SEISMIC INFORMATION SYSTEM FOR NATIONAL LAND MANAGEMENT

by

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ABSTRACT

This paper introduces the basic concept of National Land Management that is advocated by Ministry of Construction in Japan recently. By especially concentrating on the relation between the earthquake disaster prevention and the National Land Management concept, the function and the promising technologies of the seismic information system is explained. The technologies include the advanced ones such as the high-resolution image from the artificial satellites and GIS. Besides those hardware/ software technologies, the importance of the system architecture for data sharing is considered. Those topics for SIS are being organized as a manual by PWRI, whose structure is also explained.

KEY WORDS: Seismic Information System
Earthquake Disaster Prevention
Information Sharing

1. INTRODUCTION

To secure the energetic activities and to achieve the safety of the country, construction of civil infrastructures has been enforced in Japan. However, considering the recent circumstances such as change of natural environment and the experiences of severe natural disasters, only constructing facilities is not sufficient. To cope with those wide area problems or emergency situations, management for national land including observation and planning as well as construction is necessary. This concept is proposed as "National Land Management" (NLM) by Ministry of Construction (MOC).

As it concerns many advanced technologies, MOC has launched the new four-year project: "Development of Advanced Technologies for National Land Management" since fiscal year of 1999 as one of the Comprehensive Research Development Projects. One of its main sub projects is the risk management information system by utilizing the recent advanced technologies including the remote sensing from the artificial satellites and GIS.

However, there is not the completely united view or concept for NLM yet. Thus, first this paper shows one of the understandings of NLM from the viewpoint of earthquake disaster prevention. Second, it concentrates on the seismic information system (SIS) that realizes NLM-based earthquake disaster prevention, and lastly, state-of-the-art of the technologies which can be applied for SIS.

2. NATIONAL LAND MANAGEMENT AND EARTHQUAKE DISASTER PREVENTION

In this paper, NLM is defined as the combined tasks to cope with the missions to secure and improve the efficiency and the safety of the

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people's life, where the various measures are utilized as well as the construction measures. General understanding of NLM is shown on Fig. 2.1.

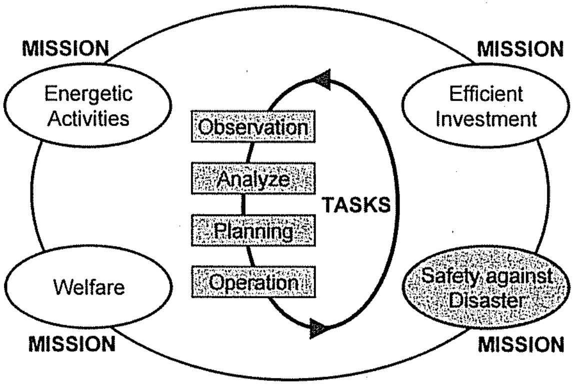

Fig. 2.1 General understanding of NLM

To cope with the missions, usually the four tasks are executed. Those tasks, observation, analyze, planning and operation are common to the activities of people and organization.

Disaster prevention is one of the important missions of NLM. There are two distinct management methods for the disaster prevention as shown on Fig. 2.2.

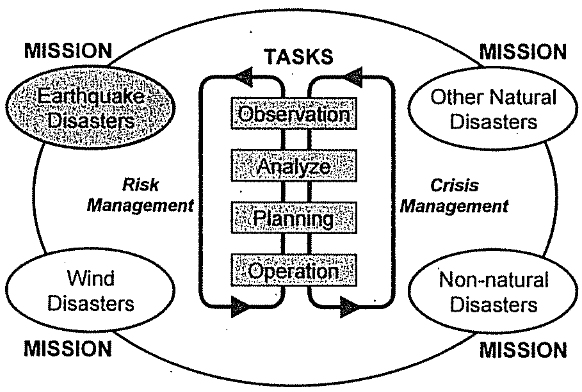

Fig. 2.2 Disaster prevention for NLM

One is the risk management where the risk means the expected loss or damage with uncertainty or chance of occurrence. Therefore, the risk management aims to minimize the expected risk based on the uncertain or probabilistic information before the disaster. The other is the crisis management where the crisis means the emergency situation after the occurrence of the disaster. Therefore the crisis management aim to localize and minimize the negative effects of the disaster once it occurs.

