES" (Gps Regional Array for PrEcise Surveying/ Physical Earth Science). (Miyazaki et al.,1996) This system used 24hours data for analysis, as larger data set was necessary to solve the longer baselines. The two networks were working separately as for the difference of their configuration.

A large earthquake occurred at east offshore of Hokkaido on October 4, 1994, just four days after GRAPE system had started to operate. Crustal deformation caused by this earthquake (Hokkaido East Offshore Earthquake, M8.1) was detected by the analysis on GPS data observed GRAPES sites. The eastward displacement of Nemuro site, which was the nearest station to the source region, referred to the Usuda, station in the central Japan, was as large as 40cm. Other sites on the eastern Hokkaido showed remarkable eastward movement, too. As, these co-seismic movement were revealed just a few days after the earthquake, the efficiency of GPS continuos observation has been appealed to the public.

Two other large earthquakes occurred one after another within a half year after this earthquake. One was Sanriku Far Offshore Earthquake(M7.5, Dec. 30, 1994), and the other was Southern Hyogo Earth Quake(M7.2, Jan. 17, 1995) which is known as Kobe Earthquake. Crustal deformation caused by these events was also detected. Not only co-seismic deformation but also postseismic deformation was detected for these two earthquakes. (Heki, et al., 1997)

These results established the recognition that GPS continuous observation networks is one of the most basic tools for geodynamics study in Japanese society. About 400 more observation sites were added to the array in FY1995, and two networks, COSMOS-G2 and GRAPES were combined into one system to deal all sites data together. There are about 1,000 sites of GPS continuous observation covering the all Japanese islands, now. (Figure 1)

3. Configuration of GEONET

GEONET consists from about one thousand GPS observation sites with average distance between two neighboring points being 25-30 km. Data observed by the receivers at those sites are sent to data central station in GSI (at Tsukuba) and analyzed once per day.

Observation sites are called "GPS-based control point". Each site equips one GPS receiver, antenna, communication device, backup battery, those are installed in the stainless steel pillar. A pillar is five meters high, standing on the concrete base which is two meters cube. (Figure 2)

Receivers installed in the pillars are dual frequency types. Most of receivers are scheduled to receive dual band carrier phase data and code data every 30 seconds. Receivers have extension memories to keep their data for several days to provide the back up data for data communication failure. Some receivers are scheduled to receive GPS data every one second that could be used for kinematic positioning. But such data is kept in data memories of the receiver temporally for a few days and overwritten by new data if there are no special downloading request.

An antenna is set on the top of the pillar covered with a radome. Communication devices are terminal adapters in most sites where digital telephone line is connected, however modems are used for a part of the sites which only have an analog telephone line.

The central station for controlling the network and data analysis is settled in Tsukuba, at the main office of Geographical Survey Institute. The central station controls the operation of the all observation sites, data communication, data management and archive, analysis, etc.

Data flow of observed data is shown on Figure 3. Data stored by the receivers are downloaded once per day from the central station. Generally the downloading is carried out in midnight.

The size of one day data is about 800KB per site. The communication time necessary for downloading is about two or three minute for a site with digital telephone line, besides ten to fifteen minutes for a site with analog telephone line. It takes about two hours to download the data from all stations.
Downloaded data is archived into the database in RINEX(Receiver INdependent Exchange) format. One day data set for routine analysis starts from 0h and ends by 24h of JST. The data control unit carries out quality check whether any data is missing, cycle slips exists, etc.
After archiving data, the data processing unit starts network solution process of GPS data. The data processing units consist from eight engineering workstations with UNIX operation system. The main data analyzing software is BERNESE, the product of the Bern University.
The satellite orbit data used for routine processing is "combined ephemeris". This is a combination of IGS (CODE) rapid solution orbit and predicted orbit. IGS rapid solution orbit is a product of International GPS service using a data set from satellite tracking stations and available from CODE(Coordinate Orbit Determination Center in Europe) by the internet. Only the data set for the day before the observation in UT is available. Therefore the orbit data for 0h to 9h of the day is rapid solution besides that of 9h to 24h is predicted orbit which is extrapolation of rapid solution orbit. This combined orbit is more precise than broadcast ephemeris.
Network solution procedure of GEONET starts 9h of JST just after downloading IGS rapid solution orbit and predicted orbit. Three dimensional positions of all stations are determined referred to Tsukuba site. The network solution process takes about three to six hours according to the quality of the data. The product of solution is stored into the database in the SINEX(Software INdependent Exchange) format.
This is the routine procedure for quick solution of GEONET data.
Two weeks after the observation, IGS final orbit becomes available. The final orbit is the most precise ephemeris data available for GPS study. The final solution for GEONET is carried out using this orbit data. In this final network solution, data of all sites are arranged to the 24h data set starting from 0h and ending by 24h of UT, and these data sets are used for the analysis. Therefore the product of final solution is three dimensional positions for the day in UT. SINEX file for the final solution is also stored in the database.
The database has a simple data viewer with which users can display and print out the result of the analysis in various formats. For example, time series graph of coordinates of certain site, time series of relative position of two sites or horizontal displacement vector in certain term can be displayed on a screen and printed out by a printer.

4. Result of observation

4.1. Coseismic and postseismic deformation by large earthquakes

This network has detected a number of coseismic crustal deformations such as that of Kobe (Hyogo-ken Nanbu/ Southern Hyogo Prefecture)earthquake as mentioned before. The horizontal displacement vector caused by this earthquakes is shown on Figure 4. The epicenter of this earthquake located on the northern part of Awaji island. The mechanism of the earthquake was strike slip with east-west compression according to the seismological observation. The horizontal displacement observed by GPS is consistent to this analysis.
Post seismic deformation after large earthquakes are found by this GPS network. Sanriku Haruka Oki(Sanriku Far offshore) earthquake occurred on December 28, 1994 was a large interplate earthquake with the mechanism of low angle reverse fault. Coseismic displacement

was observed at the sites along the eastern coast of northeast Japan. The direction of coseismic displacement vector was eastward. Postseismic displacement, of which direction was same as coseismic one, observed by the network continued at least for two months. It is considered that this postseismic movement means very slow slip followed to the main event as a silent earthquake. (Figure 5)

4.2. Crustal deformation by earthquake swarm

Not only the crustal deformation caused by such great earthquakes but also by earthquake swarm activities are detected. Izu peninsula is a seismic active region and such earthquake swarm events have occurred several times after the beginning of GPS network observation. Uplifting of the ground has been observed by leveling survey and tide gauge observation for these twenty years. These crustal deformation is related to the seismic activity. GPS observation shows that the rate of the deformation is closely related to the seismisity. Figure 6 shows relationship of seismic activity and crustal deformation during the event in April to May, 1998. When seismic activity was high, the baseline extended prominently, besides when the number of earthquake is small, the extension of the baseline slowed down.

4.3. Crustal deformation by volcanic activity

Another notable observation result is detection of volcanic activity. Mt. Iwate volcano is one of the active volcanoes that are regularly monitored by JMA. Notable seismic activity has started from the beginning of 1998, and GEONET detected the extension of the baseline crossing the volcano. The phenomenon was considered that the mountain expanded by uplifting of magma. GSI installed eight temporal GPS observation stations around the volcano to monitor the more detailed crustal deformation. Especially on the sites where the telephone line and power supply line was not available, observation system with solar battery and satellite communication system were installed. Such four units were set on the sites nearer to the mountain ridge where the center of the dilatation of the crust locates. These eight temporal GPS station has been operating until now and they detected co-seismic displacement caused by the largest earthquake(M6.1) occurred on September 3, 1998, near this array as well as the inflation of the mountain which is considered to be related to volcanic activity. (Figure 7)
GSI has been carrying out these kind of mobile GPS observation connected to GEONET on some occasions. Observation around Mt. Iwate has been continuing until now.

4.4. Stationary deformation of Japanese island

As well as such coseismic deformation, the accumulation of observation results shows the continuous crustal movement regularly occurring on Japanese islands. Some typical patterns of crustal movements can be seen on the horizontal crustal movement vectors.
Figure 8 shows the horizontal displacement vector referred to Ohgata station on the coast of Sea of Japan in Niigata prefecture. The vectors on this figure can be interpreted as a horizontal movement of the stations relative to Eurasian continent. The sites on the eastern and southern coast of northeast Japan seem to move toward west and northwest according to the subduction of the Pacific plate and the Philippine Sea plate. On the other hand, the northern part of southwest Japan moves toward east, according to the eastward movement of the Amurian plate. These patterns of crustal movements coincide the model constructed from the result of geodetic surveys for one hundred years. But GEONET made it clear within a few years. These results gave a large impact to the study of tectonics around the Japanese islands, which is very important as a background to discuss the seismic risk of each region. These figures of horizontal

deformation vectors in late one year are reported to Earthquake Research Committee, Headquarters for Earthquake Research Promotion in Prime Minister's office, once per month.

5. GEONET and new geodetic coordinate system

GEONET will be utilized as the geodetic control frame of Japan. The geodetic systems of Japan will be changed to a geocentric system in 2000. The GPS based control points network consists the most important part of the geodetic control frame connected to VLBI stations. As Tokyo datum, the current geodetic coordinate system in Japan, was established about one hundred years ago, it is based on the non-geocentric ellipsoid. It is pointed out that systematic shift exists between the Tokyo datum and other geocentric system, such as WGS84. And distortion of the network is found by recent study by space based geodetic observations. Three dimensional coordinate determined by GPS is based on a geocentric system, and the result of survey using GPS or totalstations is very accurate that such problem cannot be ignored. Therefore, GSI, which is responsible to control the geodetic reference frame of Japan, decided to restructure the geodetic system into a new system which is consistent to the new survey systems. Most of the first order control points and some lesser order control points are connected to the GEONET as a backbone network of the new geodetic system, and network adjustment calculation was carried out with the constraint of VLBI observation result. Those control points in backbone network will have a new coordinates based on the newest survey result. The coordinates of other lower order control point are determined by the network adjustment based on these backbone network but not with newest observation result. However, most of the coordinate will be consistent to the new system according to the experimental survey result.

6. GEONET data service

GSI is also planning to supply observation data of GEONET for surveying and navigation through the internet and telephone line in near future. A part of archived observation data of GEONET became available through the internet from the beginning of August 1999. Users can download RINEX format observation data from the homepage of GSI. However, there are some limitations in this service, now. At first, only the data observed within late three months are provided in the server. Older data should be requested to GSI by e-mail or printed letter. As the data is archived in one file per day, JST 0h to 24h, user should download all 24 hour data even if shorter data is necessary. Finally, only Japanese page is provided for this downloading site. When new servers for data service are available, these limitation should be removed. Other GPS data service planned by GSI is real time data service for kinematic GPS. There are 22 GPS based control stations in Kanto, Kansai, Tokai and Sapporo regions which serve GPS observation data for RTK(Real Time Kinematic) survey by MCA(Multi Channel Access) radio communication. Users can obtain every one second carrier phase data from GPS-based control point using MCA radio receiver. The experience for this data service system started 1997, and the public service is planned to start in this fiscal year. (Figure 9)
GSI is planning to extend this real time data service to other communication media such as portable telephone or satellite communication system, and to establish a data service center which will control all kind of GPS data service in various manners. In near future, it is expected that GPS data observed by GEONET station will be available to many users from such data service center.

6. Conclusion

GEONET was established for the monitoring the crustal deformation. It revealed many

interesting geodynamic phenomena relating to the plate motion, mechanism of earthquakes and volcanic activity. This network can detect co-seismic movement as well as stationary crustal deformation which are helpful to the study of geodynamics and earthquake engineering. GSI is considering to maintain and extend this network for more detailed (both in space and time domain) monitoring. The data by GEONET will be served to users of various fields in near future.

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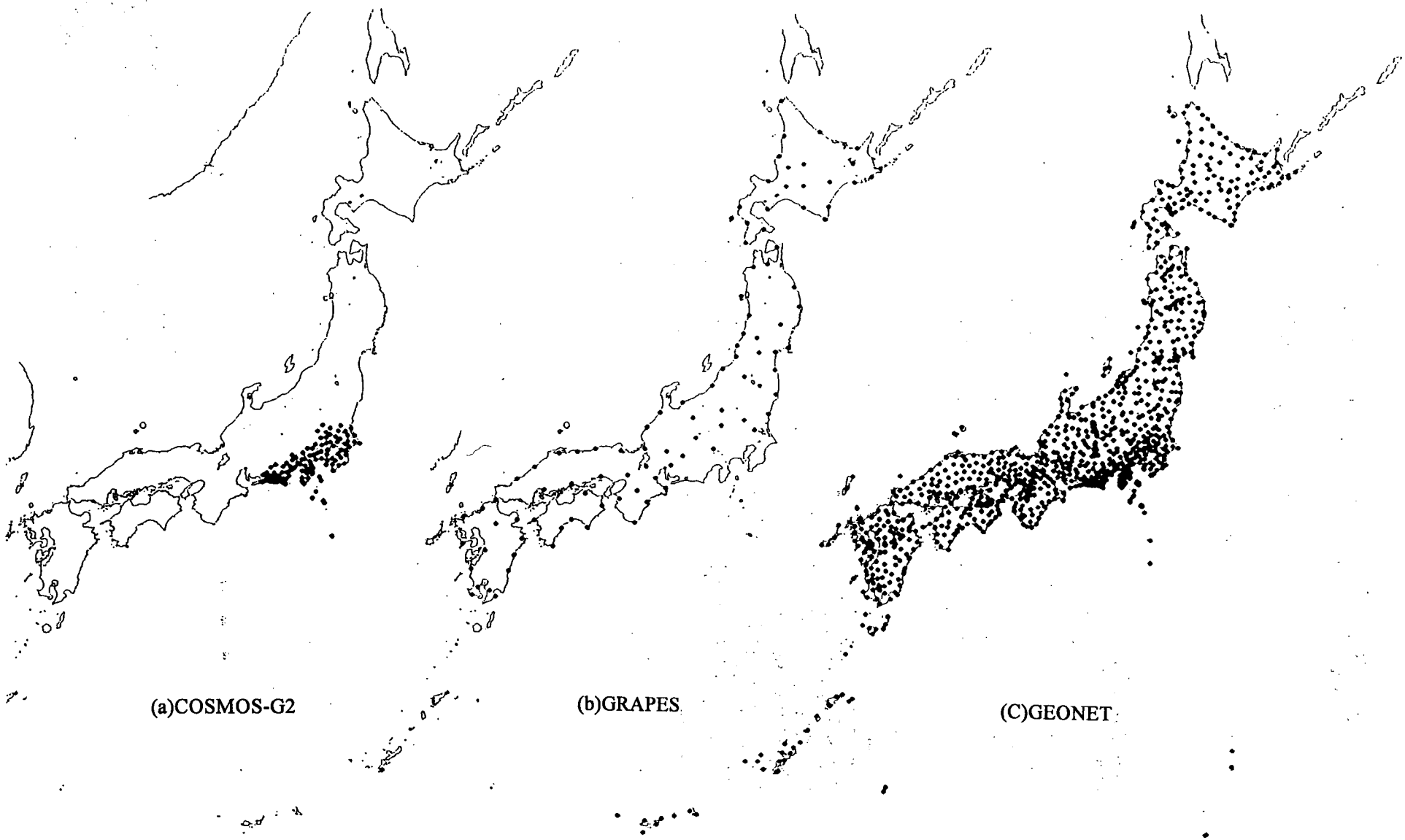


Figure 1. Extension of GPS observation sites network.

GPS-based Control Point (Tsukuba site)

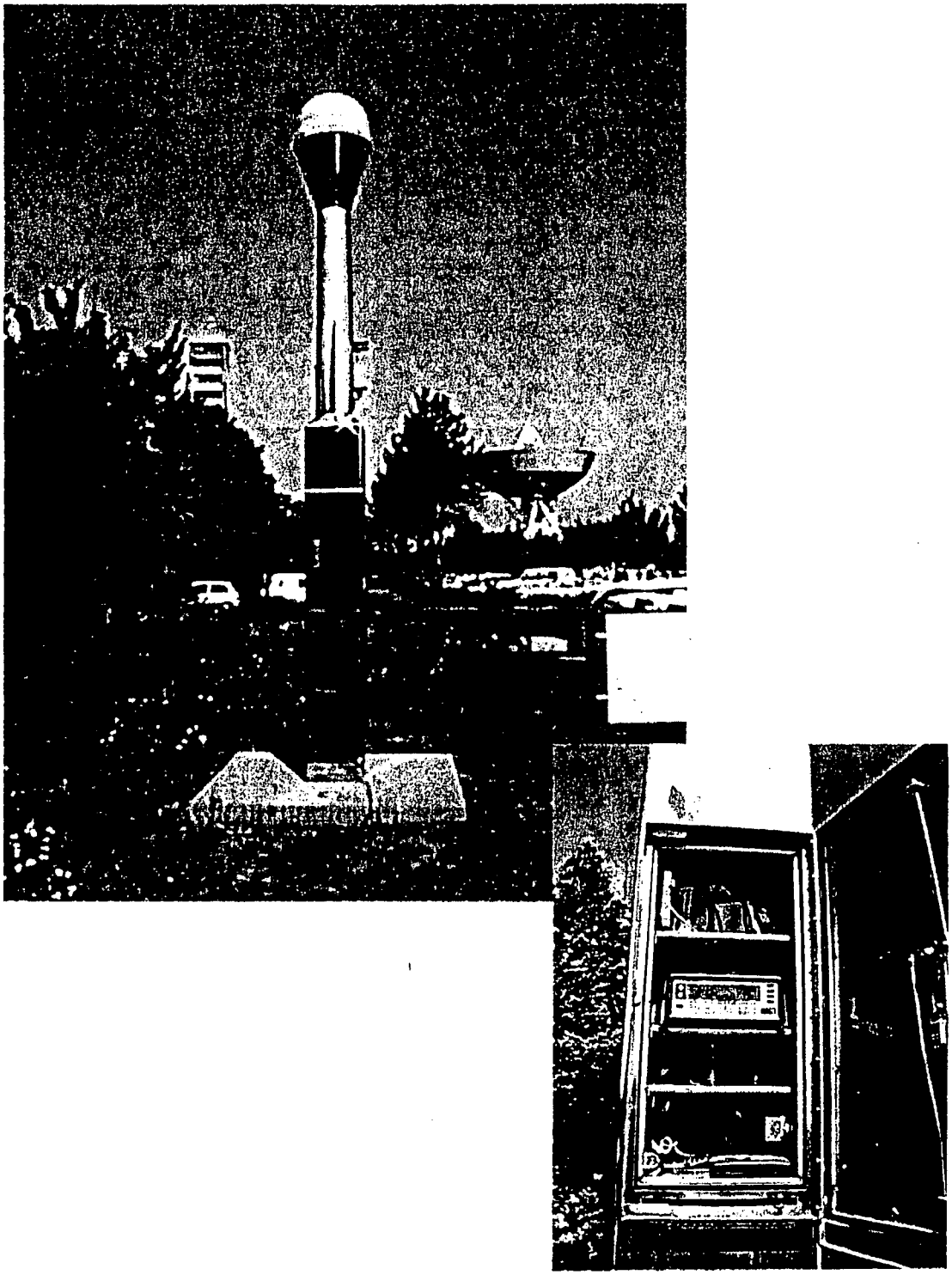


Figure 2. GPS based control point in Tsukuba site.

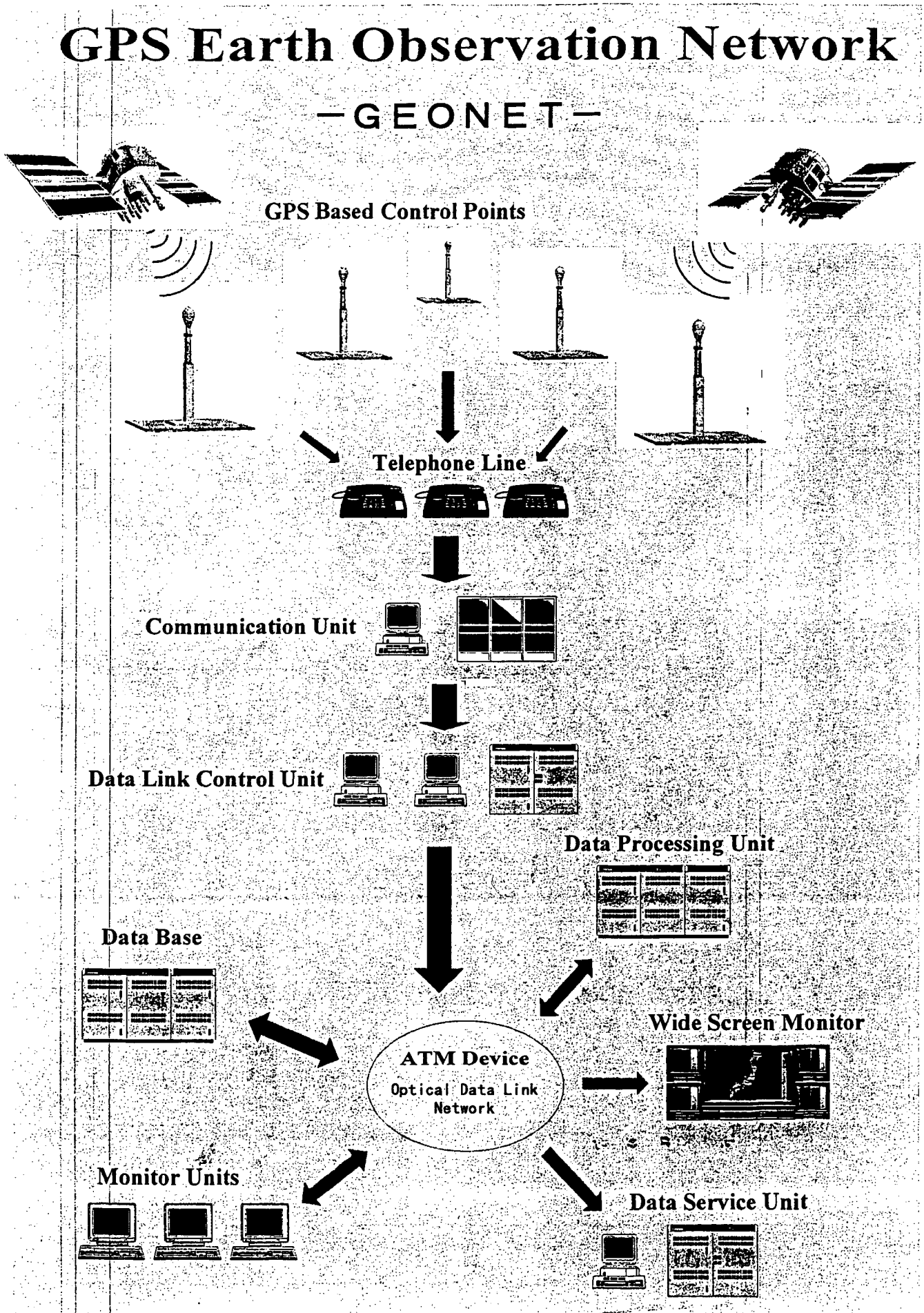


Figure 3. Components and data flow of GEONET

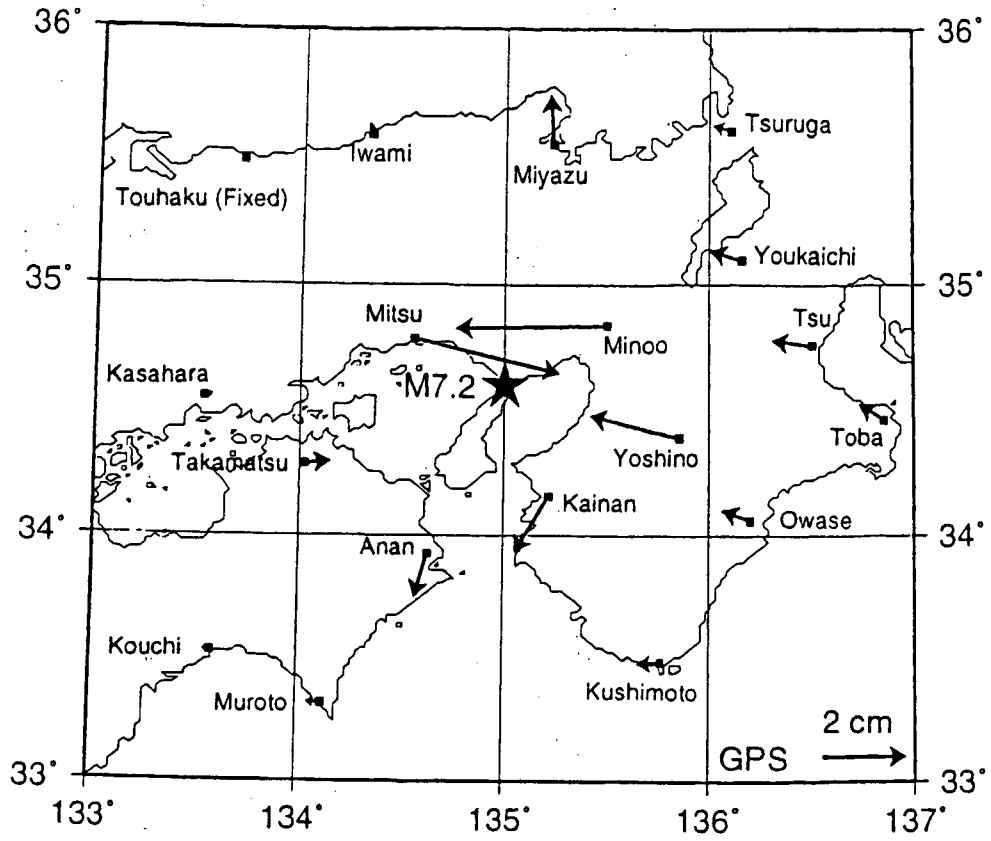


Figure 4. Horizontal displacement vector caused by Kyogo-ken Nanbu Earthquake (Jan. 17, 1995)

