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A TRIAL APPLICATION OF REAL-TIME DISASTER MITIGATION SYSTEM BASED ON STRUCTURAL CONTROL SYSTEMS

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SUMMARY

A real-time disaster mitigation system (RDMS) is proposed to provide effective damage information on a building's facilities and structures based on data obtained from arranged sensors, cameras and information devices of building equipment using network communication means immediately after earthquakes. This is useful for quick recovery for the owners and administrators and brings a sense of security to occupants. It also provides information on a building's routine maintenance and security. This paper describes a trial application of RDMS to an actual building in Tokyo that has been equipped with an Active Variable Stiffness system (AVS) since 1990.

INTRODUCTION

Various structural control systems have been proposed to reduce vibration during earthquakes and strong winds, and a lot of research and development has been carried out from the theoretical, experimental and verification viewpoints [7, 14]. These systems are divided into passive control systems, which don't require any control computer or energy supply to ensure building safety during severe earthquakes; active and hybrid control systems, which require control computers and structural control devices with an energy supply to provide living comfort to building occupants; and semi-active control systems, which also require control computers and structural control devices, but with a smaller energy supply than the active control system to achieve the ultimate purpose of providing more efficient seismic protection to structures during severe seismic events. The semi-active control system seems to be playing the leading role in the future of active structural control [28]. The world's first semi-active control system, the active variable stiffness (AVS), was completed in 1990, and its effectiveness against large earthquakes has been established [12]. Since then, semi-active control systems have been applied to buildings and studied [5, 15, 17, 25, 29, 35].

However, their structural control systems, except for the passive one, require control systems composed of vibration sensors and control computers. This paper discusses only the active, hybrid, and semi-active structural control systems. These systems are generally efficient only during seismic events or strong winds. Furthermore, the control computer for the structural control system has a short life, often seven years or less. This is less than that of the controlled device or building itself. Therefore, the control

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computer system should be renewed regularly in order to maintain the system performance. Actually, the control computer of the AVS system mentioned above has been renewed twice, in 1994 and 2002 [23, 26].

For the building owner who is considering introducing a structural control system, the repeated cost of renewing the control computer may be a disincentive. However, that fact that the control system is composed of a computer, vibration sensors and a communication system gives us an idea. With recent advances in information technology, cheap and simple high-performance computers have become available. With the development of the Internet, it is natural for communication networks to exist anywhere in a building. Moreover, for building equipments, it seems to be a trend to make their operation and maintenance more efficient with energy management using operation data transferred from the communication networks. This enables various building equipment to communicate with each other. This is called the spread of building automation open networks [e.g. 33].

Thus, if the structural control system cooperates with the Internet, various building equipment or their networks, or, if it has another daily and efficient role as discussed above, it could maintain the building owner's motivation for renewal of the control system and it has the great advantage of popularizing structural control systems.

Moreover, the rapid progress of information technology in recent years has made building functions in urban area depend greatly on the technology, and it makes these functions increasingly complex, sophisticated [11] and more fragile against earthquakes. Thus, even minor damage can lead to a large disaster [e.g. 1]. However, in spite of this weakness, the importance of building equipment functions is increasing. As a result, disaster prevention in urban areas is becoming still more difficult. Moreover, recently, the degree of cognition of the crisis of a severe earthquake has been increased. Therefore, a solution to the problem is required.

Our proposal focuses on this point. As discussed above, structural control systems have vibration sensors to detect the arrival of a seismic event and the building responses it causes. Therefore, for a seismic event, a proposed real-time disaster mitigation system (RDMS) with a structural control system performs comprehensive disaster mitigation functions for buildings as well as being the disaster information hub. As a result, the structural control system can dispense with the need for a category of special equipment for building structures, thus combining it more tightly with buildings as comprehensive disaster prevention equipment [36].

Recently, many researchers in the structural control field have become interested in structural health monitoring or damage sensing of buildings with vibration sensors, strain sensors and various sensors for surveying the condition of structural elements after a seismic event [e.g. 8, 16, 18, 21, 40]. Although these researchers take particular note of measurement or surveillance, they seem not to pay attention to disaster mitigation. Many of these researches on structural health monitoring use communication networks on the Internet to supply information to the remote office and analyze it manually [e.g. 9, 31]. Meanwhile, the proposed RDMS should be characterized by its purpose and real-time performance. The purpose of the proposed RDMS is to mitigate building disaster based on vibration observation data and building equipment operation data immediately after an earthquake using a communication network on the Intranet in the Internet. Moreover, the proposed system acts automatically in severe real-time.

There is another research item that is important from the building owner's standpoint. Some building owners require reliable and timely expert advice on whether or not to occupy a building following an event. Damage to steel structures is frequently not immediately visible due to the presence of building finishes and fireproofing. Because this invisibility causes the lack of certainty regarding the actual deformations that the building has experienced, the post-earthquake inspector makes a conservative judgment. If the building has a yellow or red tag, it may not be available for several days following the earthquake. This is large disadvantage for the building owner. With this system, the expert engineer obtains the observed data using the Internet and analyzes it manually in loose real-time. In fact, researchers are very interested in real-time engineering [4].

Meanwhile, so-called real-time earthquake engineering has been studied extensively. Topics include utilization of *pre-earthquake* information [e.g. 20, 22, 39], function control of public lifelines [e.g. 34] and a method for immediately estimating the seismic center and earthquake disaster, etc. [e.g. 6, 10, 19, 32]. Research has rapidly progressed against a background of great advances in information technology [e.g. 27, 30, 38]. Many research objects have been treated in widespread urban areas, but not in individual buildings. The proposed RDMS is characterized by the fact that it can function in the *pre*-, *mid*- and *post-earthquake* situation, where the *pre-earthquake* includes normal conditions, utilizing structural control systems.