The earthquake disaster prevention is particular because of several characteristics: e.g., extremely small chance of occurrence and large amount of damage once it occurs, and demand for especially quick response immediately after the earthquake. In other words, the earthquake disaster prevention can be said that it deals with the very much specific aspect of NLM.

To cope with the difficulties of the earthquake disaster prevention, several methods are required to accomplish the four tasks of NLM.

- wide-area monitoring to acquire the overall information both before and after the earthquake
- data collection to acquire data at limited sites for detailed information of phenomena and state of facilities before/ after the earthquake
- analyze to aggregate, filter and overlay the data to extract the useful information for the planning and the response
- decision making support to provide information for choosing alternatives of planning and operation through more complicated execution than analyze

In reality, the methods above are executed by the personnel and the information system that organize the earthquake response system to cope with the earthquake disaster. The seismic information system (SIS) is expected to improve the speed/ efficiency of the earthquake resistant actions[1)2)](Fig. 2.3).

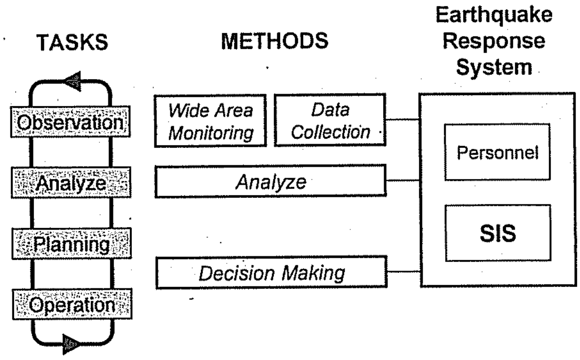

Fig. 2.3 Earthquake disaster prevention for NLM

The examples of the technologies regarding SIS are, the high resolution image data from artificial satellites, Global Positioning System (GPS) and Geographical Information System (GIS). Also, hi-performance personal computers (PCs) and network technologies are the key technologies. The state-of-the-art of those technologies are introduced in the sections from 3 to 6. Besides those element technologies, the system architecture especially concerning to data sharing is important to SIS, and is explained in section 7. From the viewpoint of the extensibility and efficient information sharing, Public Works Research Institute (PWRI) is preparing the draft construction manual of SIS, which is briefly introduced in section 8.

3. MONITORING TECHNOLOGY FOR WIDE AREA

Monitoring the state and the phenomena of the national land is the fundamental of NLM (Fig. 3.1), and it is also useful for SIS. Objectives of the wide area monitoring (WAM) are listed as follows.

- risk survey : detecting active fault, assessing landslide risks, monitoring crustal deformation, investigating risk factors such as accumulation of population and properties