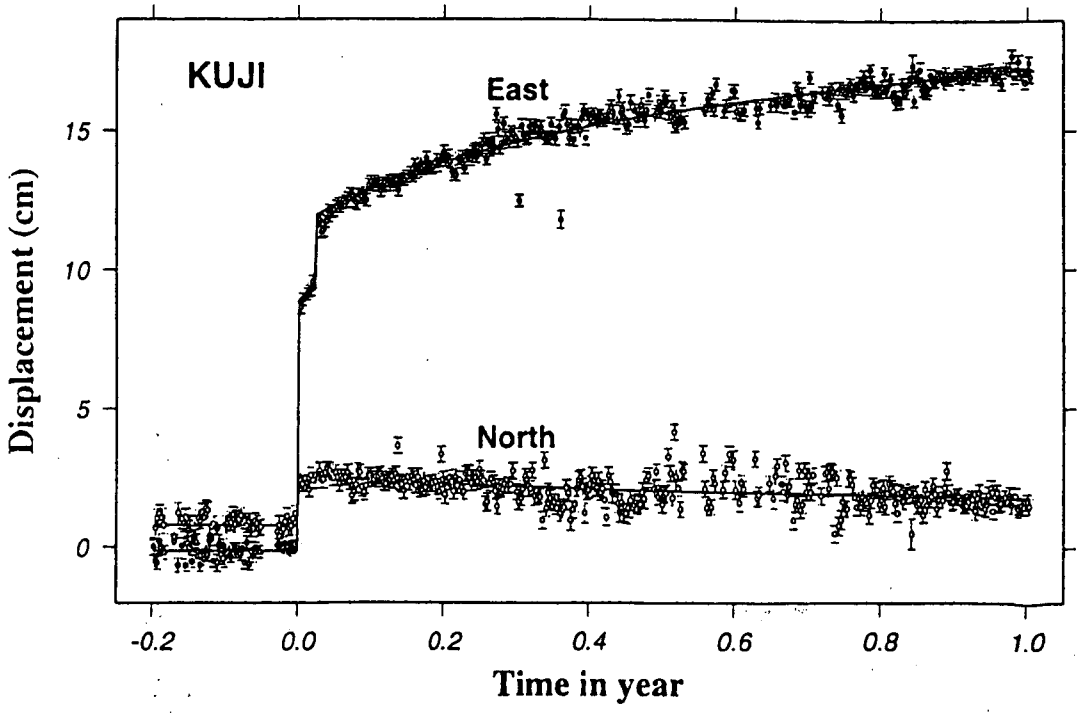
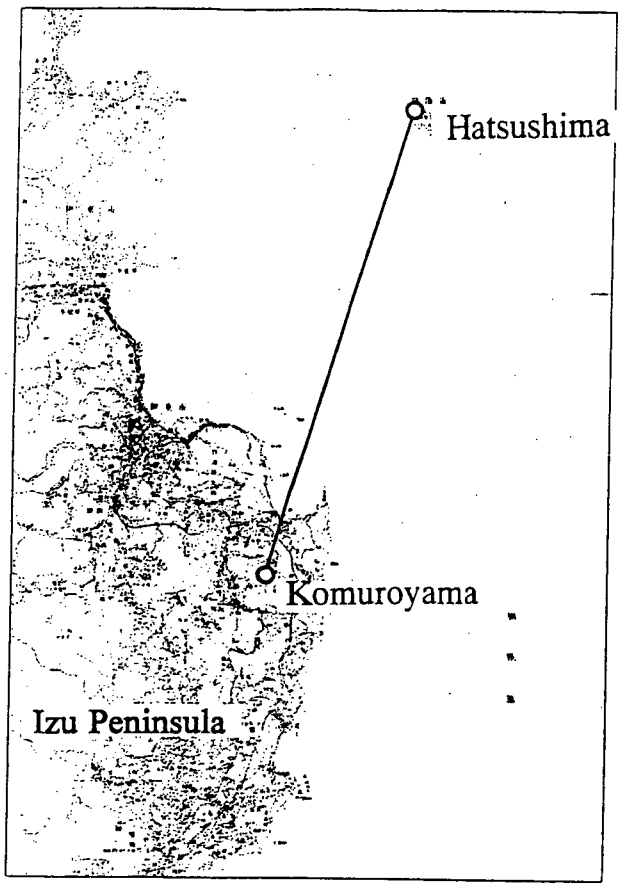


Figure 5. Long term post-seismic deformation following 1994 Sanriku Haruka Oki earthquake (after Heki et al., 1997)



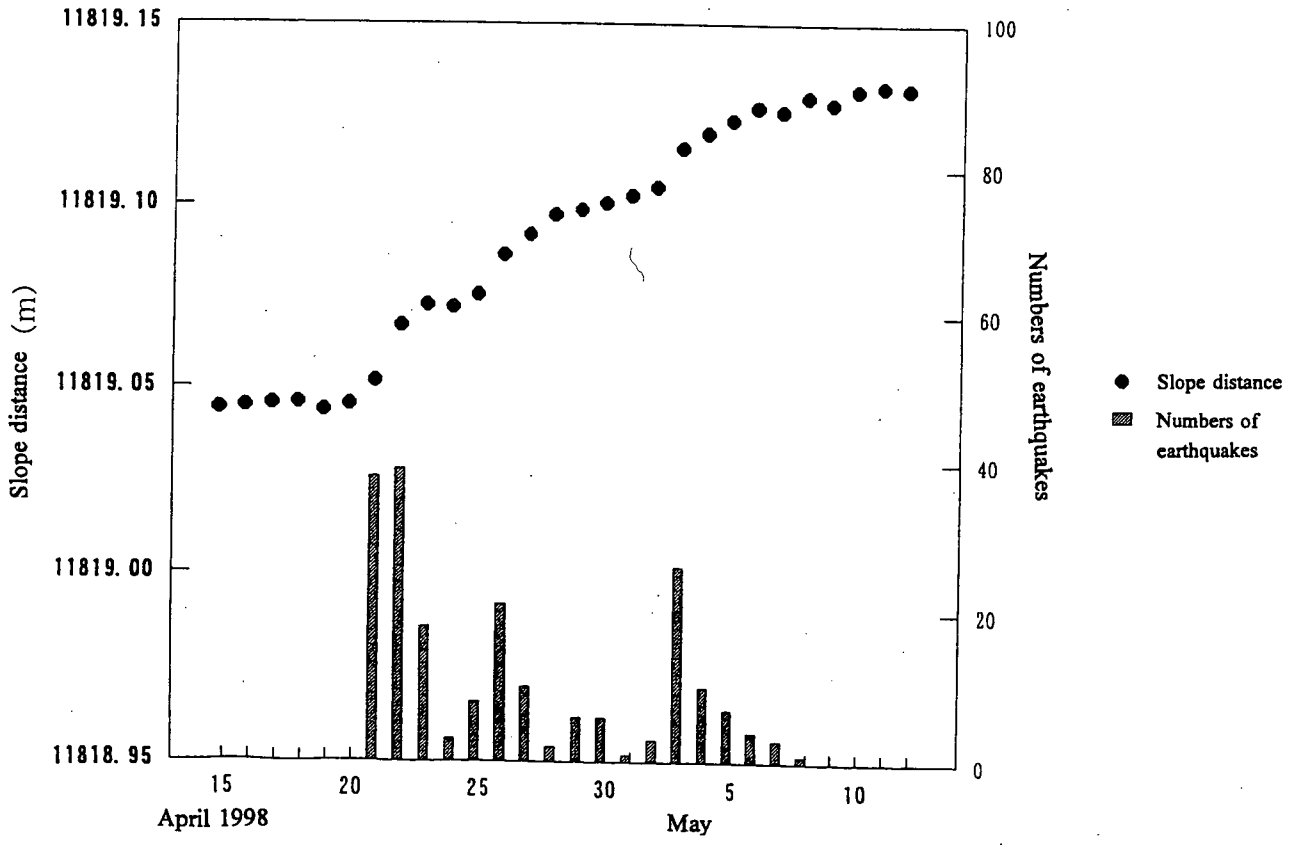


Figure 6. Relationship between seismic activity and crustal deformation in Eastern Izu Peninsula, the slope distance between Komuroyama to Hatsushima during the event from April to May, 1998

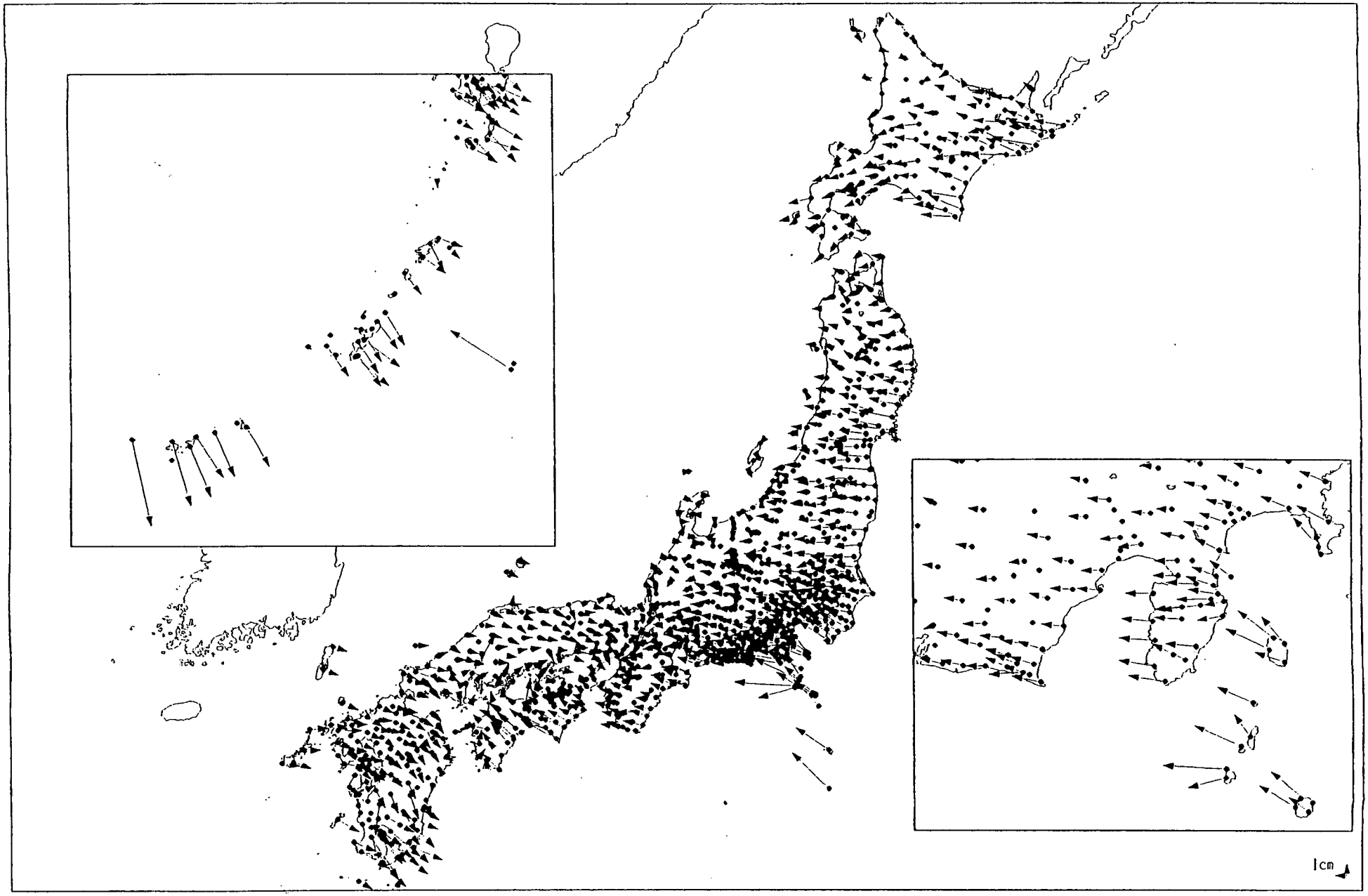


Figure 7. Horizontal displacement vector from July 1997 to July 1998 referred to Ohgata station

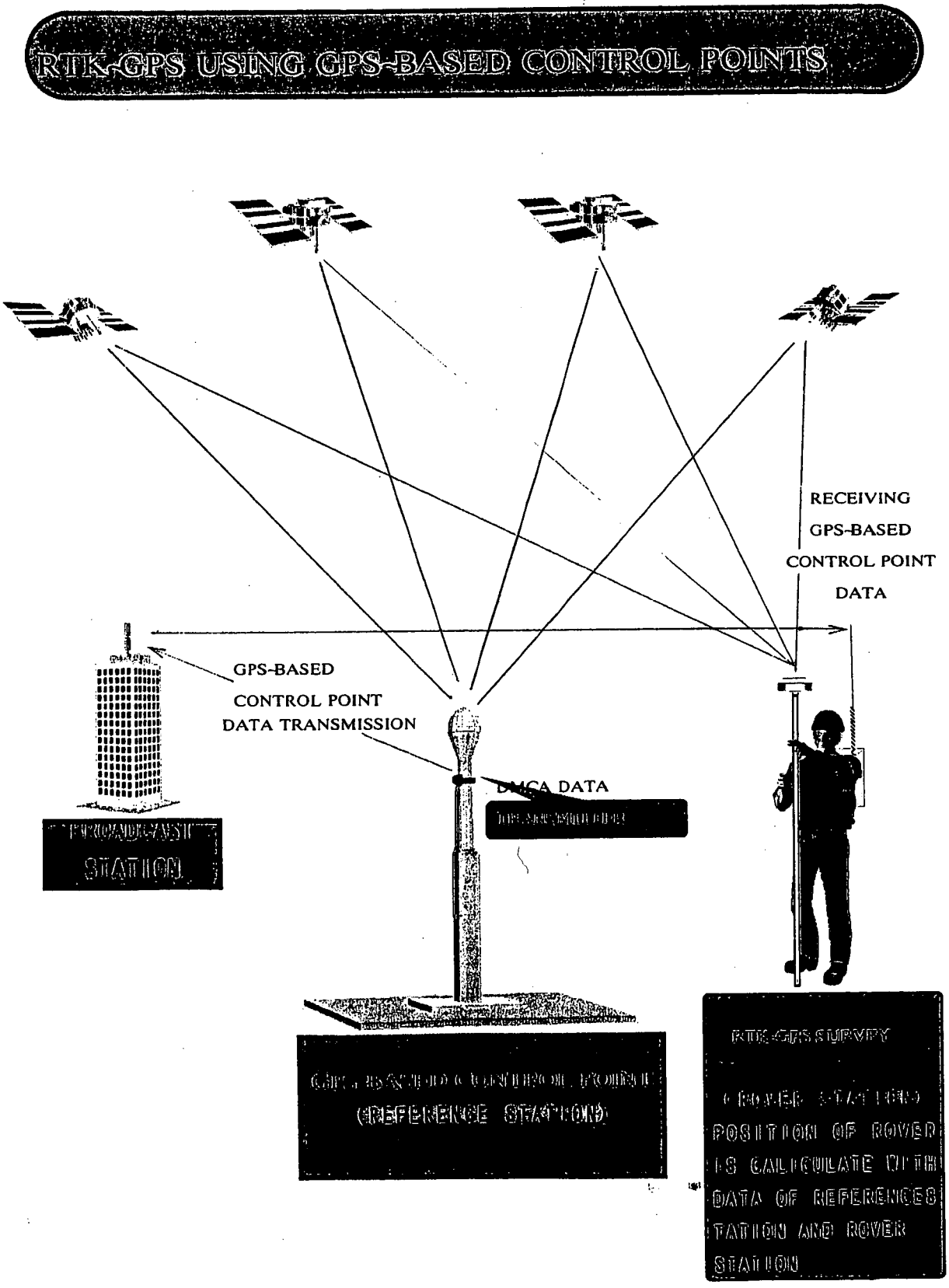


Figure 8. RTK-GPS with GPS-based control point and MCA radio communication

Session VII: Risk Management- Loss Estimation

- A Seismic Hazard Map for the Earthquake Resistant Design of Buildings, *Izuru Okawa* (BRI), Mitsumasa Midorikawa, Shin Koyama, Kazuo Dan, Masanobu Tohdo*
- Natural Hazards Exposure Mapping in the United States, *Stuart Nishenko (FEMA)*
- Seismic Countermeasures of Electric Power System on the Basis of Risk Management, *Yoshiharu Shumuta (Central Research Inst. of Electric Power)*
- American Lifelines Alliance- Reducing Risks to Utility and Transportation Systems from Natural Hazards, *William Savage (FEMA)*

A Seismic Hazard Map for the Earthquake Resistant Design of Buildings

OKAWA Izuru[1], MIDORIKAWA Mitsumasa[1], KOYAMA Shin[1], DAN Kazuo[2], TOHDO Masanobu [3]

ABSTRACT

The BRI proposal for the future design seismic force is described. In our recommendations, the design seismic force is firstly defined in acceleration response spectrum, although the base shear force is the fundamental property for current design practice in Japan. The basic design spectrum is defined at the engineering bedrock that lies in underground with shear wave velocity larger than approximately 400 m/s. The basic design spectra is modified with soil amplification coefficient to incorporate the dynamic property of surface ground. In addition, a coefficient is introduced to consider the difference of the seismic activity. Two classes of performance requirements are assigned in the new proposal, i.e., the human life safety and the damage limitation of the building which define the two levels of earthquake motions, the moderate and large earthquake ground motions. The return periods of the two motions are approximately 500 years and 50 years, respectively.

In this report, our attempt on the new seismic hazard maps corresponding to the levels mentioned above at the engineering bedrock.

KEY WORDS: Hazard Map, Return Period, Soil Conditions, Engineering Bedrock, and Soil Amplification

1. INTRODUCTION

It is said in Japan that earthquake occurs any locations nationwide. However, when earthquake source locations are closely examined, their occurrences vary with the locality and ground motion varies depending upon the earthquake magnitude, distance to the source and surface soil conditions. As a result, expected earthquake ground motions within a period differs for each locality. The difference in the expected ground motion amplitude is considered as seismic zoning coefficient in the current Japanese Building Code. Nearly 20 years has passed since the enforcement of the present building code. Several devastating earthquakes occurred for these years. The technology of predicting strong motions has advanced mainly due that many data became available including those recorded in the near-source.

2. DESIGN SEISMIC FORCE

In the current Japanese Building Standard Law, the difference in the earthquake load with respect to locality is considered with the seismic zoning coefficient. Earthquake forces for buildings are specified as follows. When building is simply modeled with multi-mass model as shown in Fig.1, the story shear force

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Q_i is specified in the current Japanese building code as,

$$Q_i = Z \cdot R_t \cdot A_i \cdot C_0 \cdot \sum_{j=i}^{n} w_j$$

where, Q_i: Shear force for i-th story

Z: Seismic zoning coefficient

R_t: Design spectral coefficient

A_i: Lateral shear distribution factor

C_0: Standard shear coefficient

w_j: Weight of the i-th story

Each member of building is designed with this earthquake load. The seismic zoning coefficient Z indicates the relative value of the expected ground motion amplitude at each jurisdiction from 0.7 to 1.0, regardless of the earthquake return period. The coefficient is shown in Fig.2

The map was made based on regional difference in ground motion values from several representative hazard maps proposed in Japan and with additional necessary engineering judgment. The map making process is shown in the reference [1]. The coefficient is determined when the locality is fixed. The design spectral coefficient Rt depends on the fundamental period of the building and the soil condition. A question will be raised that the proportion of the frequency content, i.e., spectral shape, differs according to the locality even when the soil condition may be identical. This is partly because the attenuation property varies between short period component and longer period component.

This means that the difference between localities varies with the period. However, this difference can not be incorporated in the current zoning coefficient specified in the BSL.

3. SEISMIC HAZARD MAP

A seismic hazard map is generally made based on the data regarding location of past earthquake occurrence, its earthquake magnitude, and its occurrence time. However, the occurrences of the earthquakes are so uncertain that our second choice is that we assume the occurrence pattern of the earthquake in the past repeats itself in near future. And we will estimate the expected values of earthquake motions with in the specified period, and draw the distribution maps as earthquake hazard map.

It is important to mention here that the seismic force is represented with story shear force that directly results in structural response to earthquake motion, and is not identical to the response spectrum of the base input motion. We need to correlate the base shear coefficient with the spectral value of the corresponding design motion. A research using the uniform shear beams with SRSS combination for maximum response estimation says that the spectral values are 10 to 20% larger than those corresponding to the assigned base shear coefficient. [2]

3.1 DESIGN EARTHQUAKE MOTION

The design ground motion is firstly defined to give design seismic force in the next step. The design

seismic force currently in use specifies the story shear force without apparent prescription of the corresponding design ground motion. Therefore, this method is so correct to pursue the design procedure. However, an inconsistency arises that the derived earthquake ground motions are not equal even within the class, since the design force is derived from the response values of the building itself and the design force is prescribed uniformly with a class of buildings.
Considering these thoughts, in order to give seismic design force applicable for any buildings, we reached the conclusion that the seismic design should start with the defining the input earthquake ground motion. This also coincides with the idea of performance-based structural design method advocating more flexible application.

3.2 ATTEMPT FOR MAKING HAZARD MAP

The ground motion is represented with its acceleration response spectrum. The basic ground motion is firstly defined at the engineering bedrock corresponding to the seismicity of the area.
The engineering bedrock is defined herein as follows.
The engineering bedrock is defined as soil layer commonly and widely underlain within the area concerned. The mechanical properties of soils overlying the engineering bedrock are obtained by soil. The properties will have much variation for softer surface ground, and will have fewer records for harder underground. This will validate the use of the engineering bedrock for design as compromise of both ends. We define this upper face of the soil layer engineering bedrock. This definition of engineering bedrock gives the idea of layers with shear velocity larger than approx. 400m/s.
The amplification characteristics of the surface soil layers are to be evaluated with the geological data of the site. The design earthquake ground motion is herein represented in the following equation.

$$S_A(T) = Z \cdot G_s(T) \cdot S_0(T)$$

Where, $S_A(T)$: Design earthquake ground motion
$G_s(T)$: Amplification of surface soil
Z: Regional seismicity coefficient
$S_0(T)$: Basic spectrum at exposed engineering bedrock
T: Period in second

The basic spectrum is set up to be very basic. It consists of two parts, i.e., a uniform acceleration portion in shorter periods, and a uniform velocity portion in longer periods. The two intensities of uniform levels are determined with expected peak values and response factors for acceleration and velocity.
The intensity level of the design motion is based on the design force for the intermediate soil class specified in the current Building Standard Law of Japan.
In addition, the relationship between the story shear force and the input motion is also taken into consideration. The resultant design ground motion for the life safety is defined as 0.8G for the 5% damping acceleration response spectrum and as 80cm/s for the 5% damping velocity response spectrum at the exposed engineering bedrock. For the periods shorter than 1/4 of the intersection of the uniform

acceleration and the velocity, the spectral values are de-amplified so that the acceleration amplitude at zero period equals to the peak acceleration of the input motion. The peak acceleration is set to 1/2.5 of the uniform acceleration level.
The design spectrum thus defined is shown in Fig.3.

4. THE REGIONAL SEISMICITY COEFFICIENT

The research on the seismic hazard map on which the coefficient is based has been continued from the pioneering work by Dr. Kawasumi[3]. The advances in the prediction methodology of strong ground motion with the collection of strong motion records for near source region in these decades have become a thrust to upgrade the site-specific design earthquake motions.
The regional seismicity coefficient is evaluated as relative factors representing the difference in the expected ground motion parameters such as peak ground acceleration or peak ground velocity with regions for both of large and intermediate earthquake motions. In addition, since the frequency content presumably differs in the expected values, the coefficients are to be defined with separately for acceleration and velocity, respectively. Therefore, as results, the four types of coefficients are proposed reflecting the intensity levels and the frequency contents.
To prepare the regional maps, the following two ground motion levels are defined,
Large earthquake motion is represented by the largest annual maximum in 500 years
Intermediate earthquake motion is represented with the 10^{th} largest annual maximum in 500 years
The data used in this study are as follows. (See Fig.4)
(1) Earthquakes occurring during 1496-1984 selected from the Usami's Engineering Catalogue
(2) Earthquake data issued from the Japan Meteorological Agency (JMA) during 1985-1995
(3) Fault parameters which have been proposed for major past earthquakes
This is for take the dimension of the epicentral area into account.
The following two empirical formulae (attenuation formulae) was used to estimate the peak amplitudes for the earthquakes. These formulae are applicable to the near source area such as Kobe during the 1995 Hyogo-ken Nambu Earthquake [6]

(1) Peak Ground Acceleration (A) for the diluvial soil class, [4]

$$\log A = 0.51M - \log[R + 0.006 \cdot 10^{0.51M}] - 0.0033 + 0.59$$

(2) Peak Ground Velocity (V) for the engineering bedrock level, [5]

$$\log V = -0.22M^2 + 3.94M - \log[R + 0.01 \cdot 10^{0.43M}] - 0.002R - 11.9 - 0.71 \cdot \log Vs$$

Using these formulae, the expected peak values for each location were calculated. Regional maps were drawn based on the computed vales normalized by 0.32G and 40cm/s for large earthquake motion, and 0.064G and 8cm/s for intermediate earthquake motion, respectively. The maps are shown in Fig.5 through Fir.8. It is seen form the maps that larger expected values are found corresponding the epicentral locations of bigger earthquakes. For large earthquake motions, most locations shows the ratio below 2.5 in comparison with the previously mentioned engineering bedrock intensity levels for acceleration, and below 2.5 for velocity levels. The expected intensity levels estimated with the data in 500 years are

comparable with or slightly larger than the level of seismic force currently in use for the second class of soil condition.