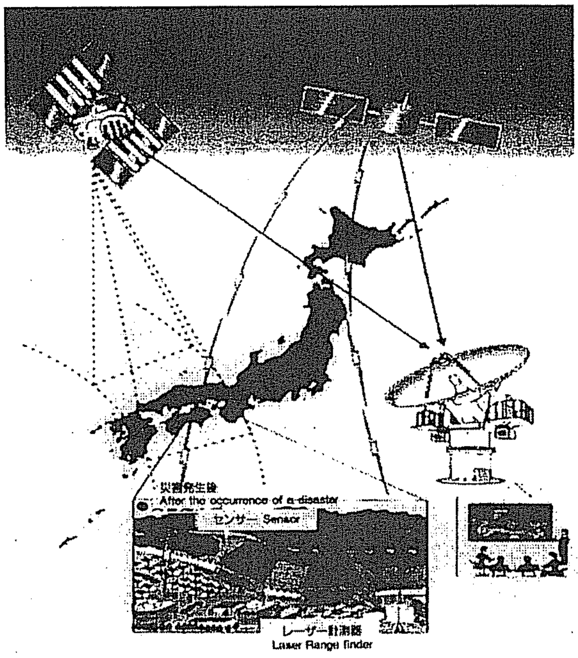

Fig. 3.1 Technologies for wide area monitoring and data collection

- event detection : detection of earthquake occurrence and direct/ indirect damage caused by earthquake
- damage state survey : surveying distribution of fire, facilities' damage and other disasters caused by earthquake

They are characterized by facts that the information comes from wide spread area and that it must be treated in extremely short time. Several advanced technologies can be applied to realize the objectives above.

(1) Artificial Satellites

As data from artificial satellites provides information of wide area from very high altitude, it fits to the wide area monitoring objective. Usually the data is provided as the images of surface that represents the surface topography or vegetation and the underground formation and so on. The satellite remote sensing is characterized by the orbit of the platform and the type of the sensor (Fig. 3.2).

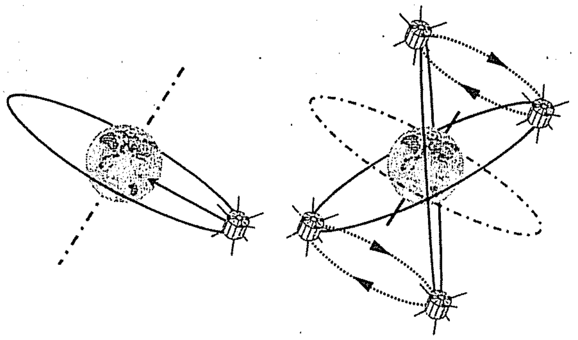

Fig. 3.2 Types of satellite orbits: geostationary orbit and sub-recurrent orbit

Because the height of the geostationary orbit is approximately 36,000 km, the resolution of the surface image cannot be much improved. For the monitoring satellites the sub-recurrent orbit with smaller height on which the satellite returns to the same position at several days interval is usually chosen.

The another characteristic is the types of the sensor equipped on the platform. The high-resolution images of the multi band sensors provide various kinds of information such as distribution of the temperature and the lineament as a clue to the active fault. The Synthetic Aperture Radar (SAR) can give the surface topography including the detailed shape of facilities.

The satellite data can be used following objectives.

- risk survey : detecting active fault by checking the lineament, surveying landslide risk based on the multi band images
- damage state survey : to detect and to survey the facilities' damage, liquefaction and landslides, fire and the secondary induced state such as traffic congestion.

Fig. 3.3 indicates the images of the same site

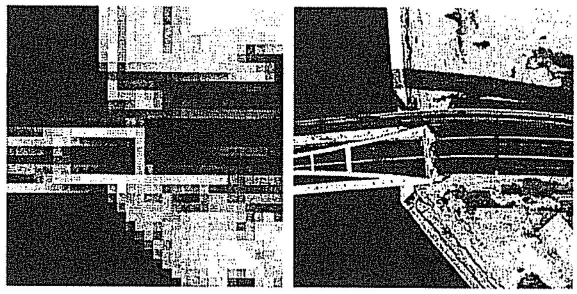

Fig. 3.3 Images: resolution 10m/ 1m

with different resolutions. Even the shape of large structure such as a bridge is hardly recognized for the resolution of 10m. On the other hand, from the high resolution image one can distinguish objects and phenomena as follows.

- structural damage in horizontal structural damage
- grand failure in horizontal direction such as ground flow and land slide
- signs of possible damages or failure in vertical direction

As the satellites with sub-recurrent orbit have their recurrent time, it may take several hours or days for them to take the image of the desired point. One must take the time for the image transaction, database control and the file transfer into account when he/she plans to use the satellite images to the emergency response.

(2) Sensors for Crisis Management

The rapid damage/ disaster detection is necessary for the efficient crisis management. Although installing sensors may cost more than WAM, it is still useful if one must detect the damage of the important facilities.

(a) GPS

Positioning a fixed point by GPS relative positioning is comparatively accurate (several centimeters for some products) than the point positioning, so one can monitor the displacement of the ground surface to detect the

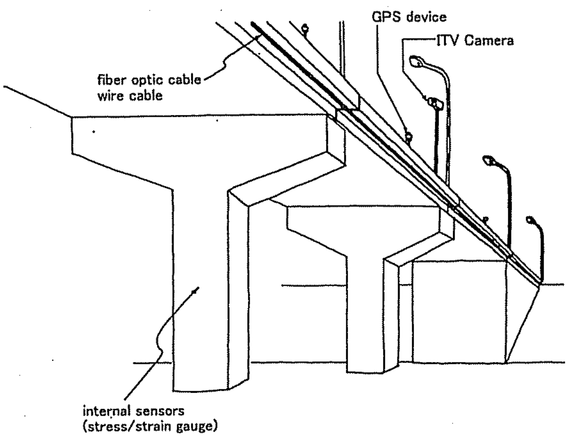

Fig. 3.4 Sensors for WAM

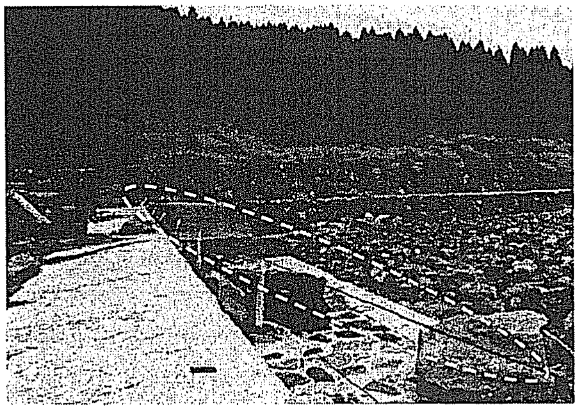

Fig. 3.5 Wire sensors installed at Sabo dam to detect debris flow (Erosion and Sediment Control Division, PWRI)

landslides and other earth disasters. Thus, GPS can be applied both for accurate risk monitoring before the earthquake and for the real-time detection of large deformation for the crisis management.

(b) Fiber optic cable

The fiber optic cable also can be used as the sensor to detect the unusual displacement/ deformation of the facilities. While GPS can monitor the positions of the dispersed points, the cable sensor can provide the location along the cable where the deformation exists.

(c) Accelerograph

(a) and (b) are the sensors to monitor the time dependent phenomena or to detect the unusual events. However, installing sensors to all the facilities will not be economically efficient. MOC has installed the accelerograph network with about 700 accelerographs so that the numerical data such as maximum accelerations are aggregated immediately after the earthquake and that they can help counter-earthquake response activities. The data cannot only be used for the reference, but also be used for other calculations such as the real-time damage estimation.

The image of the sensors installed at the bridge site is shown on Fig. 3.4. Such sensors are

Table 3.1 WAM technologies

	geostationary satellite	sub-recurrent satellite	GPS	fiber optic cable	accelerograph
risk assessment					
active fault	X	O	X	X	Δ
crustal movement	X	Δ	O	Δ	X
landslide risk	X	Δ	X	X	X
social state	O	O	X	X	X
crisis management					
earthquake ocurrance	X	X	X	X	O
facility damage	X	Δ	O	O	Δ

O : level of practical use
D : potentially practical with R/D
X : not level of practical use/ no relation

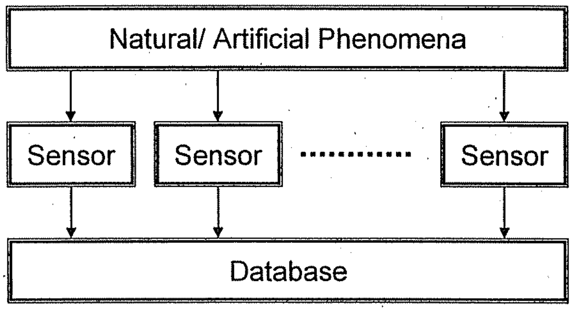

Fig. 3.6 WAM subsystems

already utilized for the response to other disasters including erosion and sediment control[2)3)]. Fig. 3.5 shows an example of the wire sensor installation to detect the debris flow.