5. CONCLUSION

The maps shown herein is one example of evaluation using the sets of proposed empirical formulae and generally available data. Therefore, a more extensive study including applying other methodologies or referring other proposals will be necessary to establish the regional seismicity coefficient maps to be specified in the building code or provisions.

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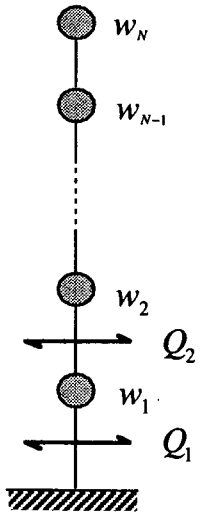


Fig.1 N-story model and story shear force

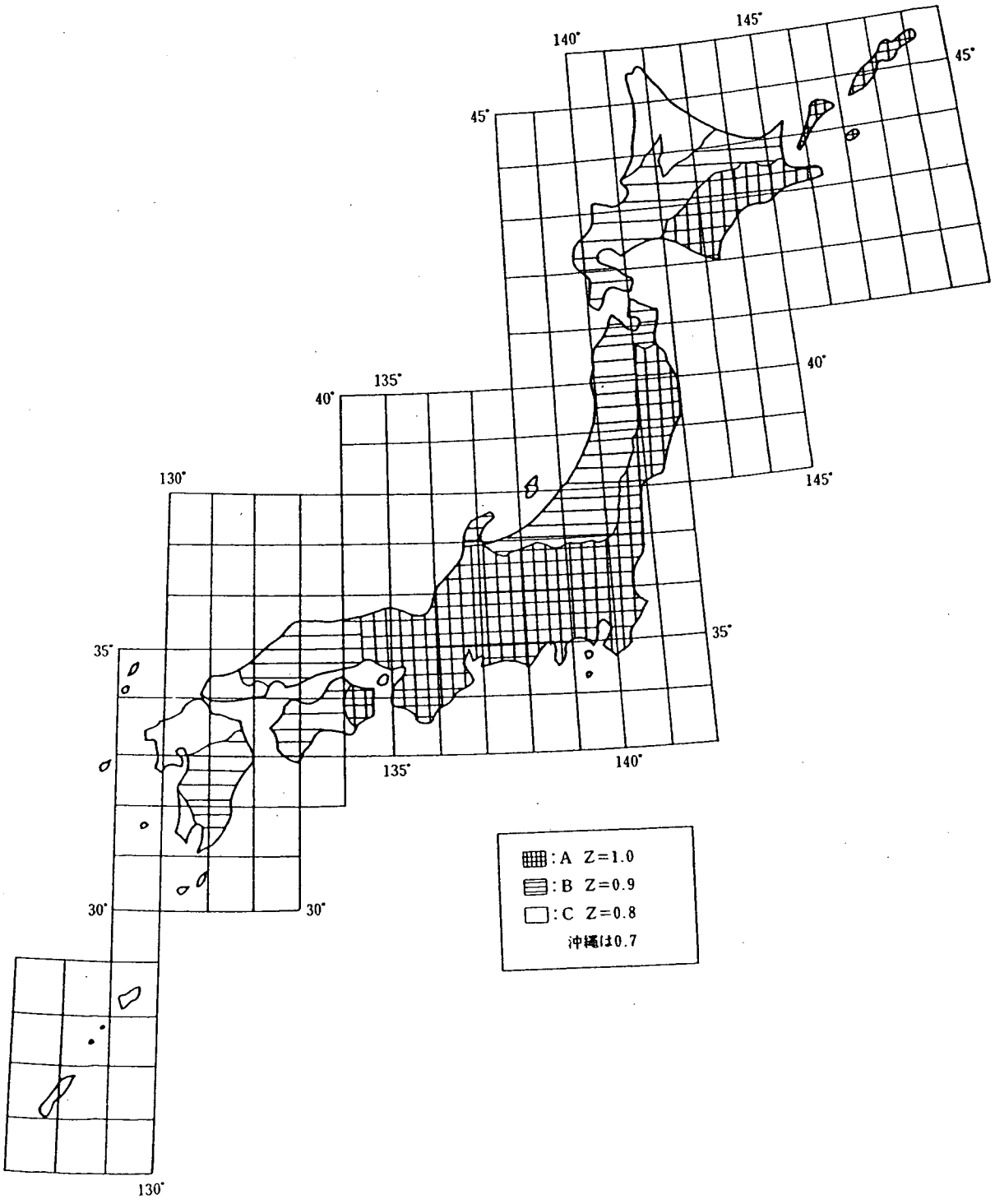


Fig.2 Seismic zoning coefficient in the current Japanese code

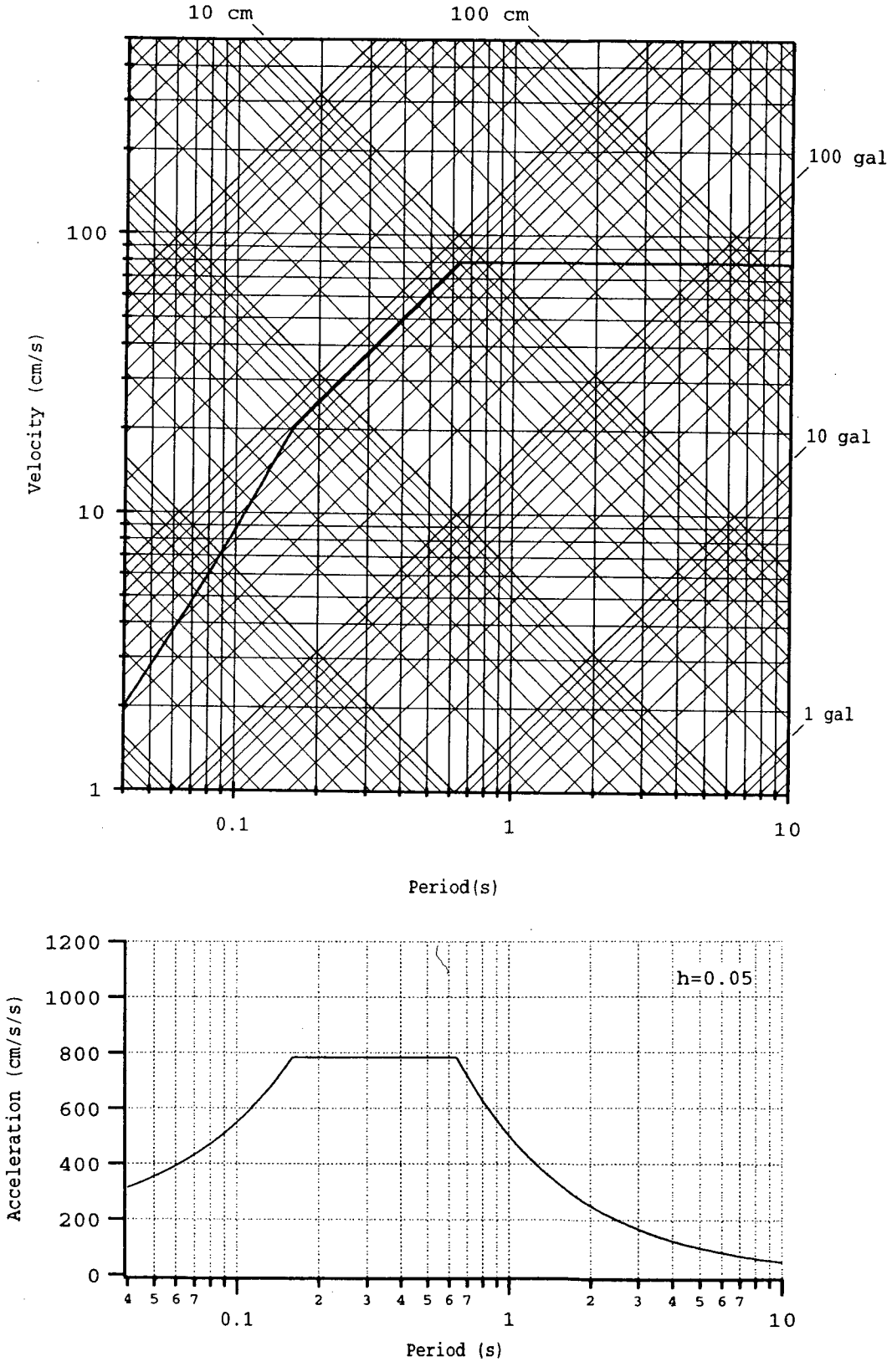
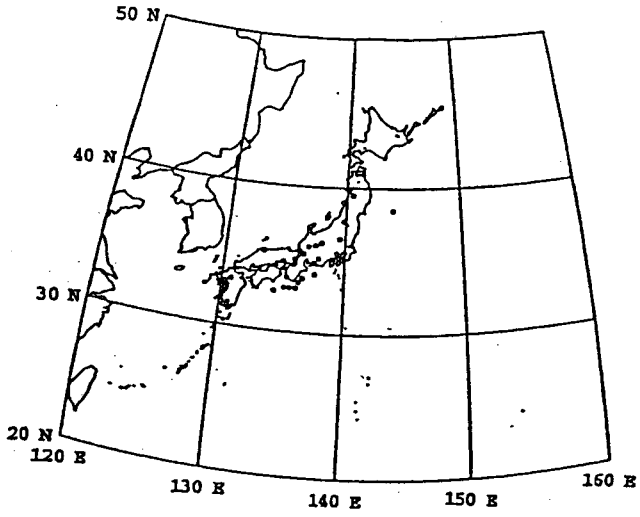
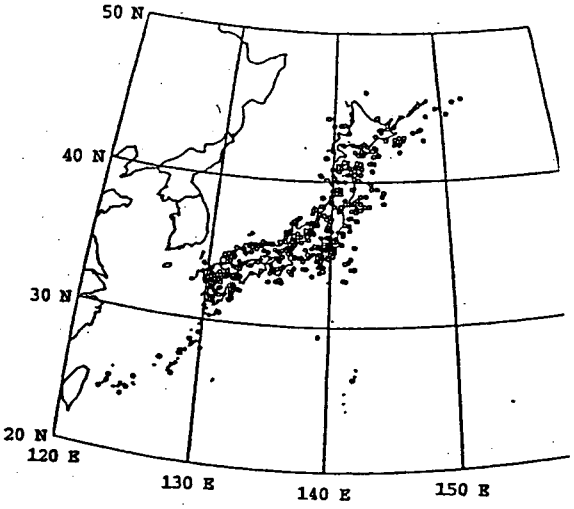


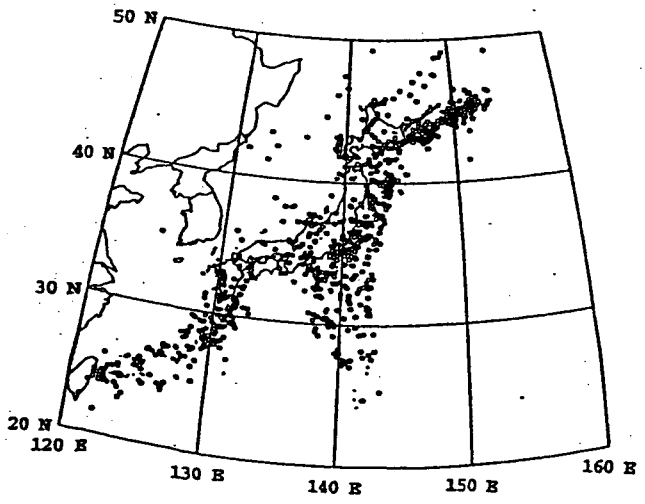
Fig.3 Design Ground Motion at Engineering Bedrock



679年~1494年（41地震）



1498年~1984年（534地震）



1985年~1995年（1234地震）

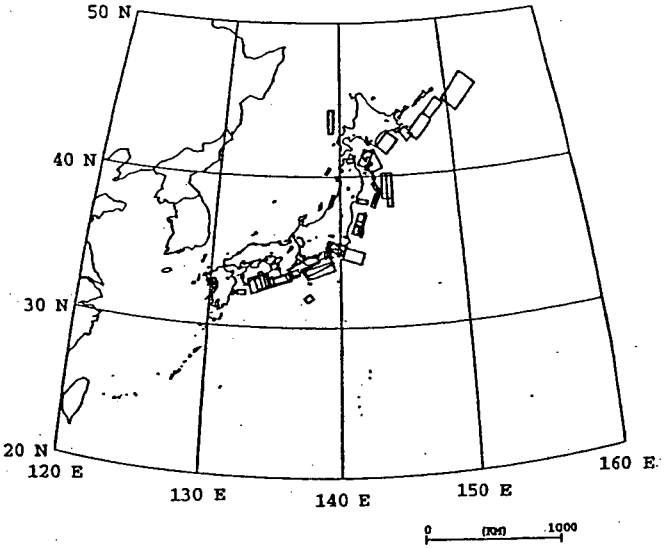


Fig.4 Earthquake Data used in this study

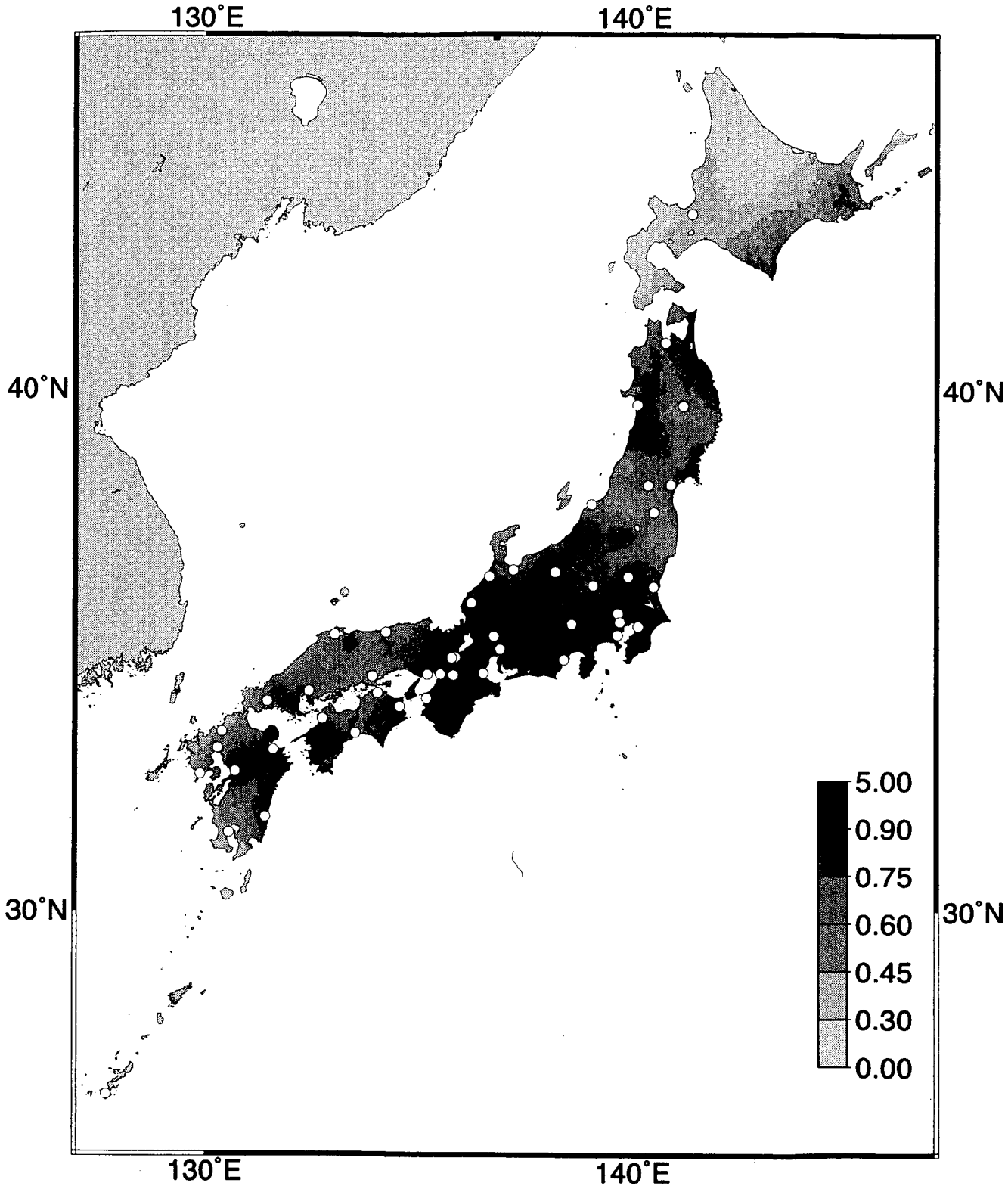


Fig.5 A Regional Seismicity Coefficient for Acceleration of Intermediate Earthquake Motions (Values normalized by 0.064G)

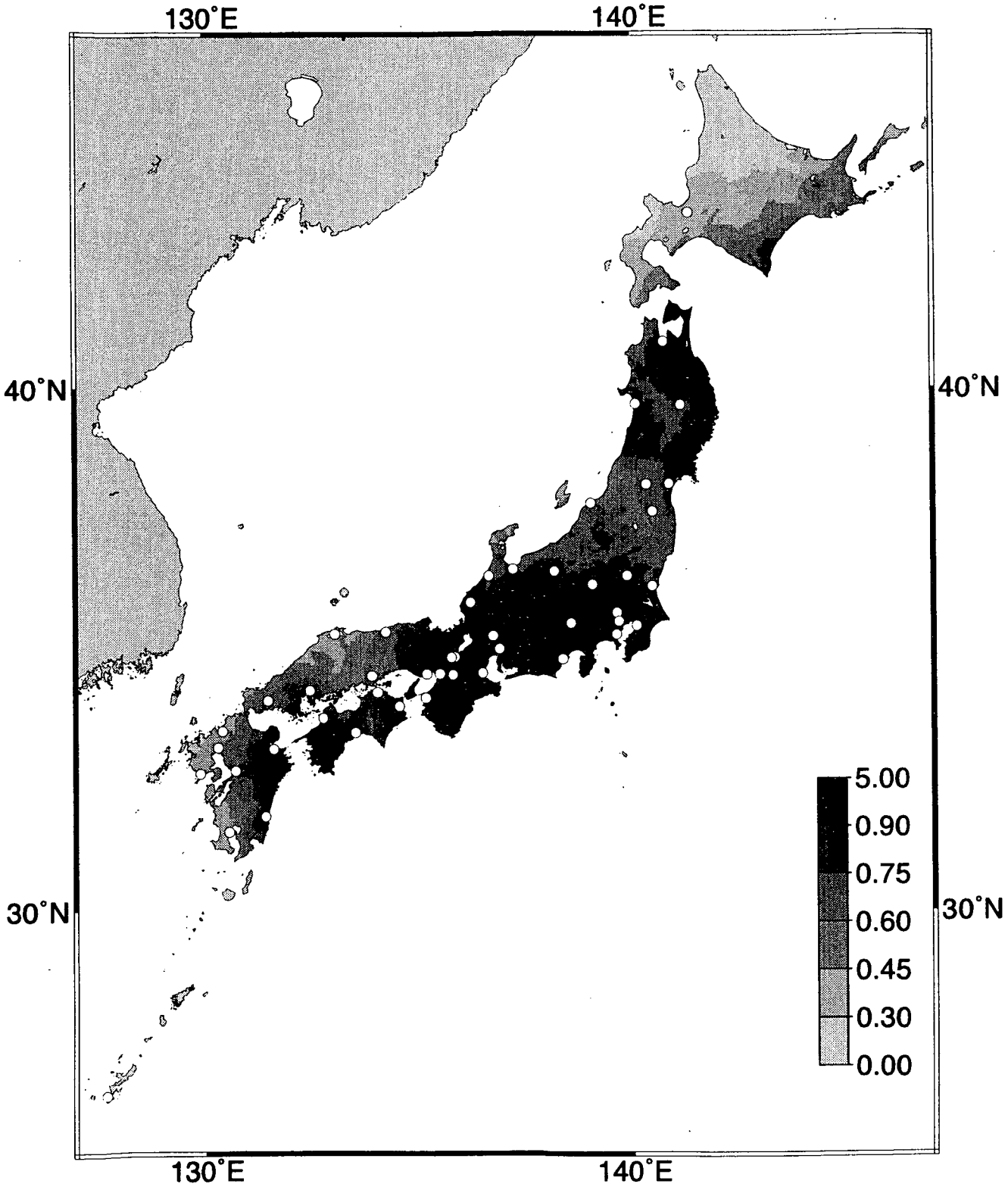


Fig.6 A Regional Seismicity Coefficient for Velocity of Intermediate Earthquake Motions (Values normalized by 8 cm/s)

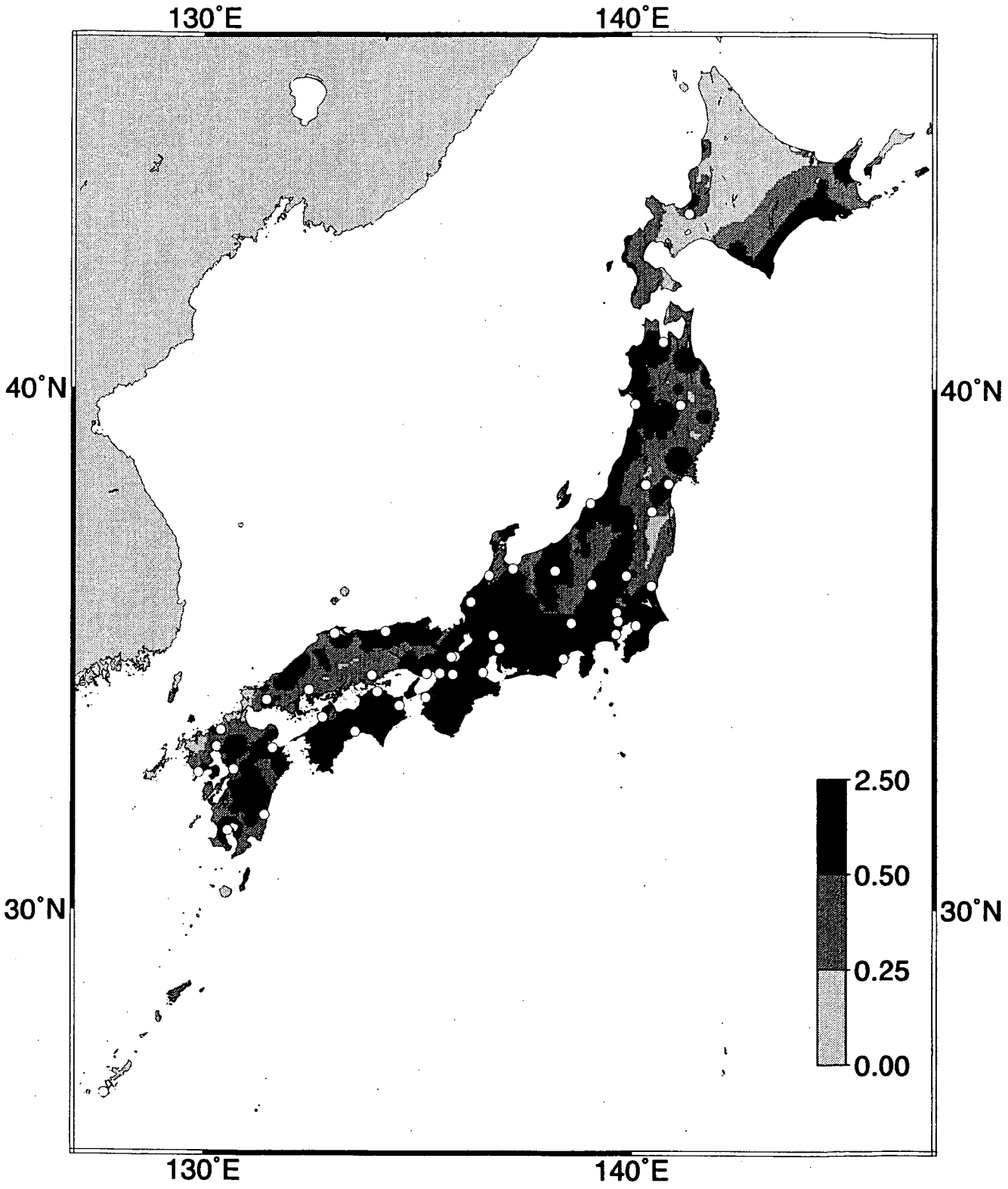


Fig.7 A Regional Seismicity Coefficient for Acceleration of Large Earthquake Motions (Values normalized by 0.32G)

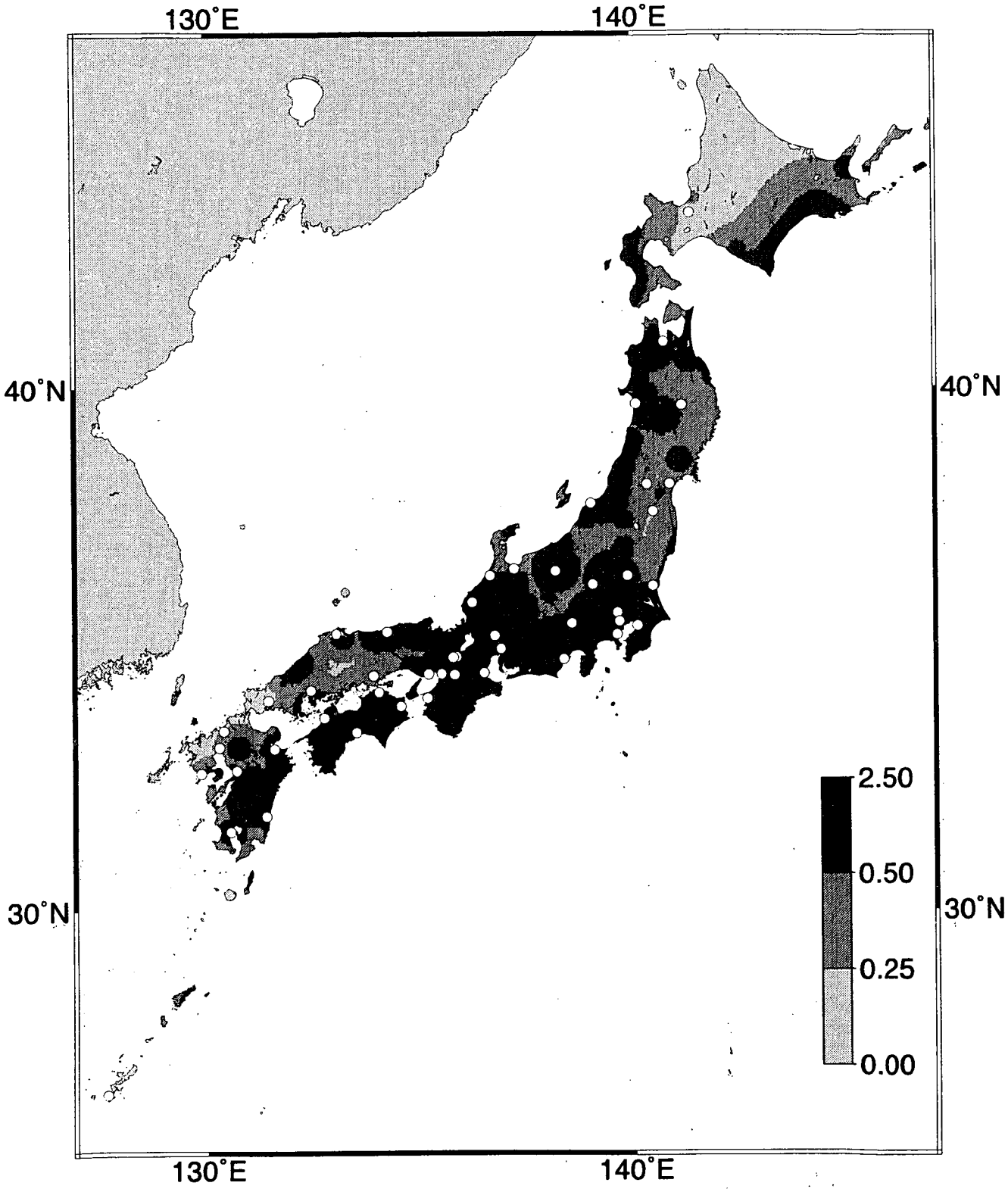


Fig.8 A Regional Seismicity Coefficient for Velocity of Large Earthquake Motions (Values normalized by 40 cm/s)

Natural Hazards Exposure Mapping in the United States

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UJNR Workshop on Seismic Information Systems
Tsukuba, Japan
November 15-17, 1999

Introduction

In the past, much of the research on natural disasters was based on developing an understanding of the *hazard* – the location, size, and frequency of earthquakes, floods, hurricanes, tornadoes, etc. - instead of the *risk*, which is a product of the hazard, the population and building exposure, and the vulnerability. Policy, land use, and development decisions at the Federal, state, and local level are risk-based decisions and need appropriate inputs. Areas at high risk may not always be coincident with areas of high hazard.

Detailed information about natural hazards is available for different regions of the United States through the efforts of various Federal agencies such as the Departments of Agriculture, Commerce, and Interior including the US Geological Survey, the National Weather Service, the Army Corps of Engineers, the National Flood Insurance Program, the National Science Foundation, and professional organizations such as the American Society of Civil Engineers. There are few corresponding risk maps, however, that could be used for risk-based planning and mitigation. Most of the general understanding about risk is restricted to property damage, insured losses, and casualties related to specific scenario events or regional probabilistic loss studies (NRC, 1989; NIBS, 1994). For example, until recently, there was no nationally consistent earthquake loss estimation methodology for the United States. Without such standardized technologies, it is infeasible to compare levels of damage or losses between regions or between hazards.

In support of the National Mitigation Strategy, FEMA has developed a standardized earthquake loss estimation methodology, HAZUS (Hazards United States) that uses a nationally consistent hazard, vulnerability, and inventory database to estimate earthquake losses throughout the United States. Similar models for flood and wind loss are currently under development. HAZUS is intended to provide local, state, and regional emergency management officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and other natural disasters and to prepare for emergency response and recovery following the events.

Since HAZUS contains as nationally consistent building inventory, it provides an ideal platform to assess and compare hazards exposure across multiple regions throughout the United States. The analysis summarized in this study consists of overlaying a series of nationally consistent hazards maps (coastal wind, riverine and coastal flooding, and earthquake ground motions) onto the HAZUS inventory of residential and non-residential buildings and population. The exposure to each hazard, at some threshold value, is presented in terms of the total cost or replacement value for residential and non-residential buildings and a per capita estimate. Both the magnitude of the exposure as well as the location of that exposure are used to develop a national exposure index.

In this analysis, the exposure to the 100 year or 1% annual flood, coastal wind or earthquake event represents approximately $3 trillion or 25% of the total replacement value for the national building stock and is comparable for each event type (i.e. exposure to wind, earthquake and flooding are approximately $1 trillion). Geographically, however, these exposures are quite diverse. Hurricane wind exposure is spread along the Atlantic and Gulf coasts, flood exposure 'uniformly' distributed across the nation, and earthquake exposure is primarily concentrated in the state of California. Exposure to the 500 year or 0.2% annual flood, wind, and earthquake events represents approximately $6.6 trillion or 50% of the building inventory replacement value and is dominated by hurricane wind events.

Hazards Characterization

This study considered three hazards for analysis: earthquake, riverine and coastal flooding and hurricane winds. While there are many more hazards to consider (e.g. FEMA, 1997), these three hazards were chosen for this analysis because:

- They represent the major causes of damage in the United States
- National consensus definitions of the hazard, in a probabilistic framework, are available
- Mapped hazard frequencies are compatible (all maps based on 100 and 500 year events, or 1% and 0.2% annual chance events).

Flood

Flood hazard maps are taken from countywide Q3 program data, distributed by FEMA as part of the National Flood Insurance Program and available as supplemental data in HAZUS. These digital maps (see Figure 1) show the areal extent of the 100 year and 500 year (1% and 0.2% annual frequency) riverine and coastal flood event and are available for 1200 of the 3000 counties that comprise the United States. These 1200 counties contain approximately 75% of the population and the majority of major flooding sources

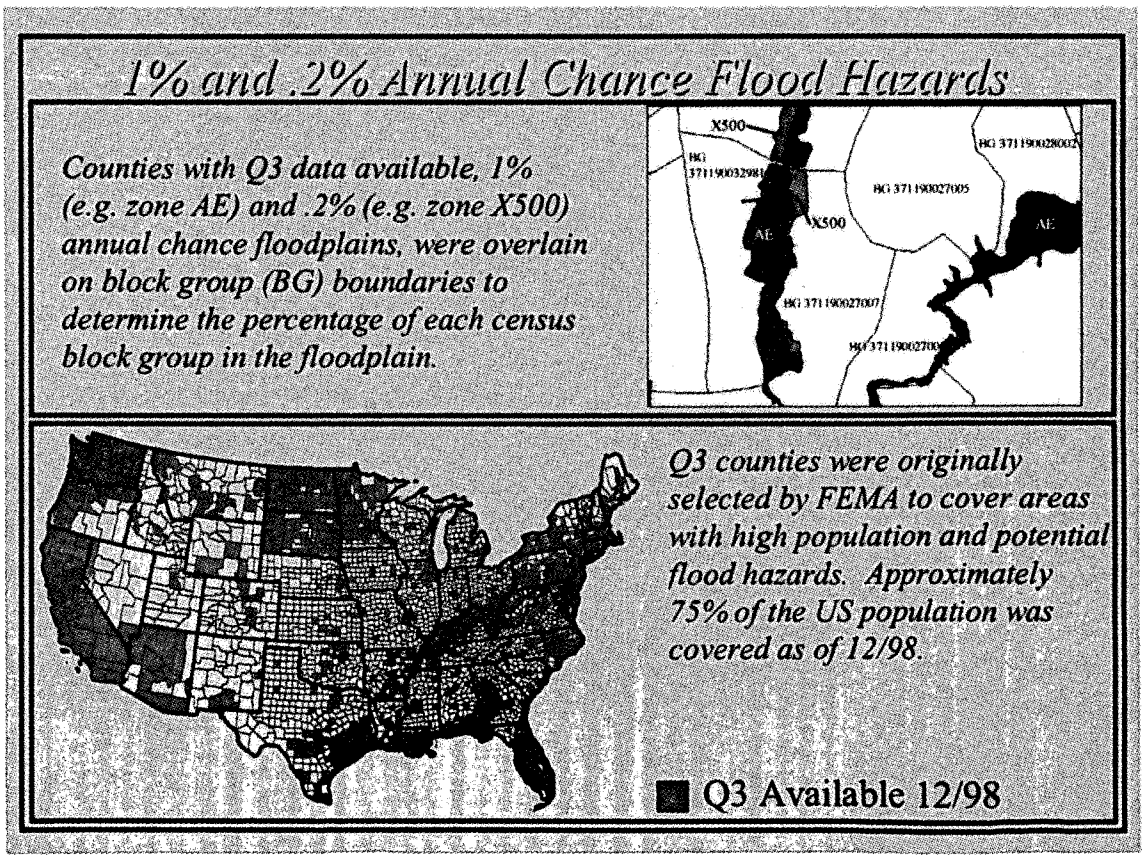


Figure 1. Distribution of counties in the United States with digital, Q3, flood maps.

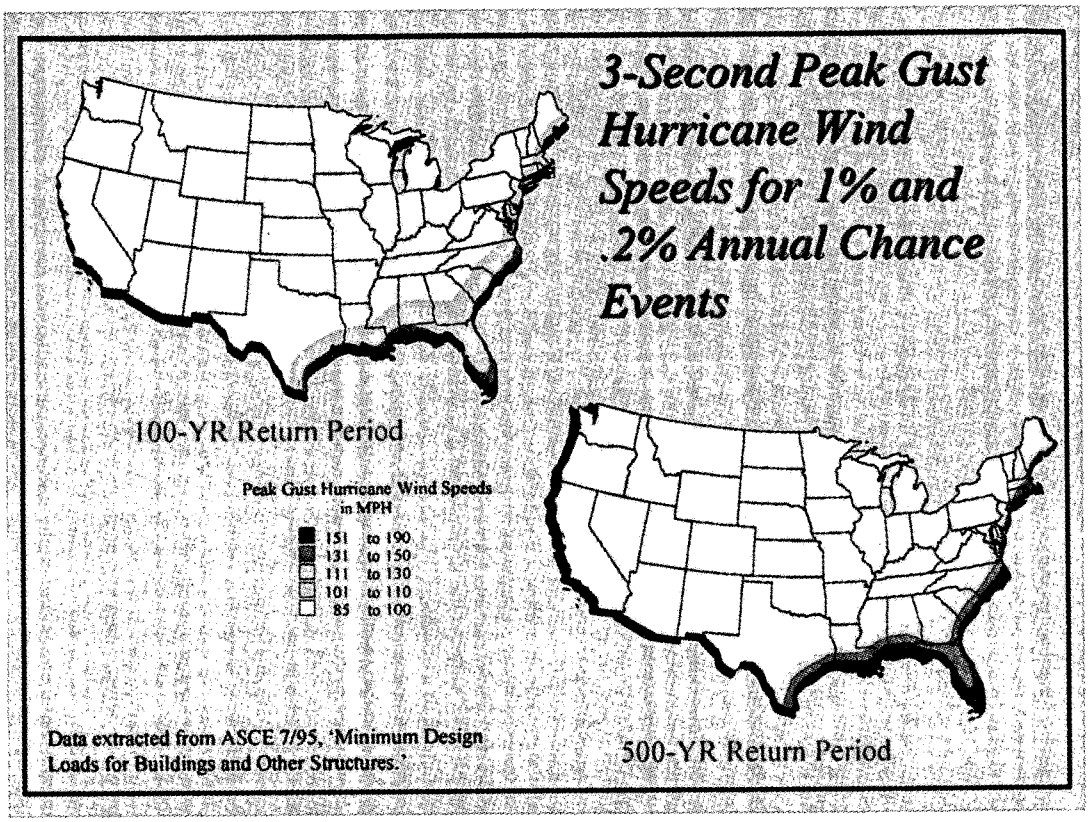


Figure 2. Distribution of 100 and 500 year peak gust hurricane winds along the Atlantic and Gulf coast coastal (based on ASCE, 1996, 1998).

Hurricane Winds

Hurricane wind hazard maps are based on the 100 and 500 year wind speed maps developed by Applied Research Associates and published in ASCE 7-95 and 7-98 (ASCE, 1996. 1998). These maps show isolines, in miles per hour, for 3-second peak gust winds along the Atlantic and Gulf coasts of the United States (see Figure 2). Wind speeds greater than or equal to 120 mph, which represents the threshold for significant wind related damage from hurricanes along the Atlantic and Gulf coast, are used as the exposure threshold in this study. At the local and regional level, orographic effects, local terrain, 'special wind zones' in ASCE 7-98, and vegetation and roughness effects need to be considered for more detailed loss estimates.

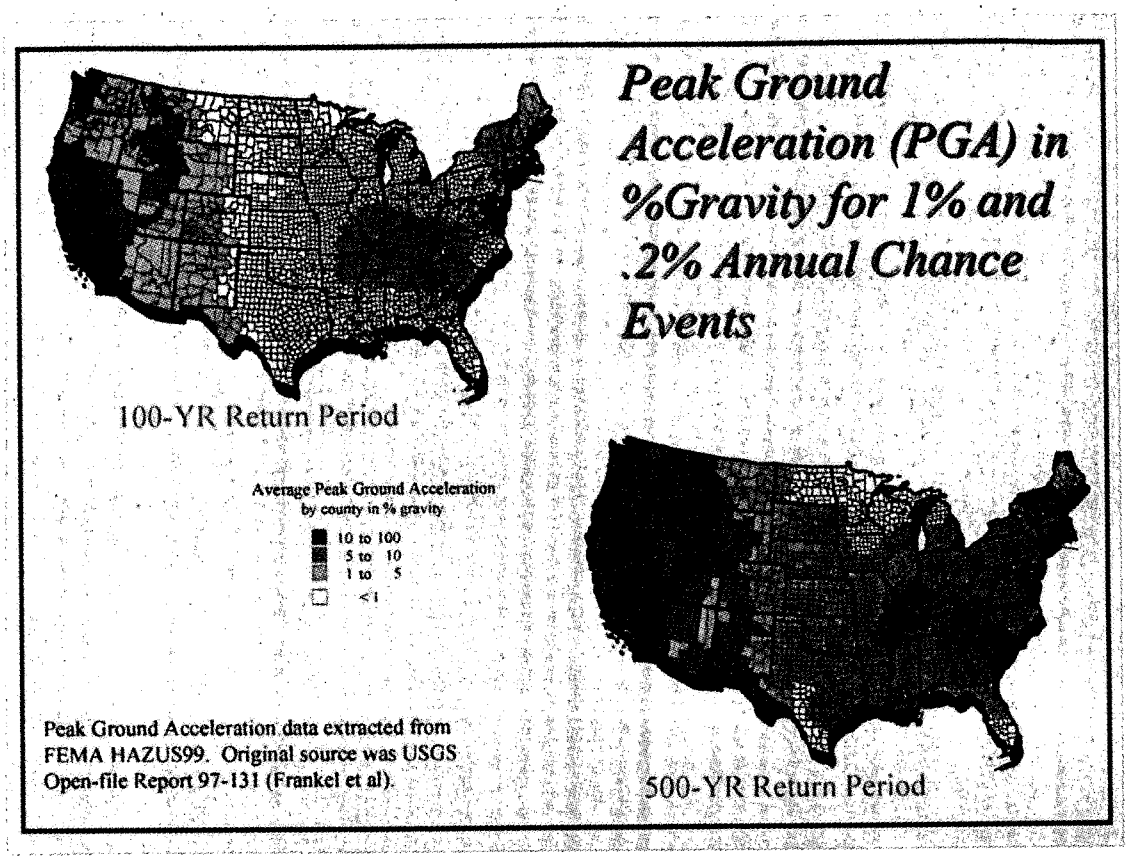


Figure 3. Earthquake ground motions in the United States (after Frankel, 1996)

Earthquake Ground Motions

Earthquake strong ground motion maps from the US Geological Survey (Frankel et al., 1996) provide estimates of the peak acceleration (in percentage of gravity, g) due to strong ground shaking at annual frequencies of 1% and 0.2% (100 and 500 year events). Accelerations are mapped for default rock (NEHRP 'B') site conditions nationwide. These data were gridded at the census tract level, taking an average value at the center of each census tract and then aggregated to the county level (see Figure 3). The threshold acceleration chosen for this analysis was 20% g, which represents the onset of very strong ground shaking and moderate structural damage to buildings (Modified Mercalli Intensity VII).

Exposure Characterization

Total Exposure (TE) for a county or state, as defined in this study, is an estimate of the total replacement cost for residential and nonresidential building structures. Total exposure is determined by multiplying the total building square footage in a census tract by a square footage replacement cost and a regional cost modifier. See equation 1. This value is

$$TE = SF*RC*CM \qquad [1]$$

Square Footage (SF) data for a census tract was taken directly from the national HAZUS database. Data on residential structures is based on 1990 US Census data (US Bureau of Census, 1992) and nonresidential structures are from Dun and Bradstreet (1995). While building types are classified according to occupancy type, details on the size and construction characteristics of individual structures are not included. Replacement Costs (RC) per square foot are based on Means Square Foot Costs for Residential, Commercial, Industrial and Institutional Buildings (R S Means 1994). Regional Cost Modifiers (CM) are based on indices published in Means (1994). These replacement estimates only address the structural and non-structural components and do not include contents, and inventory. Per capita measures of Total Exposure were also calculated using state population figures.

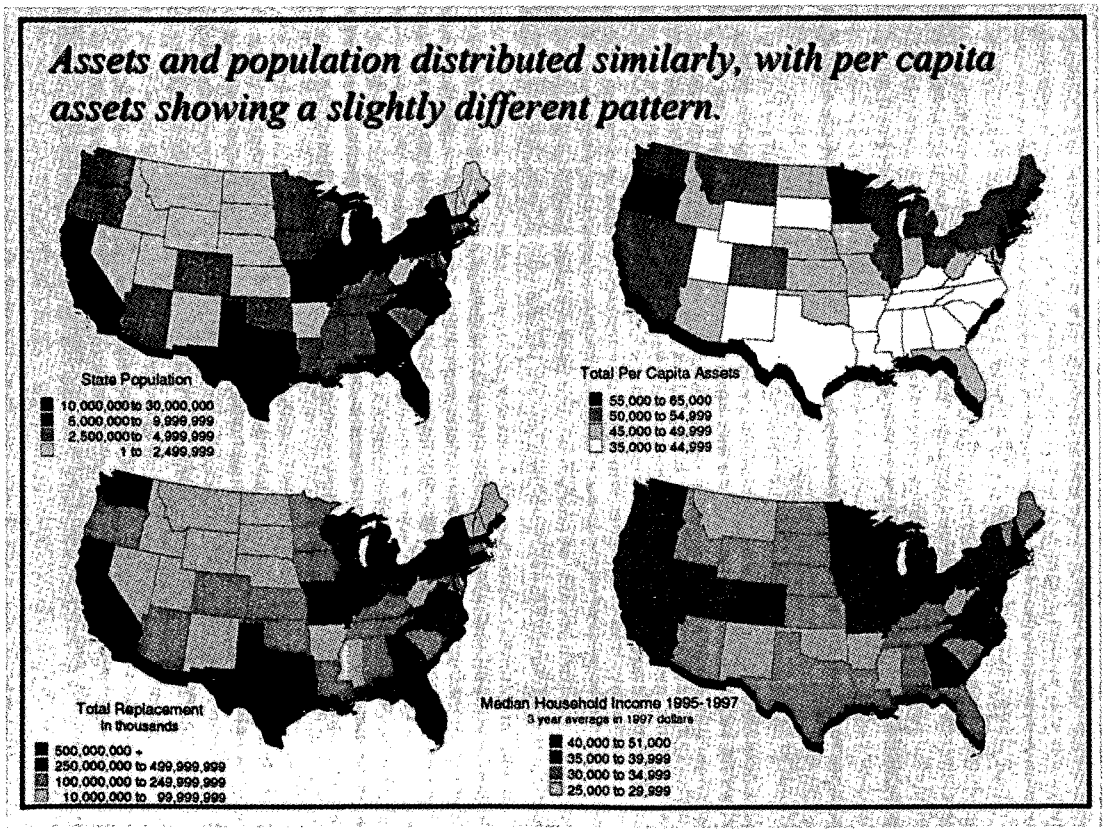
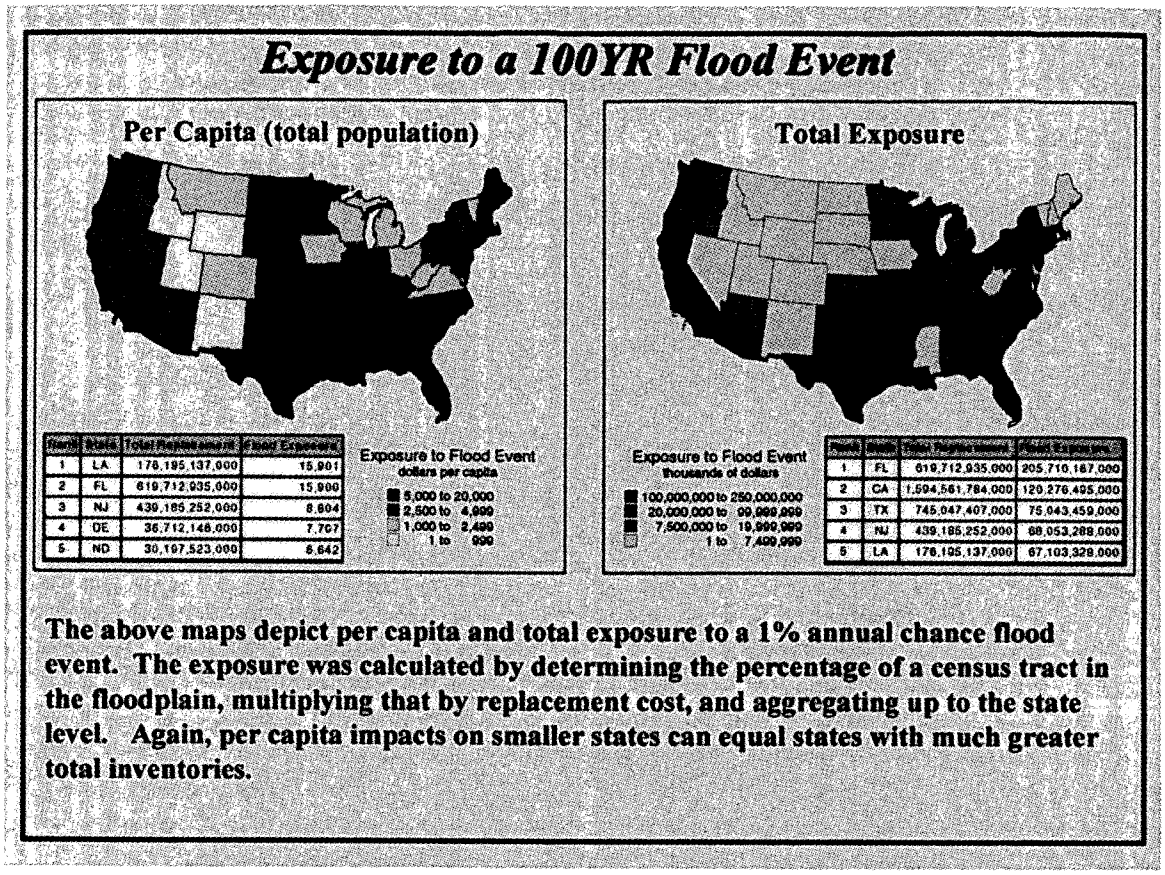


Figure 4. Summary of population, building inventory replacement value, per capita assets and median household income by state.



1	LA	176,195,137,000	15,901
2	FL	619,712,935,000	15,990
3	NJ	439,185,252,000	8,604
4	DE	36,712,148,000	7,767
5	ND	30,197,523,000	5,642

1	FL	619,712,935,000	205,710,187,000
2	CA	1,594,561,784,000	120,276,495,000
3	TX	745,047,407,000	75,043,459,000
4	NJ	439,185,252,000	68,053,288,000
5	LA	176,195,137,000	67,103,328,000

Figure 5. Per capita and total exposure to 100 year flooding at the state level.

Flood Exposure

Exposure to the 1% and 0.2% annual flood event was determined by using an overlay function in the GIS analysis and overlaying block group boundaries with the Q3 flood boundary data to determine the percentage of each block group that fell within a particular flood zone. Q3 data are at a scale that allows analysis at the census block group level. This percentage was then multiplied by the Total Exposure for that block group to determine the extent of flood exposure for the block group. Buildings were assumed to be uniformly distributed within the block group. These results were then aggregated to the census tract, county and state levels for comparison in Figure 5. Figure 5 shows thematic maps of total exposure and per capita exposure by state as well as a ranked list of the top five states and the dollar amount of the exposure for the 100 year event. Note this analysis only considered the areal extent/exposure of flooding and was not able to determine the depth of 100 and 500 year flooding on a national scale. Depths of flooding and depth/damage curves are necessary to estimate actual flood losses.