The input of WAM system is various phenomena and they are transformed to the electromagnetic signals by the sensors, and stored to the database with certain format. The data are stored to the database system to be shared by the subsystems of SIS (Fig. 3.6). Also, efficiency of WAM technologies to the earthquake risk/crisis management is summarized on Table 3.1.

4. DATA COLLECTION TECHNOLOGY

While the data are required before or immediately after the earthquake with WAM, more detailed information of the facilities' damage is quite useful to manage the efficient counter-earthquake response. Also the information about the state of response activities is necessary once it starts.

The data sent from investigation teams may take various forms: e.g., text, photograph, image and numerical data. They are categorized to two groups: that is, the investigation information and the support information. Here, the system to collect these kinds of data is called the data collection (DAC) system.

The investigation information includes the damage data of facilities, and is directly used for the following earthquake response such as immediate restoration and rehabilitation. On the other hand, the supporting information is used to know the state of response activities, which includes the position of investigation teams and helicopters.

The technologies used for the data collection include the mobile terminal to input the text and numeric data, digital still camera, camcorder and the GPS device. Recent progress of the market of mobile gears may have installation of this type equipment easier (Fig. 4.1). As for the GPS, because the point positioning has more than several tenth meters, the relative positioning technologies that need the extra communication system will be appropriate (Fig. 4.2).

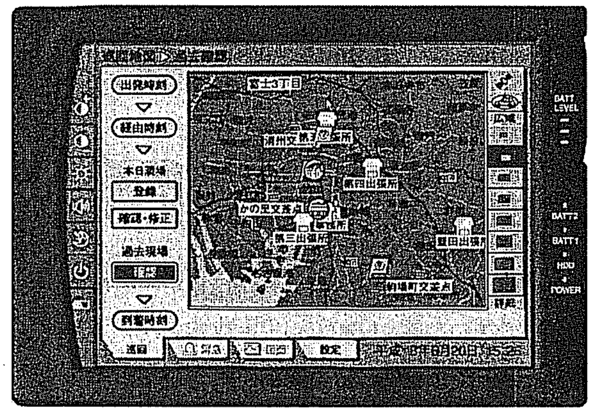

Fig. 4.1 Mobile terminal for investigation (Chubu Construction Bureau)

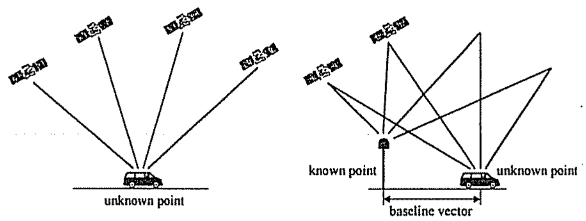

Fig. 4.2 GPS positioning: point positioning/ relative positioning

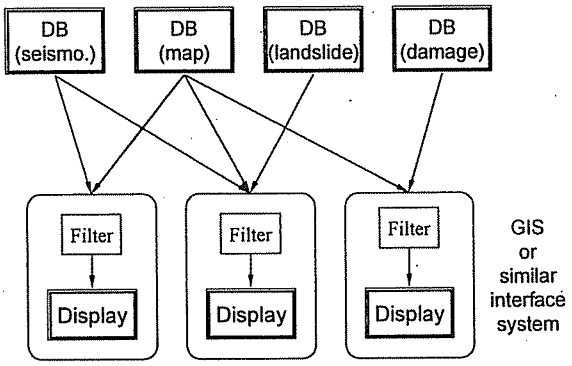

Fig. 4.3 DAN subsystems

The collected data are stored to the database just as same manner as the wide area monitoring (Fig. 4.3).