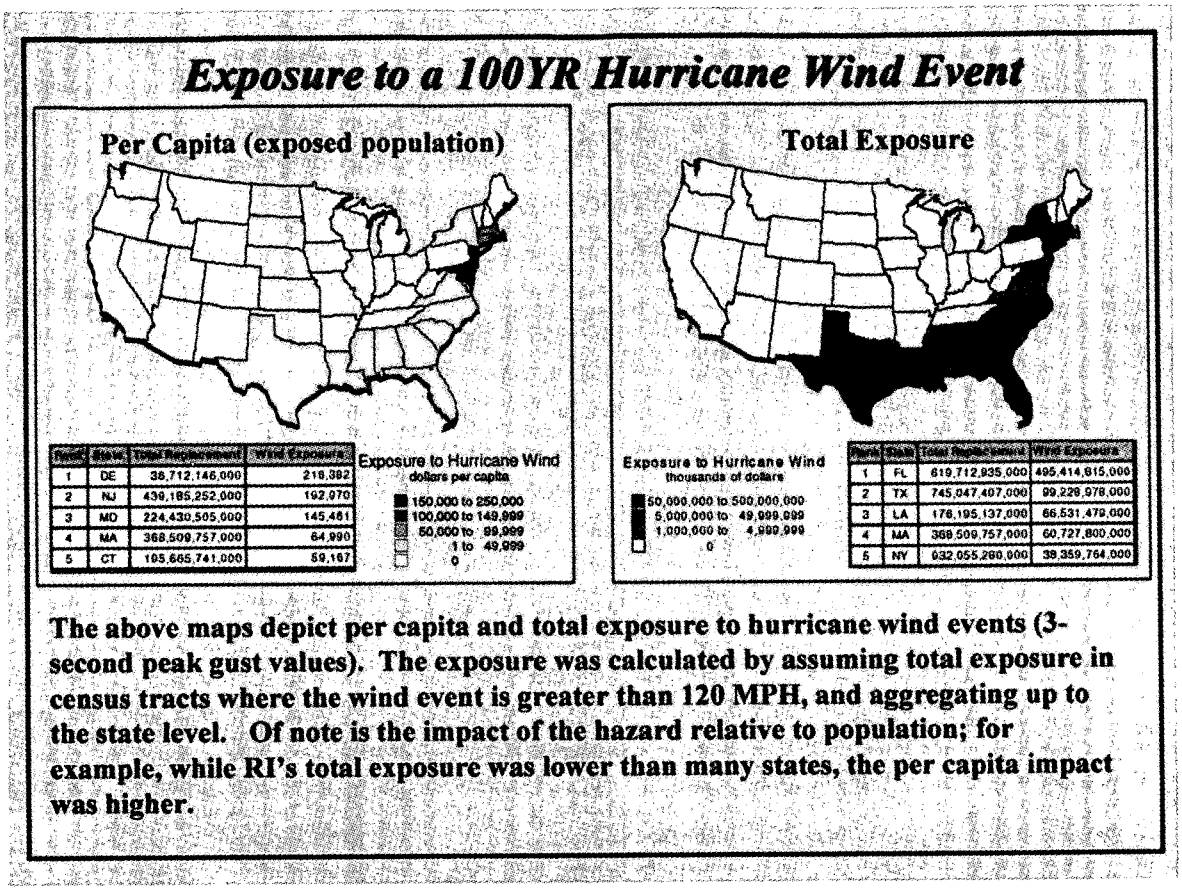


Figure 6. National exposure to the 100 year coastal wind event

Hurricane Wind Exposure

In contrast to the Q3 flood maps in Figure 1, the smaller scale of the wind speed maps did not allow for mapping at the census tract or block group level. Wind hazards were mapped at the county level. If a wind speed isoline intersected any portion of a county, the entire county was assigned that wind speed value. The wind speed threshold was chosen at 120 mph. This represents the threshold between damage dominated by storm surge and damage dominated by winds in hurricanes. Results are aggregated to the state level for comparison in Figure 6, which shows thematic maps of replacement value and per capita exposure as well as a ranked list of the top five states and the dollar amount of the exposure to the 100 year event.

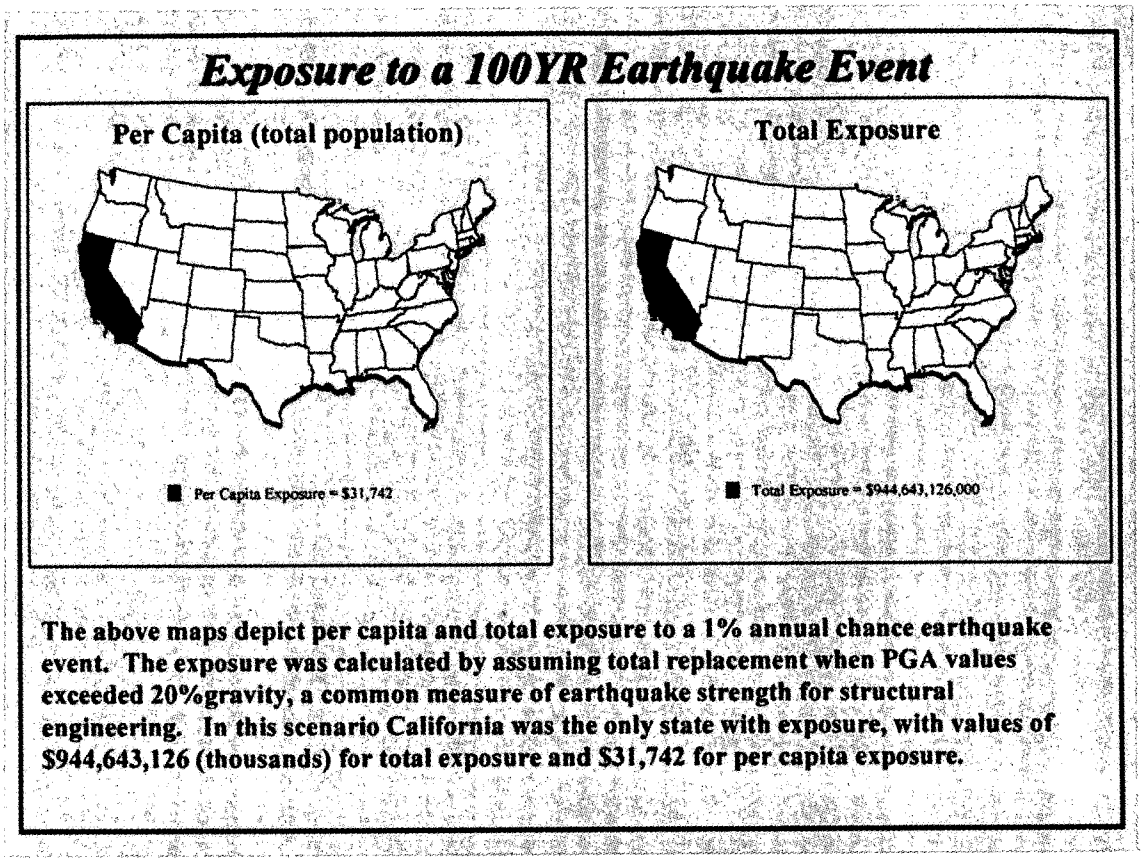


Figure 7. National Exposure to the 100 year earthquake (peak ground accelerations >20%).

Earthquake Exposure

Exposure to the 100 and 500 year earthquake ground motions in excess of 20% g were determined at the census tract level and aggregated to the county and state level for comparison. In contrast to the wind and flood hazard exposures in Figures 5 and 6, the majority of the 100 year earthquake exposure occurs in the state of California (see Figure 7). A more detailed analysis of earthquake exposure and risk in the United States, using the HAZUS loss estimation methodology can be found in Nishenko (1999) and FEMA (1999).

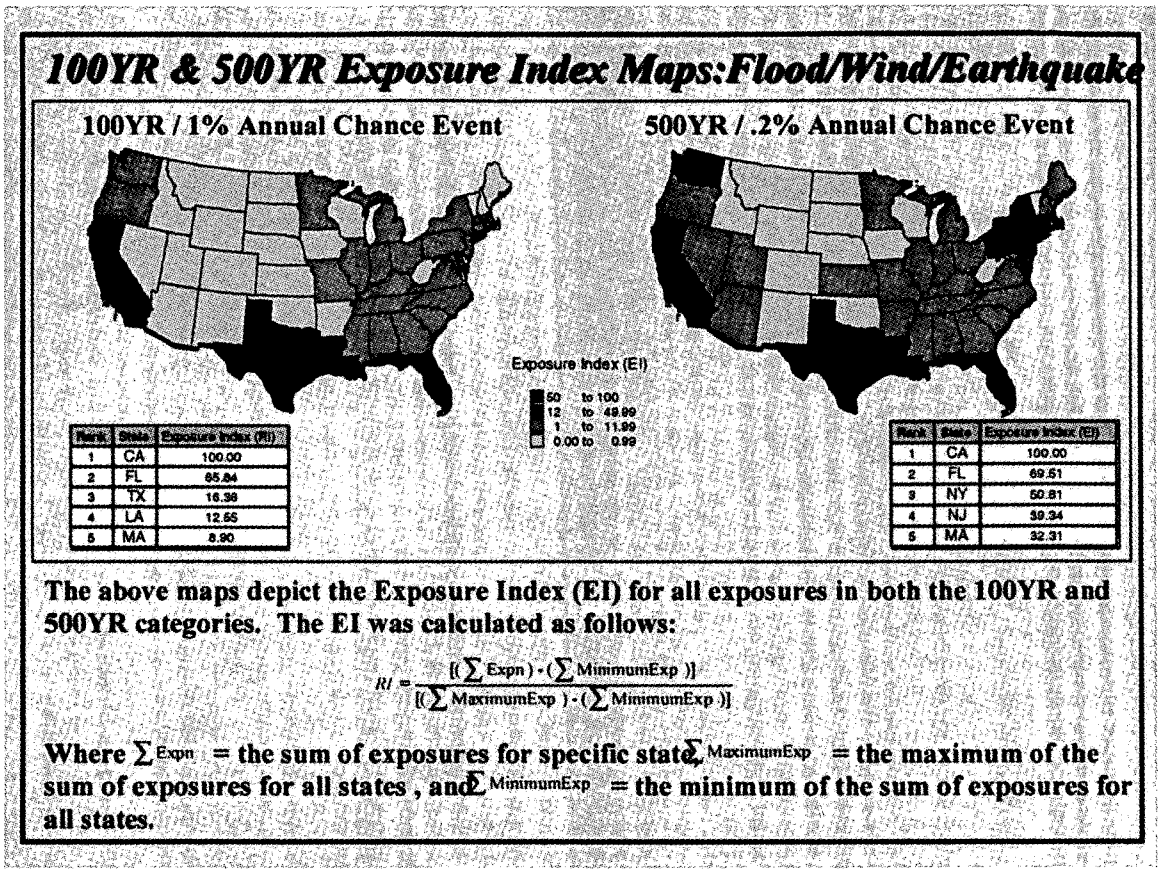


Figure 8. National Earthquake, Coastal Wind and Flood Exposure Index

Exposure Index

The exposure index is a re-normalization of the state exposure levels to create an index from 0 - 100. See Equation 2. This format allows for ease of interpretation and communication of results.

$$\text{Exposure Index} = \frac{(\Sigma \text{ Exposure}_i - \Sigma \text{ Minimum Exposure}_i)}{(\Sigma \text{ Maximum Exposure}_i - \Sigma \text{ Minimum Exposure}_i)} \quad [2]$$

Where Σ Exposure$_i$ is the sum of county exposures in a specific state, i = specific county. In Figure 8, Σ Minimum Exposure$_i$ is the smallest or minimum sum of state exposures and ΣMaximum Exposure$_i$ is the largest or maximum sum of state exposures determined in this study. Figure 8 shows thematic maps of the exposure index for the 100 and 500 year events and a ranked list of the top states with their exposure index values.

Discussion

Natural hazard exposure data, aggregated to the state and national level are shown in Figure 8 and Table 1. Each presents a different perspective on the issue. Figure 8 summarizes the exposure at the state level and indicates the California and Florida have the highest exposures (Exposure Index [EI] > 70) to the three perils selected for this analysis at the 100 and 500 year frequency. New York also has a significant exposure (EI > 50) at the 500 year level. Table 1 summarizes these same data by hazard type at the national level and indicates that the exposure to the 100 year or 1% annual flood, coastal wind or earthquake event represents approximately $3 trillion or 25% of the total replacement value for the national building stock. In addition, the individual exposures are approximately comparable for each event type (i.e. exposure to wind, earthquake and flooding are approximately $1 trillion each). Geographically, as seen in Figures 5, 6, and 7, these exposures are quite diverse. Hurricane wind exposure is spread along the Atlantic and Gulf coasts, flood exposure is 'uniformly' distributed across the nation, and earthquake exposure is primarily concentrated in the state of California at the 1% annual probability level. Exposure to the 500-year or 0.2% annual flood, wind, and earthquake events represents approximately 50% of the building inventory replacement value and is dominated by hurricane wind events.

Much of this analysis was based on data collected during the 1990 United States Census. The 2000 Census will provide an opportunity to reevaluate the Exposure Index and examine whether America's exposure to natural hazards has increased or decreased during the decade of the 1990's.

Table 1. Summary of National Building Inventory Exposure to 100 and 500 year Earthquake, Wind, and Flood Events, expressed as a function of replacement value.

Category	U.S. Dollars
Replacement Cost	12.3 Trillion
Exposure to 1% Annual Chance Hurricane Wind (>120 mph)	942 Billion
Exposure to 1% Annual Chance Earthquake (>20%g)	969 Billion
Exposure to 1% Annual Chance Flood	1.1 Trillion
Exposure to 0.2% Annual Chance Hurricane Wind (>120 mph)	3.4 Trillion
Exposure to 0.2% Annual Chance Earthquake (>20%g)	1.7 Trillion
Exposure to 0.2% Annual Chance Flood	1.5 Trillion

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Seismic Countermeasure of Electric Power System on the basis of Risk Management

Yoshiharu Shumuta[1)]

ABSTRACT

This paper presents a framework of our study associated with risk management orienting cost-effective seismic countermeasures. The state of the art of seismic countermeasure for electric power system in Japan is investigated. On the basis of it, future subjects of seismic countermeasures are discussed. Finally, our risk management research orienting mainly cost reduction of a seismic countermeasure is illustrated.

KEY WORDS: Risk Management, Seismic Countermeasure, Electric Power System, Cost Effectiveness, Lifeline

1. INTRODUCTION

Electric power system consists of a huge number of special order and standardized facilities. It is widely spread on various seismic ground conditions. In order to maintain its high performance in seismic events, a large amount of investment for the seismic countermeasure of a whole power system is required. On the other hand, compared with life cycle of electric power facility, large earthquakes such as the 1995 Hyogo-ken Nanbu earthqauke has too long reappearance cycle. Such low frequency large earthquake has seldom struck each power facility during its own life cycle. Thus, the optimization of trade-off relation between the seismic supply reliability and the investment cost for the seismic countermeasure should be considered from various points of view.

This paper presents a framework of our research associated with risk management orienting cost-effective seismic countermeasures. The state of the art of seismic countermeasures for electric power systems in Japan is investigated. Future subjects of seismic countermeasures are discussed based on the result. Finally, our risk management research orienting mainly cost reduction of a seismic countermeasure is illustrated.

2. THE STATE OF THE ART OF SEISMIC COUNTERMEASURE

2.1 Seismic design concept of each facility

Since Japan has experienced a lot of earthquakes, seismic design methods for electric power facilities have been studied enthusiastically. As a result, seismic design criteria were changed every occurrence of

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big earthquake. After the 1995 Hyogo-Ken Nanbu earthquake, a government commission reported a basic concept of seismic design for structures in its disaster prevention plan. According to the concept, two types of earthquake motions should be considered in assessing the aseismic capacity of structures including power facilities. The first type is likely to strike a structure once or twice while it is in service. The second type is very unlikely to strike a structure during the structure's lifetime, but when it does, it is extremely strong. Japan Society of Civil Engineering defined these two earthquake motions as "Level I", and "Level II" earthquake motions respectively.

Earthquake resistance level of power facilities is divided into two levels as follows based on these two earthquake motions. Power facilities associated with nuclear power plant are, however, excluded from following district:

(1) Earthquake Resistance District I (ERD I)

Earthquake Resistance District I (ERD I) is the level in which serious functional loss of facilities does not occur when Level I earthquake motion strikes, and human life is not seriously affected by damaged facilities due to Level II earthquake motion. ERD I is applied to Dam structure, LNG tank, and Oil tank.

(2) Earthquake Resistance District II (ERD II)

Earthquake Resistance District II (ERD II) is the level in which serious functional loss of facilities does not occur when Level I earthquake motion strikes, and long and wide range of functional loss of a whole power system does not occur when Level II earthquake motion strikes. ERD II is applied to power generation, transmission, substation, distribution, load dispatching, and maintenance facilities.

2.2 System performance criterion

Electric power system has a system performance criterion to maintain supply reliability against accidents or natural disasters. The system performance criterion indicates reliability level of electric power system to be ensured. The system performance criterion is divided into two levels as follows:

(1) Primary system

No functional loss of power system arises when a single accident in a power facility occurs.

(2) Secondary and Distribution systems

Functional loss is recovered in short time when a single accident in a power facility occurs.

Note that electric power system plays following important roles as energy source to retain social activities: a) transportation of a large amount of power, b) complement of each power system, c) power distribution to local area, d) power distribution to customers. The power system with functions of a) and b) is called "primary" system. That with function of c) and d) is called "secondary" and "distribution" systems respectively.

2.3 Protecting relay system

Protecting relay system is introduced into Electric power system in order to minimize its damage due to natural disaster or accidents. The functions of the protecting relay system are to 1) remove system accidents such as short and ground short, 2) maintain system stability, 3) minimize facility damage, 4) protect facilities from abnormal electric flow.

2.4 Close relation of each power system

Japan Power Company is divided into ten companies at present. Those power companies not only serve their respective regional service area, but also cooperate with each other to ensure a stable and efficient nationwide electric power supply. The companies work together to exchange electricity to provide power in most efficient manner in order to cope with emergency situations, from power supply problems or failures to peak demand during summer. To ensure the smooth operation of power exchange, extra-high voltage transmission lines link the entire country from Hokkaido in the north to Kyushu in the south. Each company supplies power to each area.

2.5 Preparedness for restoration

Power company declares a state of emergency based on each company's emergency manual and set up emergency office. The purpose of the emergency office is to collect damage information, and organize following topics: a) dispatching restoration staffs, b) adjustment of restoration material, c) offering lodging and food, d) power system operation, e) scheduling restoration activity, f) estimation of partial restoration date, g) others associates with restoration.

Even if power company's staffs are not ordered by emergency office in seismic event, they are supposed to engage in their restoration works respectively based on an employment activity guide.

Some materials and facilities are stocked at material center. In seismic event, these materials are supposed to be carried to damage area by their pre-contracted tracks, helicopters, and ship.

2.6 Earthquake monitoring system

Earthquake monitoring system consists of seismometer networks. The purpose of earthquake monitoring system is divided into three:

(1) Accumulation of existing earthquake motions: to inspect the earthquake resistant capacity of electric power facilities, earthquake motions are collected.

(2) Support of emergency decision making for partial restoration: to support emergency decision making such as emergency shut down, ground motion including acceleration or seismic intensity (SI value) is utilized in early restoration stage after earthquake.

(3) Support of restoration planning: to evaluate damage degree and make effective restoration plan, acceleration records are utilized.

Though all power companies in Japan have their own earthquake-monitoring system, it is mainly utilized for the purpose of accumulation of existing earthquake motions. Power company usually uses on-line data associated with power operation instead of earthquake motion data for restoration support. In even future plan, few power companies try to apply it to support of emergency decision-making or restoration planning after seismic event. The reason and the on-line data application in emergency is summarized as follows.

2.7 Carrier monitoring system

Load dispatching office is always monitoring on-line data such as power flow, voltage level, and switch's open and shut down conditions to control a whole power system. These on-line data are called " carrier" in this paper. Using " carrier" monitoring system, load dispatching office and emergency office grasp following a power system condition in seismic event: a) area of power failure and isolated power system, b) relay condition and tripped circuit breaker, c) level of power failure, d) functional condition of

damaged power plant, d) uncontrolled equipment.

Generally speaking, detecting damaged part (point) in early stage after seismic event is the most important thing for restoration process after seismic event. Compared with earthquake monitoring system, carrier-monitoring system is more powerful to detect damaged part. This is because carrier-monitoring system monitors system's functional condition directly from the damaged power system. On the other hand, since earthquake monitoring system monitors seismic intensity of surface ground under the power system, it needs a lot of assumptions and complicated estimation process in order to evaluate or detect the damaged part. Therefore, Power companies use carrier-monitoring system in emergency restoration process.

However, if a lot of facility damage occurs to power system simultaneously due to a big earthquake, power companies always dispatch staffs to inspect all facilities and collect off-line data associated with facility damage. In this situation, not only on-line data but also off-line data from a tour of inspection are utilized to detect the damaged part.

3 FUTURE SUBJECTS

Seismic design criteria of electric power facilities have been changed every occurrence of big earthquake in their long history. Electric power system consists of a huge number of facilities. Thus, many old facilities remained non-renewing or non-retrofitting even nowadays.

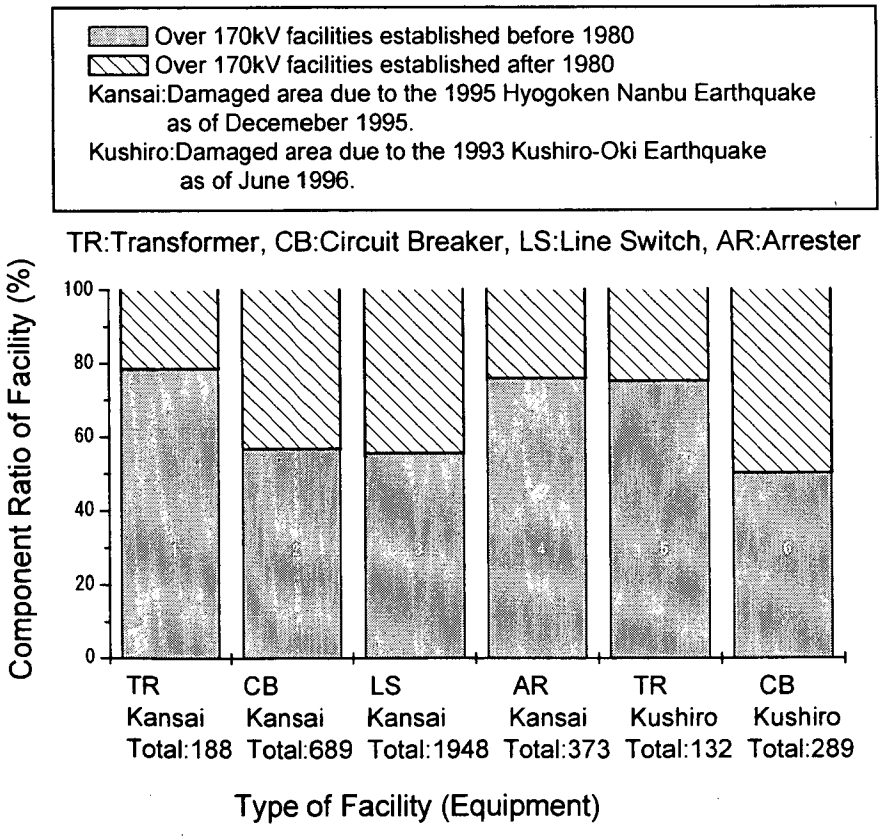


Fig.1 Component Ratio of substation facilities located in high seismicity area

For example, a Japan standard seismic design guide (JEAG5003)[1] for substation facilities of over 170 kV voltage level was established in 1980. JEAG5003 has been widely applied to all substation facilities including those of lower than 170kV in Japan. **Fig. 1** shows a component ratio of substation facilities in high seismicity area. "Before 80" and "After 80" indicate substation facilities established before and after 1980 respectively. **Fig.1** suggests that many preexisting facilities, which do not accord with current seismic design, have remained in current power system because of prohibitive cost for upgrading. It has been widely noticed that earthquake damage to electric power system is concentrated in such non-upgraded facilities.

Compared with life cycle of electric power facilities, large earthquake such as the 1995 Hyogo-ken Nanbu earthquake has too long reappearance cycle. Such low frequency large earthquake (Level II earthquake) has seldom struck each power facility during its own life cycle. Thus, facilities of Earthquake Resistant District (ERD) I and II (see 2.1) are accepted seismic damage due to Level II earthquake. ERD I and II, however, are not defined by quantitative criteria such as system performance criteria (see 2.2). This is because quantitative evaluation against earthquake inevitably entails uncertain factors such as expected seismic force. It is difficult to define deterministic and quantitative criteria. Therefore, trade-off relation between the seismic supply reliability and the investment cost for the seismic resisting should be studied on the basis of risk management concept.

4 A RISK MANAGEMENT RESEARCH ORIENTING COST-REDUCTION OF SEISMIC COUNTERMEASURES

4.1 Concept of seismic risk management

To make an optimum-upgrading plan for preexisting facilities or target reliability of a whole power system within limited budget, a cost effectiveness evaluation method should be studied. **Fig. 2** shows the relation between retrofit cost and company loss against an earthquake scenario. Decrease in retrofit cost causes increase in company loss. On the other hand, decrease in company loss indicates increase in retrofit cost. In this way, if seismic retrofit cost, company loss, and power loss are evaluated quantitatively, an optimum condition of a whole power system such as minimization of total cost could be determined from various points of view.