5. ANALYSING DISASTER CONDITION

As the data collected by DAC system are of the objects that have their own positions, attributes and the times of incidents, they are best to be treated on GIS system. With its ready-to-use functions such as route searching and buffering functions, GIS can be a good interface not only for the display but also for the analyzing equipment for investigation data and the investigation supporting.

The data that monitored, stored and collected are not very much useful until they are processed and combined together. Followings are the several examples of such data analyze.

- to analyze the image data: for example, survey active faults by emphasizing lineament with image filtering
- to clarify the seismic risk by overlaying the hazard data and the socioeconomic data to clarify the risk
- to check the emergency investigation activities by overlaying the damage map and the investigation teams' GPS data
- to search, sort and filter the facilities with specific keys such as types, routes and design conditions

Those data processing with general algorithms are defined as the data analyze (DAN) here, which can be realized with the stored data monitored or collected and with the general GIS or similar interface system. Here, such function that just displays the aggregated data on the CRT or other devices is included in this data analyze function. Fig. 5.1 shows the image of the data analyze (and display). Based on the databases of accelerograph observation, maps, landslide risk and facility damage, each terminal with filtering and displaying function can aggregate, filter, compose and display that each user wants to know.

6. DECISION MAKING SUPPORT

(1) Decision Making for Risk/Crisis Management

To support the decision making regarding the earthquake risk/ crisis management, more specific functions than simple data processing techniques are required[2]. Examples of such function, decision making support (DMS), are

- earthquake disaster loss estimation including

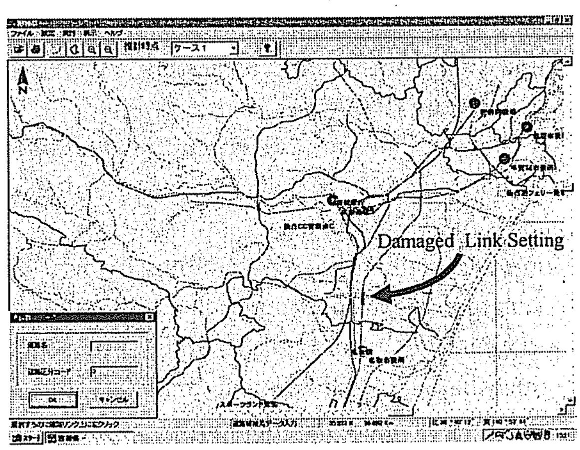

Fig. 6.1 Example of socioeconomic effect loss estimation system (PWRI)