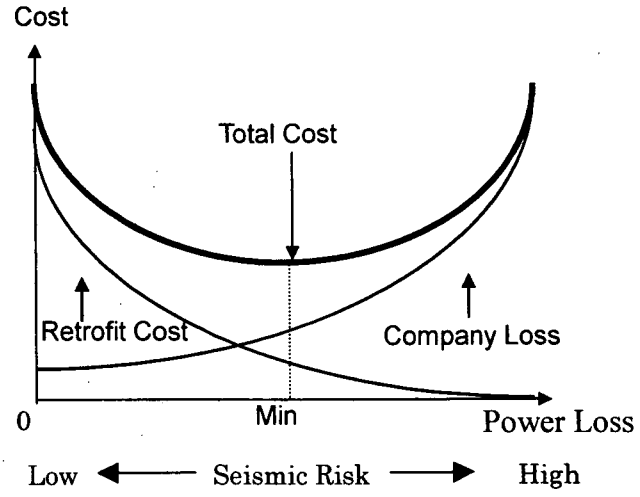


Fig.2 Relation between Retrofit Cost and Company Loss against an Earthquake scenario

Following example presents a method of cost effective analysis for seismic retrofit planning of substation facilities based on the risk management concept of **Fig.2**. The proposed method enables us to design an optimum number and priority of substation facilities to be retrofitted within limited budget.

4.2 Formulation of cost effectiveness analysis

Fig. 3 shows a flow chart of a cost evaluation analysis. The proposed method is divided into three steps. Step one is a process to evaluate seismic damage probability of each facility. Step two is a process to evaluate the total power loss (failure) of a whole power system. Step three is a process to analyze cost effectiveness for seismic retrofitting of each facility.

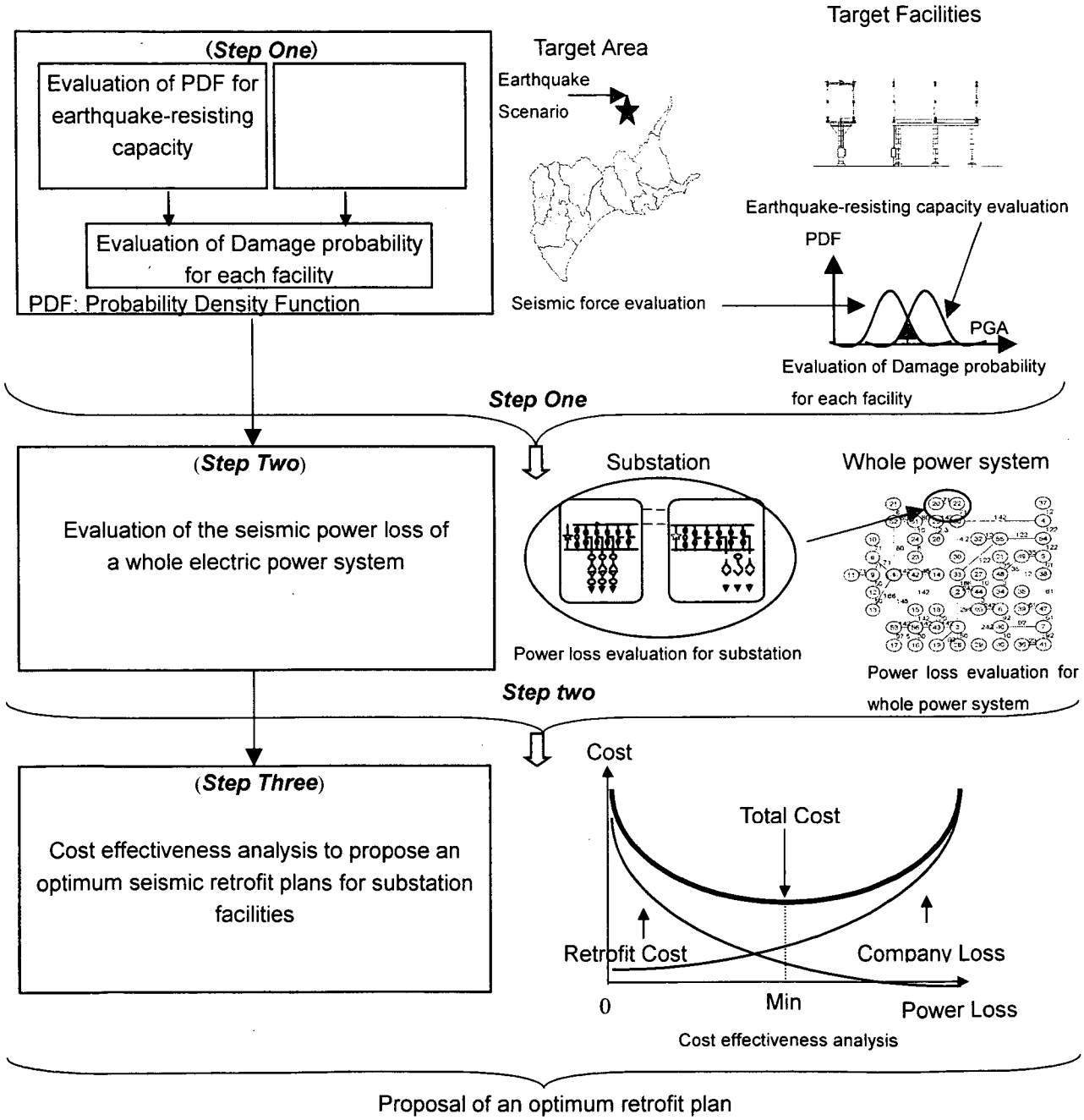


Fig.3 Flow-chart of a cost effectiveness analysis

(1) Step One

The seismic damage probability of each facility is evaluated as follows: An earthquake scenario is determined on the basis of past earthquake records in a target area. A seismic damage mode of each substation facility is previously assumed from an investigation[2] of existing seismic damage mode. Probability density functions of the earthquake-resisting capacity of facility i ($f_{Si}(s)$) and seismic force to facility i ($f_{Ri}(r)$) are evaluated based on the earthquake scenario and the assumed seismic damage mode of substation facilities. As for substation facilities, unit of s and r is usually maximum acceleration. It is assumed that there is an independent relation between $f_{Si}(s)$ and $f_{Ri}(r)$. On the basis of these functions, the seismic damage probability (P_{fi}) for substation facility i is defined by equation (1).

$$P_{fi} = \int_0^\infty f_{Si}(s)\left\{\int_0^s f_{Ri}(r)dr\right\}ds = \int_0^\infty f_{Si}(s)F_{Ri}(s)ds \qquad (1)$$

Where, $F_{Ri}(s)$ = the probability distribution function.

(2) Step Two

The total expected power loss of the whole power system against the earthquake scenario is evaluated as follows. The total expected power is utilized to evaluate seismic risk of the whole power system corresponding horizontal axis of **Fig.2.** Its value is also applied to evaluate company loss against the earthquake scenario.

a) Definition of power loss (failure)

Fig.4 shows a simplified restoration process in a damaged power system. The restoration process is divided into two levels. If earthquake occurs, a power system is damaged and reduces its performance to *S1*, *S1* = the supply-power just after earthquake. On the other hand, since the damaged power system has redundancy, it allows system operators to quickly improve the supply-power from *S1* to *S2* by a system switching procedure without replacing damaged facilities. *S2* = the supply-power after partial restoration without the physical repair of damaged facilities.

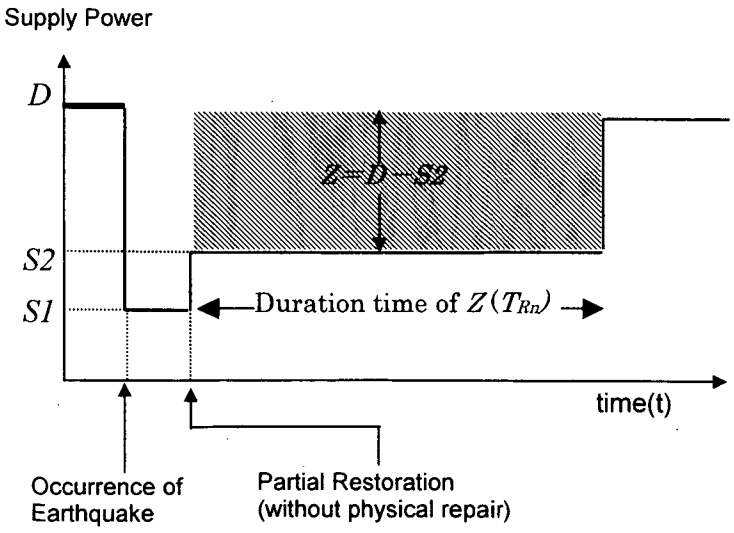


Fig.4 Conceptual figure of power loss (failure) of a whole power system after an earthquake scenario

It is usually difficult to evaluate *S1*. This is because the power loss just after earthquake is caused

by not only physical damage of facilities but also non-physical damage such as short, ground short, or wrong action of power equipment. Therefore, for the purpose of evaluating *S1*, it is difficult to identify and assume the cause of the power loss in *S1*. Furthermore, Statistical data associated with such non-physical damage are very few.

In contrast, it is relatively easy to evaluate *S2*.This is because the power loss after the partial restoration is caused by just only physical damage of facilities. Some databases associated with physical damage of facilities also exist and the relation between the physical damage and *S2* has already studied [3)4)] .This paper, therefore, defines the power loss as Equation (2).

$$Z=D-S2 \tag{2}$$

Where, D = the supply power just before occurrence of earthquake

b) Evaluation of expected power loss (failure)

In order to evaluate the power loss (Z) as an expected value, the following process is executed: First, the power loss of each substation is calculated for every trial in the Monte Carlo simulation. Each substation is modeled as a sub-network consisting of a bus (*BUS*), line switch (*LS*), circuit breaker (*CB*), and transformer (*Tr*). These facilities are modeled as nodes, while lead lines connected to each facility are modeled as links. Each node has the seismic damage probability evaluated in *step one*. On the basis of the damage probability of each node, damaged nodes are determined (assumed) for every trial in the Monte Carlo simulation. To calculate the power loss of each substation for every trial, a connectivity analysis [3)4)] is executed.

Second, the power loss of the damaged power system is calculated for every trial using a method developed by SHUMUTA[3)4)]. The power system is modeled as a main-network consisting of the above substations for nodes and transmission lines for links.

Finally, the above process is repeated to evaluate the expected power loss (*E(Z)*) on the basis of the Monte Carlo simulation.

c) Step Three

Cost effectiveness for seismic retrofitting is evaluated as follows:

Total cost in **Fig.2** is defined by equation (3).

$$E(TC) = E(CL) + RC \tag{3}$$

Where, *E(TC)* = expected total cost against an earthquake; *E(CL)* = expected damage cost of a power company due to an earthquake; *RC* = retrofit cost for facilities.

These quantitative data are useful for making an optimum seismic retrofit plan for substation facilities. The detail of the equation (3) is defined as follows.

4.3 COMPANY LOSS (*E(CL)*)

E(CL) in equation (3) is defined by equation (4):

$$E(CL) = E(CPL) + E(RL) + E(CC) \tag{4}$$

Where, $E(CPL)$ = the expected total repair cost for seismic-damaged facilities; $E(RL)$ = the expected revenue loss due to the power loss in a seismic-damaged power system; $E(CC)$ = the chargeable cost associated with the customer loss due to the power loss.

(1) Capital loss ($E(CPL)$)

$E(CPL)$ in equation (4) is defined by equation (5)

$$E(CPL) = \sum_{i=1}^{n} P_{f_i} \times RPC_i \tag{5}$$

Where, i and n = the substation facilities and the number of seismic-damaged facilities; P_{fi} = the seismic damage probability of substation facility i ; and RPC_i = the repair cost of seismic damaged facility i.

(2) Revenue Loss ($E(RL)$)

$E(RL)$ in equation (4) is defined by equation (6)

$$E(RL) = \frac{1}{m} \sum_{n=1}^{m} \{Z_n \times T_{Rn} \times PLU_L\} \times PC/Unit \tag{6}$$

Where, n and m = the trial and total trial number of the Monte Carlo simulation; Z_n = the total power loss of the power system at trial n in the Monte Carlo simulation. Z_n is calculated by the second step; T_{Rn} = the duration time of Z_n; PLU_L = the power loss unit of Local area L. PLU_L is assumed as a constant value for local area L; $PC / Unit$ = the profit cost due to the sale of electric power unit.

a) Duration time of power loss (T_{Rn})

On the basis of Applied Technology Council (ATC 1991)[5], T_{Rn} is defined by equation (7).

$$T_{Rn} = e^a \cdot DMG_n^{\ b} \tag{7}$$

Where, e = natural logarithm; DMG_n = number of damaged-facilities assumed by trial n in the Monte Carlo simulation, a and b = regression coefficients.

Note that T_{Rn} does not include the duration time from occurrence of earthquake to the completion of partial restoration without physical repair. This is because the time for the partial restoration is usually very short.

b) Power loss unit (PLU_L)

The defined power loss (Z_n) changes and reduces with progress of restoration. Thus, in order to consider the change ratio of Z_n. for evaluation of the revenue loss, PLU_L is multiplied $Z_n \times T_{Rn}$ corresponding the gray area in **Fig.4**. This paper assumes that PLU_L in same area L is always constant regardless of seismic intensity. As an example, the 1993 Kushiro-Oki earthquake (M7.8) and the 1994 Hokkaido Toho-Oki earthquake (M8.1) struck a same area. Recoded values of PLU_L are 0.753 for the 1993 Kushiro-Oki and 0.758 for the 1994 Hokkaido Toho-Oki Earthquake. These values are sufficiently

similar to be regarded as constant.

(3) Chargeable cost *E(CC)*

Chargeable cost indicates the compensation for customer. If power failure occurs, power company has to pay to customers according to the contract.

4.4 RETROFIT COST (*RC*)

RC in equation (3) is defined by equation (8) :

$$RC = \sum_{i=1}^{m} rc_i \tag{8}$$

Where, i = substation facilities; m = total number of retrofitted facilities; rc_i = retrofit cost of i.

(1) Retrofit order

In order to evaluate the tradeoff relation in **Fig.2**, a method for determining the retrofit order should be fixed. **Fig. 5** shows a flowchart to determine the seismic retrofit order of substation facilities.

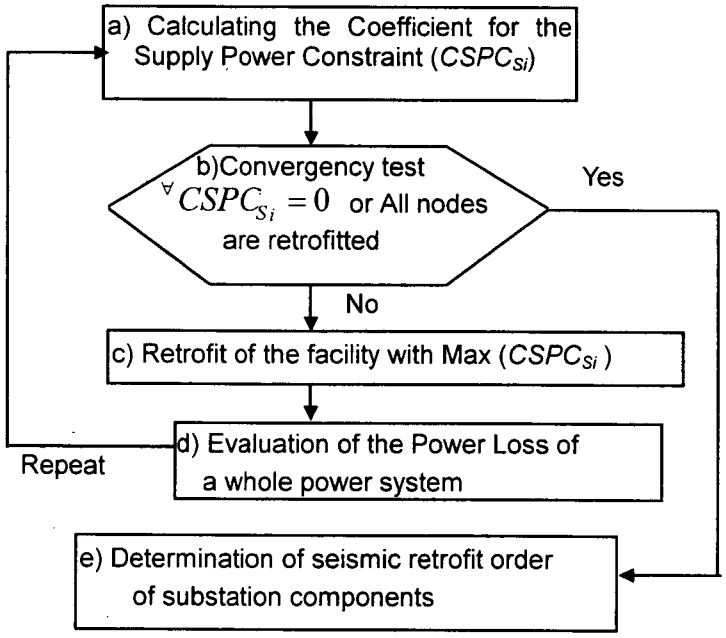


Fig.5 Flow-chart of the method for determination of seismic retrofit order

a) Calculating the Coefficient for the Supply Power Constraint (CSPC)

In order to determine the seismic retrofit order of each facility, the Coefficient of Supply Power Constraint ($CSPC_{S\,i}$) of facility i in substation S is defined by equation (9):

$$CSPC_{Si} = \sum_{d=1}^{nSd} E(DP_{Sd}{}^{i}) + \sum_{l=1}^{nSl} E(OL_{lS}{}^{i}) \qquad (9)$$

Where, $E(DP_{Sd}{}^{i})$ = expected power loss to facility d with demand power caused by the damage of facility i in substation S. nsd = total number of facilities with demand power in substation S. $E(OL_{lS}{}^{i})$ = expected over load of transmission l caused by damage of facility i in substation S. nsl = total number of transmission lines connected to substation S.

CSPC is utilized as the objective function to determine the seismic retrofit order. The formulation of *CSPC* is referred to Shumuta 1998a[1] or 1998b[6].

b) Convergence test

If *CSPC* for all facilities are equal to 0 or all facilities are retrofitted, go to e). In this study, the seismic damage probability evaluated to each facility is divided into two; pre-retrofit and post-retrofit probabilities. Retrofit indicates that the pre-retrofit probability of each facility is replaced by the post-retrofit probability of it.

c) Retrofit of the facility with maximum *CSPC*

The facility with the maximum *CSPC* is retrofitted.

d) Evaluation of the power loss of whole power system

After the selected facility in c) is retrofitted, the power loss of a whole power system is evaluated based on *Step Two*. Its evaluation needs for re-calculation of *CSPC* of each facility.

e) Determination of seismic retrofit order

Once the *CSPC* of all substations is equal to 0 or all facilities are retrofitted, the analysis to determine the seismic retrofit order is completed. The retrofit order determined by repeating steps a) to d) corresponds to the seismic retrofit order of the facility in the targeted power system.

4.5 Numerical examples

(1) Modeling of a actual secondary system

In this paper, to discuss actual seismic retrofit planning of substation facilities, an actual secondary system located in Kushiro, Hokkaido is applied. **Fig.6** shows a model of the Kushiro secondary system. It consists of 56 nodes for substations and 59 links for transmission-lines. Nodes 1 and 2 indicate primary substations, which perform as the power sources. The total demand power of the model is about 661MVA. Rated capacities for transmission-lines are shown on the side of all links in **Fig. 6**.

Each node in the main-network has a sub-network consisting of nodes for transformers, buses, circuit breakers, line switches, and links for lead lines. The total number of nodes and links for all sub-network models in the Kushiro model is 864. **Table 1** shows statistics of the Kushiro power system model. **Tables 1** includes substation number, total number of facilities in each substation, total number of line switches in each substation. Note that since nodes 8,9,42～56 in **Fig.6** perform dummy nodes for modeling junctions of transmission-lines, they are not shown in **Table 1**. In this example, particular attention is paid to 474 line switches. The cost effectiveness analysis for seismic retrofitting of 474 line switches was executed.

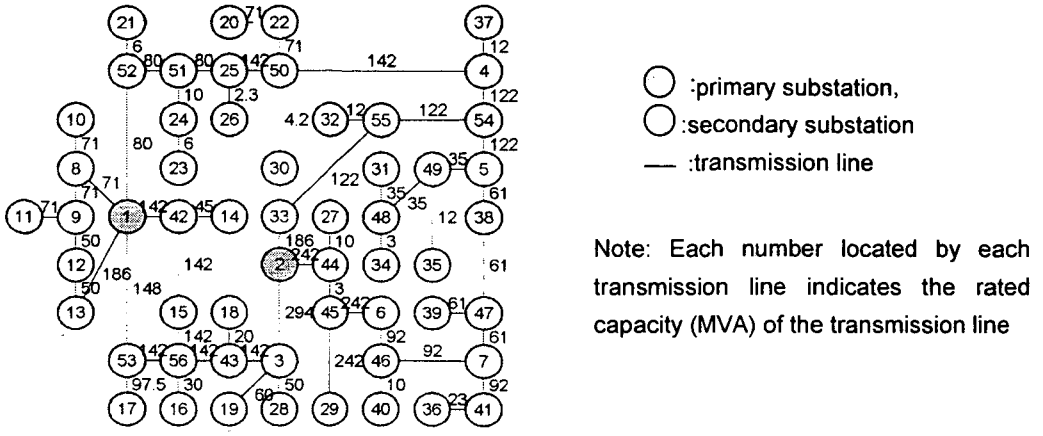


Fig.6 model of the actual secondary system in Kushiro, Japan

Table 1 Statistics of the Kushiro secondary system model

SN	1	2	3	4	5	6	7	10	11	12	13	14	15	16	17	18	19	20	21	22
NC	70	46	66	41	32	29	29	14	14	11	38	46	34	14	26	17	23	11	14	11
LS	34	22	32	26	20	18	18	8	8	6	18	22	16	8	16	10	14	6	6	6
SN	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
NC	14	14	17	8	11	26	11	11	8	14	17	17	11	23	14	17	8	11	26	
LS	8	8	10	4	6	16	6	6	4	8	10	10	6	14	8	10	4	6	16	

SN : Substation Number (=Group Number which has same seismic retrofit priority)

NC : Total number of facilities in the substation of SN

LS : Total number of targeted Line Switches in the substation of SN

(2) Initial condition

a) Earthquake scenario

The 1993 Kushiro-Oki Earthquake was chosen as the earthquake scenario. **Table 2** shows characteristics of the 1993 Kushio-Oki Earthquake.

Table 2 Characteristics of the 1993 Kushio-Oki Earthquake

Epicenter	
longitude	144° 23'
latitude	42° 51'
Epicentral distance (km)	107
Magnitude	7.8
Max seismic intensity (JMA)	6

Table 3 shows Maximum Acceleration of surface ground just under each substation against the earthquake scenario. These values are calculated based on a regression function. The regression function

is evaluated using actual maximum acceleration records reported by Science Technical Institute of Disaster Prevention[7]. Note that this example assumes that evaluated maximum acceleration has no probabilistic distribution.

Table 3 Maximum acceleration of surface ground just under each substation

SN	1	2	3	4	5	6	7	10	11	12	13	14	15	16	17	18	19	20	21	22
MA	457	553	607	314	266	411	283	518	481	446	9	0	2	0	0	0	0	0	0	1
SN	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
MA	401	373	352	362	623	638	476	334	178	292	314	202	233	221	339	278	278	318	228	

MA : Maximum Acceleration of surface ground just under the substation of SN (GAL)

b) Target facilities.

Fig.7 shows examples of line switches. 474 line switches were discussed for cost effectiveness analysis.

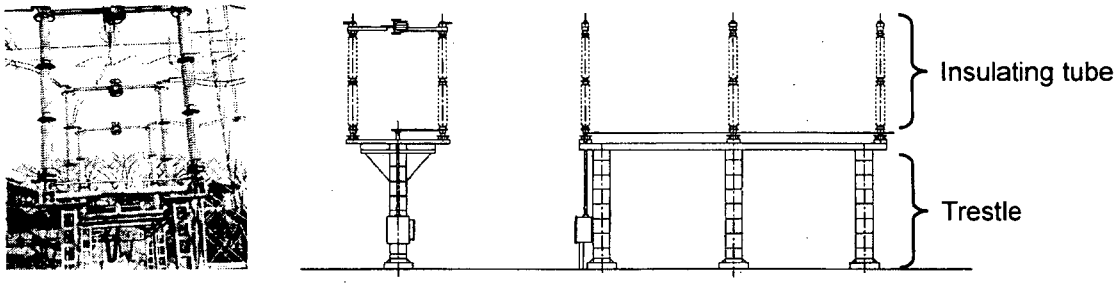


Fig.7 Line switch

e) Earthquake resisting capacity of line switch

In order to evaluate seismic damage probabilities of 474 line switches, following assumption is applied:

1) 474 line switches have a same earthquake-resisting capacity.
2) The insulation tube of line switch is damaged when the generated stress exceeds the fracture stress. The mean value of the fracture stress = 541.5kg/cm^2. The coefficient of variation = 0.137.
3) The insulating tube of a line switch with a safety factor of 1.0 experience a maximum stress of 200kg/cm^2 on the condition that a maximum acceleration of 0.3G struck on the bottom of trestle. Note that safety factor = allowable stress/calculated maximum stress on the condition that 0.3G resonant sinusoidal three waves struck the bottom of the trestle.
4) The maximum generated stress of the edge of each insulating tube is in proportion to its safety factor when a same ground motion struck the bottom of the trestle. It is also in proportion to the maximum acceleration on the ground surface.
5) The probabilistic density function of the earthquake-resisting capacity of the line switch has logarithmic normal distribution.
6) If existing line switch is retrofitted, the existing trestle is exchanged for a new one with higher stiffness. The higher trestle improves a safety factor of the line switch from 0.7 to 1.4.
7) Other facilities excluding line switch has no damage due to the earthquake scenario.

e) Group of retrofit order

In order to determine the seismic retrofit order of all line switches, line switches located in a same substation were regarded as a same retrofit group. Seismic retrofit order is determined for every retrofit group.

f) Parameters of Cost and power loss functions

Table 4 indicates parameters of cost and power loss functions.

Table 4 Cost and power loss parameters

Retrofit Cost.Unit ($\times 10^6$ Yen)	0.567
Repair Cost/Unit ($\times 10^6$ Yen)	2.6
Profit Cost(Yen/kwh)	16.25
Regression coefficients of T_{Rn}	a=-1.33, b=1.06
PLU_L	0.756

(3) Discussion of seismic retrofit plan for line switches

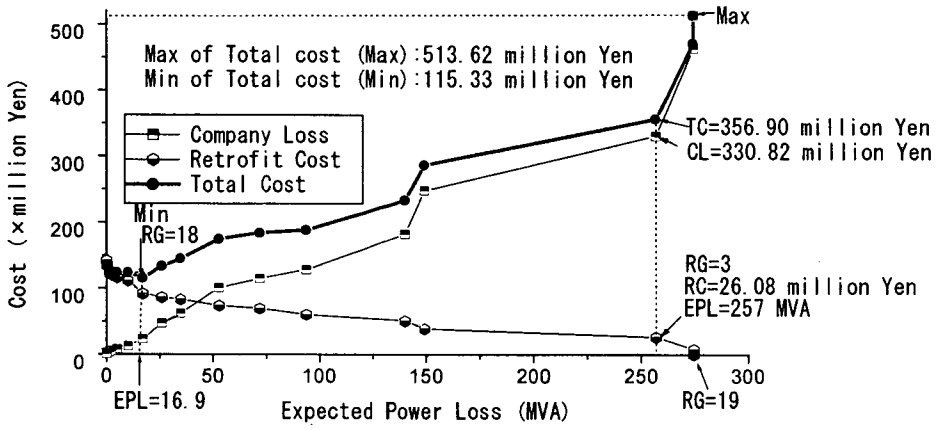


Fig.8 Cost effectiveness analysis for the retrofit planning of the Kushiro power system

Fig.8 shows one of the results of the cost effectiveness analysis. **Fig.8** shows the relation between Retrofit cost and Company loss. **Table 5** shows the list of **Fig.8**. It consists of seismic retrofit order of each retrofit group corresponding substation number, expected power loss, retrofit cost, company loss, total cost, total number of retrofitted line switches in the selected retrofit group and total accumulated number of retrofitted line switches. Retrofit of line switches proceeds with seismic retrofit order.

As an example, please note that Retrofit Group 3 (RG =3) on the retrofit cost curve in **Fig. 8** corresponds to the same number in the column of RG in **Table 5**. The seismic retrofit order (SRO) of Retrofit Group 3 is 2. Thus, Retrofit Group 19, Seismic Retrofit Order (SRO) 1, has retrofitted before Retrofit Group 3 is retrofitted. In other words, the plot point of Retrofit Group 3 (RG=3) in **Fig.8** means that Retrofit Group 19 and 3 are retrofitted. Therefore, the Expected Power Loss, Company Loss, and Total Cost reach 257 MVA, 330.82 million yen, and 356.90 million yen, respectively. If Retrofit Group 18, Seismic Retrofit Order 10 is retrofitted, Total Cost becomes minimum. In concrete terms, this condition means that (1) Facility groups 19, 3, 2, 14, 15, 17, 16, 28, 27, and 18 are retrofitted, (2) The expected

power loss is 16.90MVA, (3) The total number of retrofitted line switches is 162, which is 34.2% of the total number of line switches (474).

Fig.8 suggests that minimizing the total cost would run 91.85 million yen (=162×0.567), while retrofitting all 474 line switches would cost 268.77 million yen (=474 ×0.567). It also indicates that 250 line switches, 52.7% of the total number of line switches, should be retrofitted to reduce the expected power loss to zero (0). In the Kushiro system, it would costs only 142.79 million yen (=250×0.567) to avoid the power loss against the 1993 Kushiro-Oki Earthquake, while it would cost 268.77 million yen (=474×0.567) to retrofit all line switches.

Table 5 The Result of the cost effectiveness analysis

SRO	RG	EPL	RC	CL	TC	TNLS	TANLS	
		274.4	0	513.62	513.62	0	0	
1	19	274.4	7.94	463.17	471.11	14	14	
2	3	257	26.08	330.82	356.90	32	46	
3	2	149.3	38.56	247.71	286.26	22	68	
4	14	140.1	51.03	182.09	233.12	22	90	
5	15	93.7	60.10	127.84	187.94	16	106	
6	17	71.9	69.17	114.46	183.63	16	122	
7	16	52.9	73.71	100.70	174.41	8	130	
8	28	34.9	82.78	61.88	144.66	16	146	
9	27	25.9	86.18	47.03	133.21	6	152	
10	18	16.9	91.85	23.47	115.33	10	162	Min
11	1	10.1	111.13	12.67	123.80	34	196	
12	10	4.9	115.67	8.12	123.79	8	204	
13	11	2.3	120.20	4.96	125.16	8	212	
14	29	1.5	123.61	3.39	127.00	6	218	
15	6	0.3	133.81	2.60	136.41	18	236	
16	21	0.3	137.21	1.82	139.04	6	242	
17	23	0	141.75	1.04	142.79	8	250	

SRO: Seismic Retrofit Order of retrofit group
RG: Retrofit Group = substation number
EPL: Expected Power Loss (MW)
RC: Retrofit Cost (×million Yen)
CL: Company Loss (×million Yen)
TC: Total Cost (×million Yen)
TNLS: Total Number of retrofitted Line Switches in RG
TANLS: Total Accumulated Number of retrofitted Line Switches

5. CONCLUSION

This paper presents a framework of our research associated with risk management orienting cost effective seismic countermeasure. In order to realize future subjects, the state of the art of seismic countermeasure for electric power system in Japan is investigated. As a result, power companies in Japan take high-level seismic countermeasures. It is, however, understood that many preexisting facilities, which do not accord with current seismic design, have remained non-renewing or non-retrofitting. Earthquake damage to electric power system is concentrated in such non-upgraded facilities.

In order to coop with the above issue, a method of cost effectiveness analysis for seismic retrofit planning of substation facilities was illustrated as our risk management research. The illustrated method was applied to the Kushiro secondary system. An optimum seismic retrofit plan for 474 line switches located in the Kushiro secondary system against an earthquake scenario was discussed. As a result, it is understood that the seismic retrofit of 34.2% of the 474 line switches minimizes the Total Cost.

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American Lifelines Alliance—Reducing Risks to Utility and Transportation Systems from Natural Hazards

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Abstract

The U. S. Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE) have entered into a cooperative agreement to establish the American Lifelines Alliance (ALA) public-private partnership project, with the goal of reducing risks to lifelines (utility and transportation systems) from natural hazards. ALA's objective is to facilitate the creation, adoption, and implementation of design and retrofit guidelines and other national consensus documents that, when implemented by lifeline owners and operators, will systematically improve the performance of lifelines to acceptable levels in natural hazard events.

ALA is working with partners on existing non-consensus guidelines, standards, and industry practices, synthesizing and improving them, as appropriate, and shepherding the resulting documents through a formal consensus process. Each project involves (1) a Standards Developing Organization (SDO) for consensus development; (2) representatives from the appropriate sector of the utility or transportation community; and (3) representatives from the relevant manufacturing and technical communities.

ALA is using a general, well-established procedure for assessing the performance of utility and transportation systems subjected to natural hazards, and identifying actions to reduce their risk. When ALA-sponsored consensus guidelines are available to implement this procedure and are applied to a specific utility or transportation system, the likely performance of the system in a natural hazard occurrence is quantified, and guidance for possible mitigation actions is provided.

ALA's initial activities are focused on converting well-established practices within the utility and transportation industries into nationally applicable consensus guidelines. ALA is seeking sponsoring organizations and stakeholders to co-fund and provide in-kind support to mutually beneficial efforts. In some cases, existing practices are not sufficient to be put through a formal consensus process. In these situations, the role of ALA may include funding studies in order to improve or extend practices to the point where national consensus is achievable. ALA is also establishing extensive outreach and implementation activities.

Introduction

The U. S. Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE) have entered into a cooperative agreement to establish the American Lifelines Alliance (ALA) public-private partnership project. The vision of the

project is to reduce risks to lifelines (utility and transportation systems) from natural hazards. ALA's objective is to facilitate the creation, adoption, and implementation of design and retrofit guidelines and other American National Standards Institute (ANSI)-approved national consensus documents. These documents, when implemented by lifeline owners and operators, will systematically improve the performance of utility and transportation systems to acceptable levels in natural hazard events. Formation of the ALA is in direct response to needs identified over 10 years ago, and was requested in the 1990 reauthorization of the National Earthquake Hazards Reduction Program (NEHRP).

The process that is being developed and implemented by ALA addresses considerations that are unique to or particularly important to transportation and utility systems.

- Each lifeline system is unique in its development history, and each system typically occupies a region that has geographically varying exposure to natural hazards. The evaluation of performance of the system must be able to accommodate the specific components of the system, which were designed according to different criteria at different times, and are exposed to site-specific natural hazards.
- Most lifeline systems include networks or multiple components that provide redundancy and resilience when subjected to damage or disruption. As a consequence of this inherent functionality, a given lifeline can tolerate some level of damage while providing adequate performance as far as the users of the lifeline are concerned. The analysis of risk due to natural hazards must incorporate consideration of functionality as experienced by the user of the lifeline system.
- The consensus guidance products that result from ALA activities are being prepared to be used on a voluntary basis by owners and operators of lifelines; but they could also be adopted by lifeline regulators to provide suggested or required guidance for achieving acceptable performance in response to natural hazards. Acceptable performance criteria must be explicitly established by the appropriate stakeholders, including the lifeline agency, its customers or users, and cognizant regulators. Acceptable performance criteria must include considerations of redundancy, and should preferably be characterized in probabilistic terms.

This paper describes the approach to the development of lifeline guidelines and standards being used in ALA. A general procedure commonly being used for natural-hazards risk management serves as a template for ALA product development for all lifelines. At the present time, guideline elements are being developed in several lifeline areas.

Systems suitable for the ALA process include:

Electric power transmission and distribution
Natural gas transmission and distribution
Potable water conveyance and distribution
Wastewater transportation and processing
Oil and liquid fuel handling, transport, and storage
Highways

Railroads
Seaports and inland waterway ports
Air transportation
Telecommunications

Role and Scope of ALA

Under the guidance of a working group, ALA has identified lifeline systems for which non-consensus guidelines, standards, and industry practices exist. ALA is taking these existing documents, synthesizing and improving them, as appropriate, and shepherding the resulting documents through a formal consensus process to develop nationally applicable guidelines. Each project involves a Standards Developing Organization (SDO) for consensus development, representatives from the appropriate sector of the utility or transportation community, and representatives from the relevant manufacturing and technical communities. Placing each consensus document in an SDO will ensure that the document will be reviewed and updated on a regular basis, so that it remains current with respect to new hazards data, updated system performance evaluation procedures, and changes in society's acceptable levels of risk. ALA is working with a wide range of sponsoring organizations and stakeholders to co-fund and provide in-kind support for specific activities. ALA project working group members and FEMA personnel provide coordination and oversight of these activities.

In some cases, existing practices for natural hazards risk management are not developed enough to be put through a formal consensus process. For example, databases for ice loading hazards have been developed only in limited regions, and procedures for evaluating the performance of water conveyance pipelines have not been comprehensively assembled for the national range of pipe types, soil conditions, levels of ground shaking, and levels of permanent ground deformation. In these situations, the role of ALA includes funding or otherwise encouraging studies and projects that will improve or extend practices to the point where national consensus is achievable.

General Risk Analysis Procedure

ALA is using a general procedure for assessing the performance of utility and transportation systems subjected to natural hazards, and identifying actions to reduce their risk. When ALA-sponsored national consensus guidelines are applied to a specific utility or transportation system, the likely performance of the system in a natural hazard occurrence is quantified, and guidance for possible mitigation actions is provided.
The following six steps describe the procedure.

1. *Identify and Quantify the Natural Hazard*
   Existing nationally or regionally accepted hazard maps and other data shall be used. Probabilistic hazard analysis can be used to establish hazards for evaluation of individual components, and may be appropriate for procurement specifications in many

cases instead of fixed hazard criteria (such as maximum hazard values). Multiple scenario representations should be used to quantify hazards for evaluation of a spatially distributed lifeline system.

2. Identify and Quantify the Expected Damage States of Components within the System
Component fragility curves are used to represent the probability that the component will be in a given damage state, as a function of the intensity of the hazard. Fragility curves are established by using empirical data and engineering analysis procedures to assess the behavior of the component in terms of designated damage states at various natural hazard intensity levels. Random and systemic uncertainties in input data, engineering analysis procedures, and damage state correlations should be considered.

3. Assess the Damage States and Functionality of the System Components When Affected by a Natural Hazard
Scenario representations are analyzed in conjunction with fragility curves to assess the occurrence of component damage states, incorporating uncertainty in location and amount of damage. The functionality of each component is evaluated when it is in the given damage state.

4. Evaluate System Functionality
Component functionalities from each damage-state scenario are incorporated into a system model, and are used to assess the system's ability to accommodate post-hazard service demands for multiple damage-state scenarios. This evaluation considers reduction in user serviceability of the system, service restoration time, and life safety threats. The evaluation should incorporate operator experience and judgment. The results may be aggregated for both individual and multiple scenarios.

5. Identify and Evaluate Impacts of Reductions of Lifeline System Functionality and Financial or Other Losses
This analysis should consider internal impacts such as direct cost of damage, revenue loss, liability, and loss of public support, as well as external impacts such as financial losses by customers or users, and government services impacts.

6. Provide Guidance to the System Owner and Others
Guidance should be provided regarding selection of criteria for specification of acceptable performance, and criteria for new construction to minimize losses in future events. Alternatives to mitigate unacceptable performance of existing systems should be provided, and should include upgrade or retrofit of components, as well as non-engineering methods to reduce post-hazard impacts of lifeline damage, such as system enhancement, post-hazard emergency response, and recovery planning.

Implementation of ALA Guidance

ALA is also undertaking programs to encourage the implementation of natural hazards risk

reduction measures by system owners. These programs consider the many means by which natural hazard risks can be reduced within the diverse types and sizes of lifeline systems, and address owner concerns over budgeting, coordination with other internal programs, management support for risk reduction, and regulatory issues. Also, those who are currently implementing natural hazards risk-reduction programs are being asked to identify particularly useful existing guidelines and standards, as well as barriers to their implementation. ALA is coordinating these efforts with other public/private partnerships such as FEMA's Project Impact.

Status of ALA Activities

Since its inception in 1997, ALA has developed and begun to carry out the program described above. FEMA funding has been critical in supporting these initial ALA activities:

- An increasingly broad community—from lifeline engineers to regulators to lifeline owners and operators—is being informed of ALA plans and activities. A group of more than 130 Corresponding Advisors has been established to provide input and feedback on ALA plans.
- Several efforts have been or are being funded by the ALA project to take advantage of well-established industry practices.
  1. An engineering firm has been selected to prepare a comprehensive procedure for establishing earthquake vulnerability relationships for potable water conveyance pipelines and related facilities such canals, tunnels, storage tanks, valves, and control instrumentation. The vulnerability relationships determine the probability of specified damage states as a function of pipe or facility characteristics, and earthquake hazard characteristics including soil conditions, peak ground motions, permanent ground deformation, and other relevant parameters. This procedure will be incorporated in a subsequent development of earthquake performance-based design guidelines.
  2. An existing standards committee task group is being provided with logistical support to complete development of earthquake performance criteria for gas and liquid fuels transmission pipelines.
  3. An existing ice-loading hazard map that was developed for several regions in the United States is being extended to cover the entire U. S. east of the Rocky Mountains. This map will be available to be incorporated as an appendix of the ASCE 7 Standard, *Minimum Design Loads for Buildings and Other Structures*.
- FEMA, ASCE, and Pacific Gas and Electric Company (PG&E) have established and co-fund a fellowship position at FEMA. The fellowship recipient (the author of this paper) is spending one-quarter time for a year working at FEMA to bring utility expertise into FEMA's Mitigation Directorate in particular support of ALA-related activities.
- Electric power earthquake risk is one topic of the multi-participant, applied earthquake research program established in 1996 by PG&E and the Pacific Earthquake Engineering

Research Center (PEER) at the University of California at Berkeley. The California Energy Commission, the California Department of Transportation, and other utilities are also providing research support. Utility-directed studies of the seismic vulnerability of high-voltage substation equipment, seismic interactions that potentially damage interconnected substation equipment, and predictive functionality models for electric power system performance in earthquake scenarios are being conducted, with the goal of incorporating the results into an ALA-developed earthquake design guideline.

Conclusions

The American Lifeline Alliance has been established as a major initiative supported by FEMA with the goal of establishing a national consensus process to reduce risks to lifelines (utility and transportation systems) from natural hazards. The ALA effort draws on the experience and expertise of lifelines personnel, consultants, and academic researchers to build consensus agreements on practical and effective means to accomplish this goal. With the involvement of many organizations, agencies, and individuals over the next several years, ALA is expected to oversee the development and implementation of consensus guidelines and standards that, over time, will achieve a significant improvement in the performance of lifelines affected by natural hazards.

Acknowledgments

The author acknowledges the input to this paper derived from documents prepared by the ALA Working Group. Thomas McLane, Douglas Honegger, and Stuart Nishenko provided additional ideas and reviews. The support of FEMA, ASCE, and PG&E is gratefully acknowledged.

Manuscript not Presented Orally

- GPS in Dynamic Monitoring of Long-Period Structures,
  Mehmet Celebi *(U.S. Geological Survey)*

GPS IN DYNAMIC MONITORING OF LONG-PERIOD STRUCTURES

by

Mehmet Çelebi[1]

ABSTRACT

Global Positioning System (GPS) technology with high sampling rates (~10 sps) allows scientifically justified and economically feasible dynamic measurements of relative displacements of long-period structures --- otherwise difficult to measure directly by other means, such as the most commonly used accelerometers that require post-processing including double integration. Such measurements can be used to assess average drift ratios and changes in dynamic characteristics, and therefore can be used by engineers and building owners or managers to assess the building performance during extreme motions caused by earthquakes and strong winds. By establishing threshold displacements or drift ratios and identifying changing dynamic characteristics, procedures can be developed to use such information to secure public safety and/or take steps to improve the performance of the building.

KEYWORDS: monitoring, GPS, strong-motion, building, structural response, frequency, displacement, acceleration

1. INTRODUCTION

Seismic monitoring of structural systems constitutes an integral part of National Earthquake Hazard Reduction Program of the United States. In general, until recently, monitoring the response of structural systems for the purpose of assessing and mitigating effects of earthquakes (and also severe winds) has relied on measuring the shaking response by deploying accelerometers throughout a particular structure of interest to the scientific and engineering communities. In contrast, there are no efficient or feasible methods to measure displacements

[1] U.S. Geological Survey, MS 977, 345 Middlefield Rd., Menlo Park, CA 94025

during an earthquake or severe wind. Recordings of the acceleration response of structures have served us well. Studies conducted on such records have been useful in assessing design/analysis procedures, improving code provisions, and correlating the response with damage.

Since the M_s=6.7 Northridge (17 January 1994) and M_s=6.8 Kobe (17 January 1995) earthquakes, drift studies and assessment of susceptibility to damage of tall buildings have become important issues, particularly because so many steel-framed buildings were damaged, some severely and some lightly. In the Los Angeles area, for example, following the Northridge event, several hundred steel-framed buildings had to be examined, assessed, and repaired or retrofitted. Only three of these buildings were instrumented prior to the event, providing some limited acceleration response data to be used for interpretation of the widespread damage. Additional data, if available in real-time or near-real-time, could have been very useful for studies and for design of repair and retrofitting projects that followed. Therefore, there is a great need for better and more extensive monitoring of tall buildings.

Relative displacements, which are key to assessing drift and stress conditions of structures, are difficult to measure directly. On the other hand, measuring acceleration response requires a double integration process to arrive at displacements. The integration process is not readily automated because of the nature of signal processing, which requires (a) selection of filters and baseline correction (the constants of integration), and (b) often substantial judgment when anomalies exist in the records. Consequently, this process can lead to errors in the calculation of velocities and displacements. This problem is more acute for permanent displacements. Accelerometer measurements cannot be used to recover the permanent displacements at the centimeter level; and even if they could, it is questionable if it can be done in real-time. That is, the level of accuracy of displacements calculated from accelerations has not been widely verified by observations (e.g., some shake table tests performed to compare the performances of accelerometers and accelerographs have not been directed at checking displacements).

An alternative method to measure relative displacements while monitoring structural systems can be accomplished by using GPS technology, now advanced to record at 10 sps with an accuracy of ± 1 cm horizontally and ± 2cm vertically. This provides a great opportunity to monitor long-period structures reliably (e.g., tall buildings that are 20-40 stories or more). The majority of the tall buildings are flexible steel-framed structures. The fundamental period of such a flexible-framed building can be estimated with the empirical formula[2] , T = 0.1 N, where N is the number of stories of the building. This means that at least 20-40 data points will be recorded for one cycle of motion of a 20-40 story building vibrating at the fundamental period. This provides sufficient accuracy to assess the average drift ratio of a building. Such information can be very useful in assessing the damage to a building. In addition, the main value in using GPS technology to assess the condition of a building is that the displacement measurements can be made directly in real-time and with sufficient precision. As discussed later, we have made

[2] For most flexible buildings, the fundamental period (T) is approximated by 0.1N, where N is the number of floors of a building (even though the fundamental period can vary between [0.05-0.15]N depending on the flexibility of the building). Therefore, to simulate a 40-story building, we set the period (frequency) equal to 4 s (0.25 Hz) and proportioned the length, width and thickness of the cantilever.

preliminary tests to prove the technical feasibility of the application of GPS to monitoring structures.

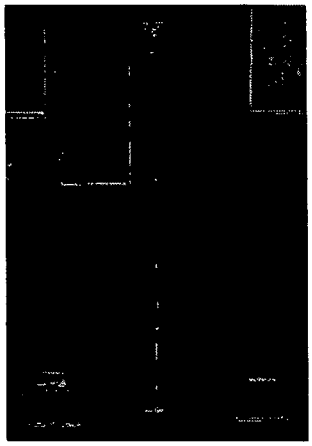
There is great potential for the application of GPS technology to monitor long-period structures during earthquakes. The application can also be extended to monitoring wind-induced deformation of tall buildings, long-span suspension and cable-stayed bridges, and tall chimneys. Furthermore, with future advances in GPS technology and improvements in sampling capability (e.g., higher than 10 sps), it will be possible to monitor short-period structures as well. Additionally, direct measurements of displacements will enable us to reliably detect structural movement caused by failure of the ground under a structure (e.g., liquefaction).

2. TECHNICAL JUSTIFICATION

In the last few years, there have been numerous studies related to the technical feasibility of using GPS to measure displacements of civil structures. Most of the initial work has been accomplished by aerospace atmospheric researchers. Studies related to the application of GPS for static or dynamic measurements of displacements of structural systems include but not limited to those by Hyzak and others (1997), Teague and others (1995), Guo and Ge (1997), Kondo and Cannon (1995), Lovse and others (1995), Hudnut and Behr (1998), Behr, Hudnut and King (1998) and Stein and others (1997). In our study, we direct the efforts to actual permanent deployment of GPS units alongside accelerometers, and also to use the displacement measurements with GPS as a health monitoring tool.

3. MODEL TESTS SIMULATING A TALL BUILDING

To investigate the feasibility of using GPS technology to monitor tall buildings (and other long-period structures), we conducted two experiments. Figure 1 depicts a photo and the overall set-up for a simple and inexpensive experiment designed by selecting a standard stock steel bar to simulate a 30-40 story flexible building. We selected the length, thickness, and width of the two bar specimens to yield a fundamental period of approximately four seconds in the weak direction.



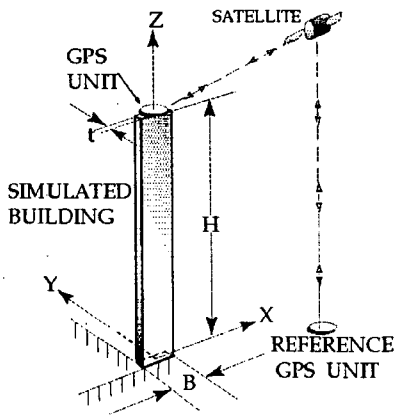


Figure 1a and b. Photo of test set-up for using GPS for dynamic monitoring of tall buildings and schematic of test set-up for using GPS for dynamic monitoring of tall buildings..

To make things simple, we purposefully selected the width and thickness of each of two bars with an extremely weaker axis in one direction. The width was varied to show the sensitivity of measurements during vibration and at 10 Hz sampling rate. Each bar was fixed at the base and the GPS unit was attached at its tip. By providing an initial displacement (simply by pulling the top of the bar and releasing), each bar was set into free vibration and its motion was recorded. Results are summarized in Table 1. Figure 2 shows the particle motion and time-history of one of the tests performed. The axes of the bar were at an angle to the NS (and EW) direction. Therefore, the NS and EW components of displacements are identical in phase and proportional in amplitude. Also, since the GPS unit is not symmetrically and concentrically mounted in the weak direction (photo in Figure 1a), the amplitudes of positive and negative displacements measured are not the same. The detection of the effect of the eccentric mass adds to the assurance that the measurements are accurate and sensitive. These simple tests and results were and can be duplicated easily and readily.

Figure 3 is a plot of NS components of measured relative displacements and corresponding amplitude spectra of Bars A and B. The figure shows the accuracy and sensitivity of the GPS monitoring technology at ten samples/second. The measurements differentiate between the frequency of the free-vibration response of the two bars with different dynamic characteristics. From the data, the fundamental frequency (period) of the two bars are identified to be 0.245 Hz (4.08 s) and 0.296 Hz (3.38 s) respectively. Also, a damping percentage of approximately 2% is extracted. This simple test shows that sampling at 10 Hz with GPS units provides a clear and accurate displacement response history from which drift ratios and dynamic characteristics of the specimen can be derived (Çelebi et al., 1997, 1999 and Çelebi, 1998). The implications of this go beyond just the measurements. It can be shown that identification of variation of dynamic characteristics can be used to identify not only different structural systems, but also possible nonlinearities that occur during vibration (e.g., due to damage and plastic behavior of the structural members, components and/or joints, or to soil-structure interaction under varying amplitudes of input motions).