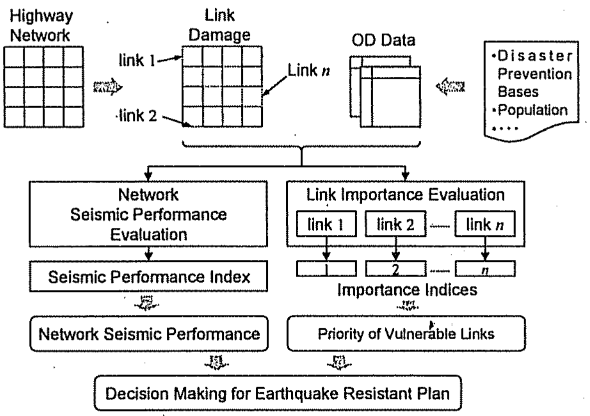

Fig. 6.2 Example of retrofit prioritizing

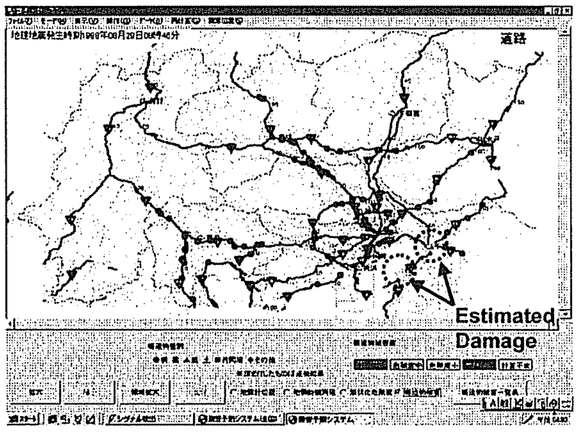

Fig. 6.3 Example of real-time damage estimation (PWRI)

direct/ indirect economic losses and other effects[4] (Fig. 6.1)

- prioritization for the earthquake resistant measures such as retrofit especially regarding the civil infrastructure as a total system such as network (Fig. 6.2)
- real-time damage estimation for the rough understanding of the severe damage possibility[5)6)] (Fig. 6.3)
- route-searching for determining detours and emergency transport routes
- optimization of dispatching personnel, distributing machines and materials for the restoration and rehabilitation

The main bodies of those technologies are the execution modules with input data given by the databases. The calculated results are stored to the databases and referred and analyzed by each terminal. Each subsystem uses the input data, and stores its results to the database to be referred by DAN subsystems.

(2) Decision Making for Contingency Planning

Besides the application of SIS to the risk/ crisis management, examining if the SIS and the counter-earthquake system including it work correctly under contingent circumstances is important for the efficiency of SIS. First, as SIS in reality is operated by personnel, the counter-earthquake activity training is useful to know potential problems. In addition, examining the performance of the responding action by simulating various contingent state is important to compensate the limited chance of real training. Such simulation function is also included in SIS[2)].

7. DATA SHARING AND EXTENSIBILITY

Even though there are many useful elemental technologies, the efficiency of the system varies depending on how it is organized. Followings are possible problems.

- if each subsystem is isolated, there are duplication of the data (*data duplication problem*)
- if SIS is developed as the single and huge system, maintenance of the data and the subsystems is complex (*maintenance problem*), and it is difficult to revise the subsystems when new technologies are obtained (*extensibility problem*).

One of the solutions to avoid those problems is to clarify the structures and the formats of the data dealt with in SIS so that each subsystem

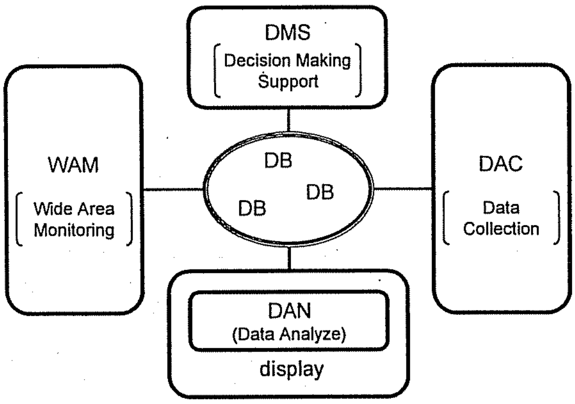

Fig. 7.1 Data sharing architecture

can understand how they are treated[2]. Once the data are shared in SIS, the former problems are solved and it acquires the important advantages.

- the system can increase its functions satisfying the new demand.
- the system can utilize the newest technologies at each time.

To obtain these advantages, first one must examine the activities and clarify the information dealt with in the system. Next, the structure of the information needs to be organized so that each subsystem can share the data (Fig. 7.1).

Recent movements in the information technology area coincide the concept proposed here. One is the 'unified modeling language' (UML) for the object oriented analyze and design. As it is for the programmers', the personnel of earthquake response system do not necessarily use it. However, it suggest that analyzing and designing the complex system needs to clarify the information structures and share them. The other example is 'extensible markup language' (XML) which is the unified method to share the data on the network regardless of the kind of hardware and software. This technology will be a candidate to develop an extensible, data-shared SIS.