4. LOOKING TO THE FUTURE: REAL-TIME MONITORING

4.1 Perceived Real-Time Monitoring

Initially, we are planning to deploy the GPS units only on tall buildings that are already instrumented with accelerometers. This will facilitate comparison of absolute and relative displacements measured by GPS and calculated by double integration of accelerations. The GPS units will be configured to provide data to indicate the real-time average drift ratios and changes in the dynamic characteristics of the buildings. This information can be made available to building managers (or interested parties) in real-time or whenever a predetermined displacement threshold is reached. The building managers can assess the response of the buildings according to (a) different threshold displacements (e.g., A, B and C as shown in Figure 4), (b) drift ratios, or (c) changing dynamic characteristics. If a situation is serious, the management can make decisions to evacuate the building for additional inspection. Therefore, one by-product of the effort would be to secure the safety of the occupants and significant contents of the building.

Thus, a real-time structural health monitoring environment will be created. At least three GPS units per building are required to monitor a tall building: two of the units should be deployed on the roof to detect translational and torsional response of the building, and the third unit will serve as a reference ground station to evaluate relative displacement. The ground site also needs excellent sky visibility.

Similar deployments are being planned for other types of long-period structures. One project in development at this time is for deploying GPS units on one of the long-period suspension bridges such as the Golden Gate Bridge and Bay Bridge (San Francisco) or Vincent-Thomas Bridge (Los Angeles). As in the case of tall buildings, changes in dynamic characteristics after the displacements at critical locations of a bridge have exceeded predetermined thresholds, can be calculated in near-real-time. When warranted, the management can make decisions to inspect the bridge (e.g., decisions can be made to stop the traffic, thus securing the bridge safety, which is one of the objectives of lifeline earthquake engineering). With the GPS technology, we can furnish time-dependent displacements for the relative movements of critical locations of structures. For example, for the bridges, GPS units placed at pre-selected locations of bridge elements can indicate, in real-time, the amplitude of the displacements of the decks and towers, as well as movements of key bridge elements relative to local bedrock reference points. Thus, movements of the piers relative to the abutments, the top of a tower with respect to its base, or the span with respect to the ground, can be made at a centimeter-level of precision, in real-time. We will recover both the dynamic motions that accompany the earthquake, as well as the static or permanent displacements experienced by the bridge once the shaking has stopped. Such permanent displacements affect the state of stress of a bridge, and provide evidence for distortion or failure of bridge elements or subsidence of piers due to ground compaction induced by earthquake shaking. A recent application for dynamic monitoring of Huber Bridge (second longest in the world after Akashi Bridge in Japan)

4.2 Current Deployments on Tall Buildings

Deployment of GPS units on the roof of two buildings in Los Angeles has been completed, and we are in the process of deploying GPS units on the roof of a building in San Francisco. Figure 5 shows the actual deployment on the roof of one of the buildings in Los Angeles. As it happens with field deployments, physical obstacles and constraints necessitate alternate approaches. In this case, the window cleaner machinery on the roof of the 44-story building travels on rails near the parapet and uses the parapet continuously. Therefore, any deployment had to be planned away from the parapet wall. To solve this problem, a stiff auxiliary support frame (Figure 5) was erected. The figure also shows the GPS antenna and the radio antenna to communicate with the reference station so that differential displacements are obtained.

4.3 Requisite Software

Requisite software is being developed to assess and mitigate the two natural hazards (earthquake and severe wind) affecting the structures by using the displacements measured by the GPS units. Figure 6 shows a screen image of software being developed to assess displacements observed with GPS and provide alarm (warning). Such collected information on the response of the

structure during strong motion events (or strong winds) can be used to make decisions for further evaluation of the susceptibility to damage of the structure, and future repair/retrofit schemes may be developed.

4.4 Benefits and Other Applications

- The collected information on the response of the structure during strong-motion events (or strong winds) can be used to make decisions for further evaluation of the susceptibility to damage of the structure, and future repair/retrofit schemes may be developed.

- The recorded data can be used to analyze the performance of the structure and such results can be used to improve future analyses/design procedures.

- The data collected can also be used to assess long-term displacements of critical locations of structural systems (e.g., permanent displacements, settlement of foundations, long-term deformations due to change of temperature and the plate tectonic deformation spanning the San Francisco Bay and parts of the Los Angeles Basin) and to develop methodologies on how the findings can be incorporated into useful practical design procedures.

5. CONCLUSIONS

It is shown in this paper that recent advances in sampling rates of GPS technology allow real-time monitoring of long-period structures such as tall buildings and long-span bridges. The advantage over conventional monitoring using accelerometers is that relative displacements can be measured reliably in real-time and with sufficient accuracy to assess potential damage to the structures. The technical feasibility is illustrated through two tests conducted on two vertically cantilevered bars that simulate tall buildings. Both approaches show that GPS monitoring of long-period structures provide sufficiently accurate measurements of relative displacements such that dynamic characteristics of the vibrating systems can be accurately identified. This capability can be used for structural health monitoring purposes. Procedures and software are being developed to permanently deploy GPS units on tall buildings and suspension bridges.

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Table 1. Results of Tests with GPS Units

Specimen	Length [H] ft (m)	Width [B] in.(cm)	Thickness [t] in. (cm)	Measured Frequency [f](Hz)	Measured Period [T](s)	Damping [ξ](%)
BAR A	6 (1.82)	1.5(3.8)	1/8 (0.32)	0.245	4.08	~ 2.0
BAR B	6	2.0(5.0)	1/8	0.296	3.38	~ 2.0

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Figure 2. Particle motion and time-history of relative displacements (NS and EW components) of simulated test specimen.

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Figure 3. Relative displacements of two test specimens (NS components only) in free-vibration and corresponding amplitude spectra identifying the fundamental frequencies of the test specimens.

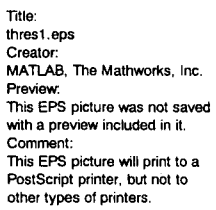


Figure 4. Hypothetical thresholds of displacements. The time-history of displacements shown is actually integrated from accelerations recorded at the 38th floor (accepted in lieu of roof) of a 44-story building. The actual record is amplified by 20 times for illustration purposes.

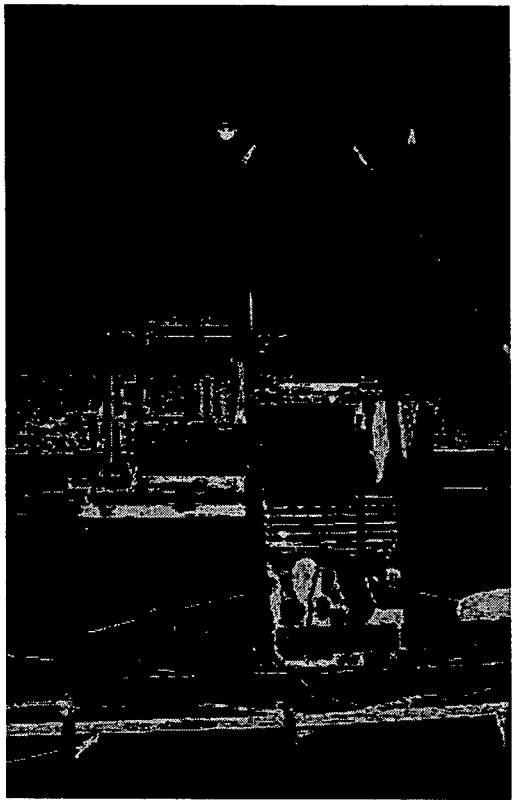


Figure 5. Deployed GPS Unit and Necessary Frame System

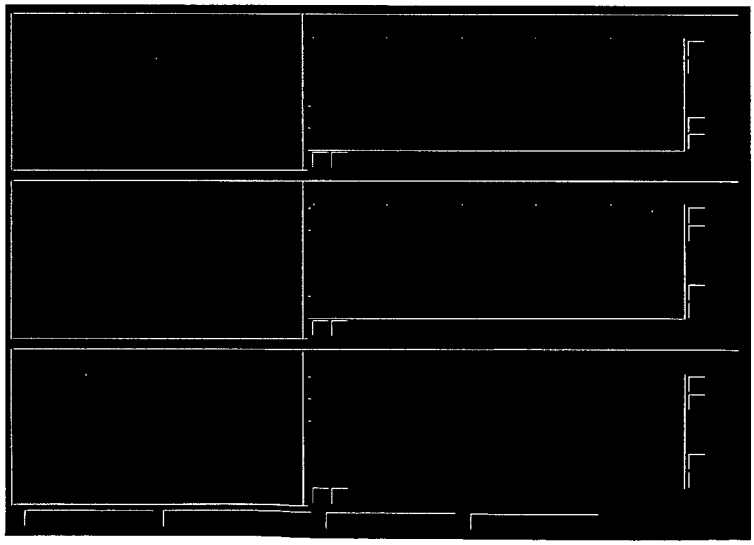


Figure 6. Software developed to provide alarms at three thresholds of displacement of an instrumented structures with GPS.

Workshop Resolutions

RESOLUTIONS OF
THE FIRST U.S.-JAPAN WORKSHOP ON SEISMIC INFORMATION SYSTEMS

Task Committee G, UJNR Panel on Wind and Seismic Effects
Public Works Research Institute, Tsukuba, Japan, November 15-17, 1999

The First U.S.-Japan Workshop on Seismic Information Systems was held at the Public Works Research Institute, Tsukuba, Japan during November 15-17, 1999 under the auspices of Task Committee G- Seismic Information Systems, UJNR Panel on Wind and Seismic Effects. The workshop was co-organized by the National Land Agency and the Public Works Research Institute of Japan and the Federal Emergency Management Agency and the Army Topographical Engineering Center of the United States. 38 experts representing the government, academia, industry and private practice participated in the workshop. 16 papers from Japan-side and 8 papers from U.S.-side were presented.

The workshop also included a technical site visit to observe disaster prevention facilities at the National Land Agency, the Tokyo Fire Department and the Center for Disaster Management and Supply Control of Tokyo Gas co. ltd..

Recognizing the importance of the technical assistance to the U.S.-Japan High-Level Earthquake Policy Cooperation Forum under the Common Agenda for Cooperation in the Global Perspective (Common Agenda), this workshop focused on the research activities in the areas below;

1) Technologies for the post-earthquake warning, notification and damage assessment
2) Technologies for the post-earthquake urgent response and restoration works
3) Technologies for the pre-earthquake loss estimation works
4) System issues and advanced technologies

The workshop participants have adopted the following resolutions;

1) The participants identified the following topics related to seismic information systems for future cooperative programs;
   a) Application of advanced technologies including GIS, GPS, satellite image, etc
   b) Development of strategies to collect, organize, archive, and distribute data from various individual seismic information systems
   c) Cost -effective technologies for the application of seismic information system
   d) Subjects that will be featured in the Third High-level Forum;
      - Information technology to provide improvements of preparedness and loss prevention measures.
      - Information technology for Tsunami hazard and risk reduction.
      - Sharing lessons learned from recent large-scale earthquakes around the world.

2) The participants recognized the importance of continued exchange of technical information, research data and research personnel. The participants further recognized the benefit of identifying and executing

specific activities comparing loss estimation methodologies, information system architectures, and risk assessment/ crisis management strategies for disaster mitigation in both countries.

3) Recognizing the integrated missions of the seismic information system, the participants encourage exchange information with the other related UJNR Task Committees and Panels on common technologies including the earthquake ground motion acquisition, the remote sensing of earthquake damage and Tsunami hazard and risk reduction. The participants also recognized the benefit of enhancing the seismic information systems to the other disasters including wind, storm surge, tsunami and flood.

4) Recognizing the importance of facilitating the development and implementation of the seismic information systems, the participants encourage continued efforts for providing the technical assistance to the Third U.S.-Japan High-Level Earthquake Policy Cooperation Forum under the framework of Common Agenda that is scheduled to be held in 2000.

5) Recognizing the importance of continued efforts, the participants recommend holding the second workshop on seismic information systems. Location, time and specific themes of the workshop will be proposed by U.S.-side chairmen of the Task Committee G, UJNR in consideration of the Third U.S.-Japan High-Level Earthquake Policy Cooperation Forum program.

6) Recognizing the importance of these activities to the earthquake disaster prevention community, the participants agreed to publish workshop proceedings, and investigate additional distribution method.

Appendices

- Workshop Program
- Participants List
- Photographs

Workshop Program

Monday, November 15

8:00- Leave Hotel (Tsukuba Dai-ichi Hotel) for PWRI

9:00- Opening Session ***(Chair: Dr. Sugita, Dr. Nishenko)***

Welcome Remarks: *Tomomitsu Fujii (Director-General, PWRI)*

Remarks from Japan: *Kazuo Okayama (Co-chairman of Japan)*

Remarks from U.S.: *William Roper (Co-chairman of U.S.)*

Introduction of Participants,
and Adoption of Agenda: *Hideki Sugita, Stuart Nishenko*

Session I : Crisis Management - Warning and Notification ***(Chair Dr. Yasuda, Dr. Nishenko)***

9:45- (1) Early Estimation System for Tsunami Hazard,
Takaharu Kiriyama (NLA), Kazuo Okayama*

10:10- (2) An Assessment of Seismic Monitoring in the United States : Requirement for an Advanced National Seismic System, *John Filson (USGS)*

10:35- (3) Real Time Provision of Earthquake Information in Japan,
Keiji Doi (JMA)*

11:00- Break

Session II: Crisis Management- Urgent Response Works and Restoration (1)
(Chair Dr. Ito, Dr. Roper)

11:15- (1) Disaster Management through Normal-service GIS Based on Spatial-temporal Database
Shigeru Kakumoto, Hiroyuki Kameda (Kyoto Univ.)*

11:40- (2) Gathering of Earthquake Shaking and Damage Information in California,
William Ellsworth (USGS)

12:05- (3) Modeling of Phase Characteristics of Earthquake Motions in Spatial Field and Interpolation of Observed Earthquake Motions, *Tadanobu Sato* (Kyoto Univ.), Yoshitaka Murono*

12:30- Group Photo

12:45- Lunch (1F)

Session III: Crisis Management- Urgent Response Works and Restoration (2)
(Chair Mr. Kiriyama, Dr. Filson)

13:45- (1) SATURN- Seismic Assessment Tool for Urgent Response and Notification,
Hideki Sugita (PWRI), Yasushi Ohtani, Tomofumi Nozaki*

14:10- (2) HAZUS Capabilities as A Near-Real Time Rapid Damage Assessment Tool,
Stuart Nishenko (FEMA)

14:35- (3) The Earthquake Damage Estimation System of Tokyo Fire Department,
Toru Fujita (Tokyo Fire Dept.)

15:00- (4) Seismic Damage Information System for Hiroshima City
Yasushi Sasaki * (Hiroshima Univ.), Hiroyuki Konishi, Satoshi Furukawa, Hiroaki Kubota

15:25- (5) "READY" A System for Real Time Assessment of Earthquake Disaster in Yokohama City,
Masanori Saito* (Yokohama City Univ.), Susumu Abe, Saburoh Midorikawa

15:50- Break

Session IV: Crisis Management- Urgent Response Works and Restoration (3)
(Chair Dr. Sasaki, Dr. Ellsworth)

16:05- (1) Systems Related to Disaster Countermeasure in NTT,
Kazuhiko Fujihashi (NTT co. ltd.), Kenzo Shigeta*

16:30- (2) Earthquake Research for Electric Utilities,
William Savage (FEMA)

16:55- (3) Development of SUPREME,
Yoshihisa Shimizu (Tokyo Gas co., ltd.)

17:20 Adjourn

17:30 Leave PWRI for Hotel (Tsukuba Dai-ichi Hotel)

18:30 Dinner hosted by Japanese

Tuesday, November 16

8:00- Leave Hotel (Tsukuba Dai-ichi Hotel) for PWRI

Session V: Crisis Management- Urgent Response Works and Restoration (4)
(Chair Mr. Nozaki, Dr. Filson)

8:45- (1) On the UrEDAS- its Development and Application for Early Warning and Rapid Information against Destructive Earthquakes, *Yutaka Nakamura (System and Data Research co. ltd.)*

9:10- (2) Geospatial Systems for Natural Disaster Planning and Recovery,
William Roper (Army TEC)

9:35- (3) Framework for Efficient Gathering of Earthquake Damage Information,
Shinsaku Zama (NRIFD), Masafumi Hosokawa*

10:00- Break

Session VI: System Issues and Advanced Technologies ***(Chair Mr. Masaharu, Dr. Savage)***

10:10- (1) Draft Manual for Seismic Information System Development,
Tomofumi Nozaki (PWRI), Hideki Sugita, Yasushi Otani*

10:35- (2) GEONET, GPS Earth Observation Network System
Kazuo Tajima, Tetsuro Imakiire (GSI), Shujiro Nishi*

11:00- Break

11:10- Special Session on Recent Earthquake Investigation
(Chair Dr. Sugita, Dr. Nishenko)

12:10- Lunch (1F)

13:10- Plenary Session

Session VII: Risk Management- Loss Estimation *(Chair Dr. Yokoi, Dr. Roper)*

14:15- (1) A Seismic Hazard Map for the Earthquake Resistant Design of Buildings,
Izuru Okawa (BRI), Mitsumasa Midorikawa, Shin Koyama, Kazuo Dan, Masayoshi Tohdo*

14:40- (2) Natural Hazards Exposure Mapping in the United States,
Stuart Nishenko (FEMA)

15:05- (3) Seismic Countermeasures of Electric Power System on the Basis of Risk Management,
Yoshiharu Shumuta (Central Research Inst. of Electric Power)

15:30- (4) American Lifelines Alliance- Reducing Risks to Utility and Transportation Systems from Natural Hazards, *William Savage (FEMA)*

15:55- Break

16:10- Adoption of Resolution

16:40- Closing Session
Closing Remarks *Masahiko Yasuda (Director of EDPRC, PWRI)*

17:00- Leave PWRI for Hotel (Tsukuba Dai-ichi Hotel)

18:30- Dinner

Wednesday, November 17 Technical Site Visit

8:00 Leave Hotel (Tsukuba Dai-ichi Hotel) to Tokyo

10:30- Information Center of Tokyo Gas

12:00- Lunch

13:30- Disaster Information System of National Land Agency

15:30- Disaster Information System of Tokyo Fire Department

17:30 Arrive at Hotel (Shinagawa Prince Hotel)
adjourn

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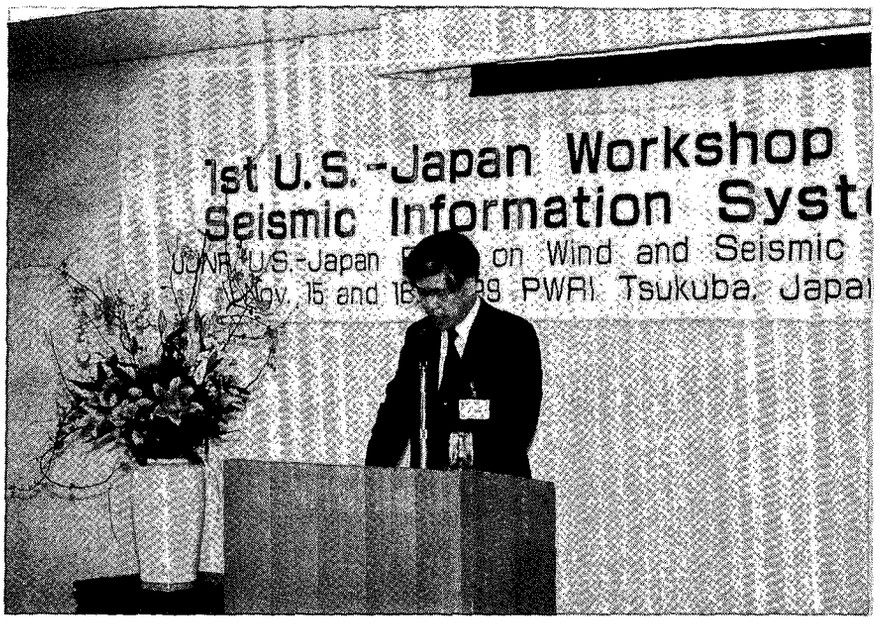
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Photographs

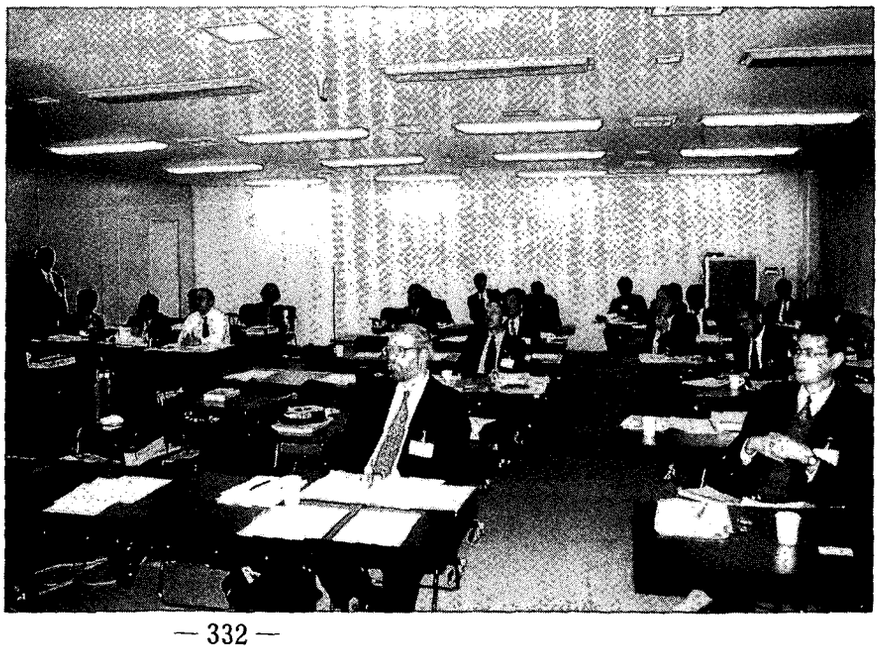
Welcome Remarks
by Tomomitsu Fujii



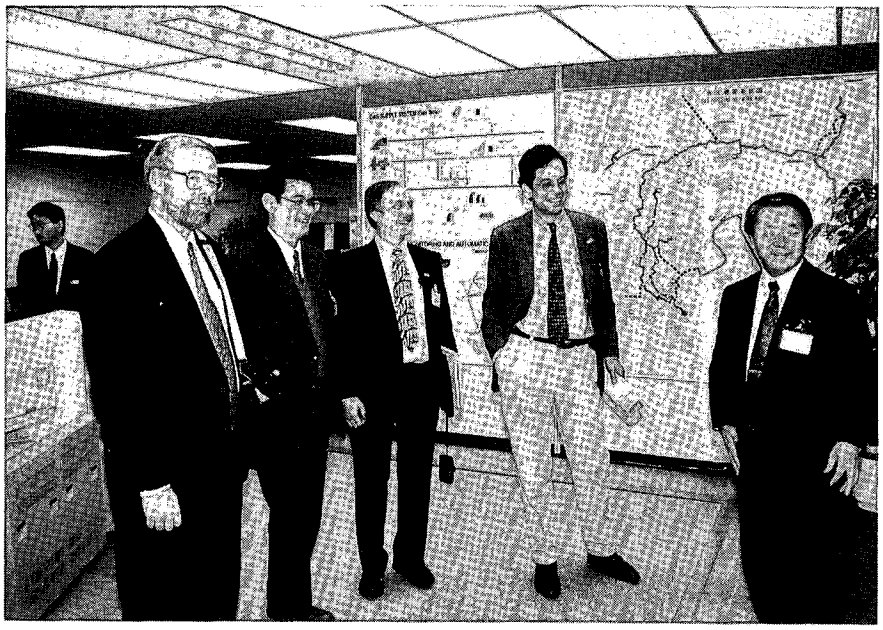
A Group Photograph



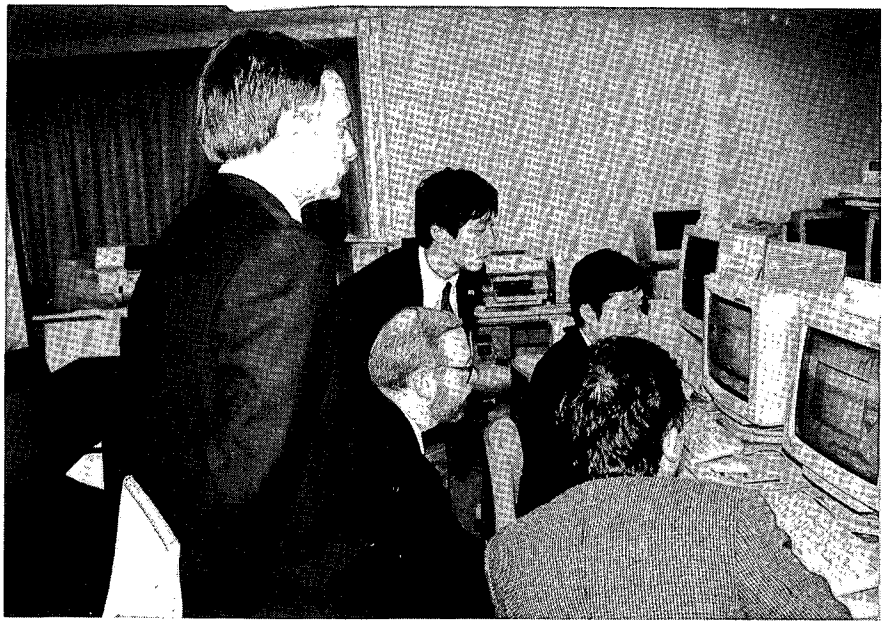
State of Meeting



Study Tour
at Tokyo Gas Co., Ltd.



Study Tour
at National Land Agency
Government of Japan



Study tour
at Tokyo Fire Department