8. MANUAL

As a guideline for the construction of efficient SISs, PWRI is developing the 'Construction Manual for Seismic Information System (draft)'. Instead that the conventional manuals of this kind usually focus on the elemental technologies, this manual also emphasizes the system architecture for extensible and data-shared system. The contents are shown below.

1. General
   1.1 Objective
   1.2 Structure of this Manual
   1.3 Terminology
2. Fundamental Philosophy of SIS Construction
3. Requirements of SIS in Terms of Counter-earthquake Activities
   3.1 Stages of Counter-earthquake Activities
   3.2 Information and Technologies for Counter-earthquake Activities
   3.3 Information and Technologies to Maintain Counter-earthquake System
4. Technologies of SIS
   4.1 Common Base Technologies
   4.2 Detection Technologies
   4.3 Communication Technologies
   4.4 Technologies for Display and Analysis
   4.5 Decision Making Support Technologies
5. Safety of SIS
   5.1 Reliability of SIS
   5.2 Security of SIS
6. Preliminary Design Example of SIS
   6.1 Target Determination
   6.2 Framework Design
   6.3 Design of Common Parts
   6.4 Design of Individual System
   6.5 Schedule to Improve SIS

9. CONCLUSIONS

(1) In this paper, first the concept of NLM is

reviewed, and the NLM for disaster prevention is carefully analyzed focusing on the tasks: i.e., observation, analyze, planning and operation. Then, focusing on the earthquake disaster prevention the methods to accomplish the tasks are examined.

(2) SIS is defined as the information/ communication systems that applies and supports earthquake disaster prevention related methods,

- wide area monitoring
- data collection
- analyze
- decision making

Also the state-of-the-art of its technological developments and their trends are examined. The points of technological developments of SIS are summarized as follows.

- Utilization of the data from satellites and GPS positioning for the wide area monitoring (WAM)
- Installation of fiber optic cables and GPS devices for the data collection (DAC)
- Application of GIS for the data analyze (DAN)
- Subsystem technologies including loss estimation, prioritization and optimization for the decision making support (DMS)
- Securing the data sharing and extensibility

(3) After the Hyogo-ken Nanbu earthquake, many public bodies and private sectors have developed the seismic information system. However, many of them are isolated in planning and development with each other. The SISs do not fully operate and support the earthquake response system until they and their subsystems are connected efficiently with each other. Thus, SISs need to be developed with common concept to share the information and to operate cooperatively.

REFERENCES

1)KAWASHIMA Kazuhiko, TOKIDA Kenichi, SUGITA Hideki, NAKAJIMA Tomoru and MATSUMOTO Hideo: Guidelines for Disaster Information Systems for Important Infra-structures, Proceedings of the 25th Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects, UJNR, pp. 475-486, 1993.5

2)SUGITA Hideki, NOZAKI Tomofumi: Seismic Information System for Civil Infrastructures, Proceedings of the 30th Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects, UJNR, pp. 306-318, 1998.5

3)YAMADA Takashi, MINSMI Noriyuki, MIZUNO Hideaki: Developing of Debris Flows Predictions and Detection Technology - Their Future Issues, Journal of the Japan Society of Erosion Control Engineering, Vol. 50, No. 5

4)NOZAKI Tomofumi, SUGITA Hideki: System To Assess Socio-economic Effect of Earthquake Disaster, Seventh U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems, 1997.11

5)ODAGIRI Shun-etsu, SUGITA Hideki, KANEKO Masahiro, NOZAKI Tomofumi and HAMADA Tadashi: Development of Real-time Information System for M.O.C, Proceedings of the 30th Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects, UJNR, pp. 425-435, 1997.5

6)SUGITA Hideki, HAMADA Tadashi: Development of Real-time Earthquake Damage Estimation System for Road Facilities, Seventh U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems, 1997,11