This paper first describes the concept of the RDMS. The relevant comprehensive building disaster mitigation functions are discussed next. At the latest renewal of the AVS control system, the first construction of the RDMS was implemented. The latter half of this paper presents a trial application of the RDMS to an actual building with an AVS system.

CONCEPT OF REAL-TIME DISATER MITIGATION SYSTEM

Concept of real-time disaster mitigation system

The concept flow of the proposed RDMS is shown in Figure 1. It is presented in a time sequence. "*Mid-EQ*" is defined as the period during an earthquake. "*Pre-EQ*" and "*Post-EQ*" are defined as the period before and after the earthquake, respectively [13]. The time period immediately after the earthquake is called "*Immediate-Post-EQ*". To distinguish between the "*Post-EQ*" and "*Immediate-Post EQ*" characterizes the RDMS research unique from other real-time earthquake engineering research studied in various ways [e.g. 27, 30]. The RDMS would function in correspondence with the *pre*-, *mid*- and *immediate-post-earthquake*, respectively, where the *pre-earthquake* includes normal conditions utilizing structural control systems.

The proposed system is essentially a disaster mitigation system for a building. However, to use a communication network like the Internet that is disposed in urban areas, the systems in a building may be connected with each other and it may become a synthetic system in an urban area with more than just a system. However, the simplest system composed of a vibration sensor and a computer without any control device acts as the minimum RDMS independently of a structural control system. The system based on the concept flow is outlined with some examples as follows.

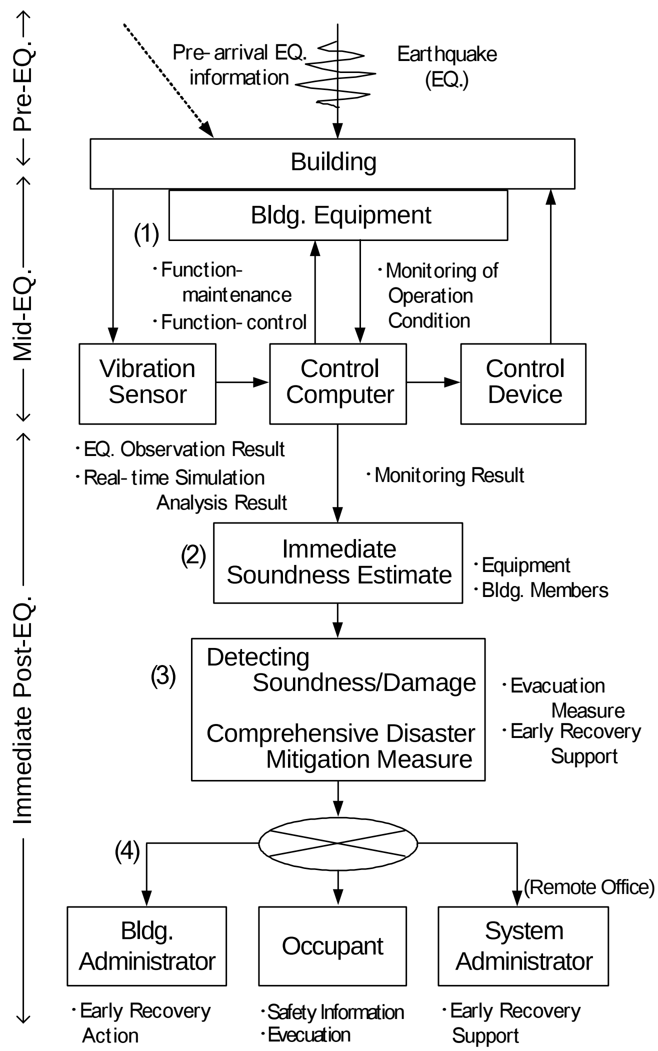


Figure 1 Concept of real-time disaster mitigation system

Maintenance function and control function of building equipment based on vibration measurement with vibration sensors

Some building equipment functions need to be maintained in the *mid*- and *immediate-post-earthquake* periods and some should cease temporarily at an earthquake response level in the *mid-earthquake* period to protect personal safety and to prevent secondary damage caused by the incident. The proposed RDMS will maintain or stop a function depending on its purpose, utilizing the vibration information obtained from its vibration sensors.

For example, the function of a private electric generator needs to be maintained. The RDMS will control the device with a vibration control unit for the generator and the supply system for the required fuel and cooling water to maintain the generator's function. To accomplish this, the RDMS estimates the damage to the supply system with a story drift angle derived from the observed vibration information and the flow information on the pipe, then detects the leakage and prevents secondary damage caused by the leakage.

As another example, the elevator seismic system triggers to protect human safety and prevent secondary damage, which is often composed with minimal seismic information in an elevator machine room, to ensure that it operates effectively with abundant information supplied from the RDMS.

The RDMS will provide effective information for us to use the authorized pre-arrive earthquake information in the near future. A water supply control system, described later, is another example of such a control function.

Immediate soundness estimate of structures, building equipment and members utilizing vibration measurement results with vibration sensors

For actual building administrators, in order to minimize damage due to earthquakes as well as natural disasters and accidents, it is essential and important to promptly and accurately check the damage and to take preventive action as quickly as possible against expanding secondary damage in a building and in building clusters. Actually, building administrators often check the building on foot without using the elevator to detect the conditions of the building, where it is not concerned with the size of the building. It may take too much time and labor for that. Therefore, with the initial correspondence supported by the proposed RDMS, it can be useful for them to estimate the soundness of structures, various building equipment, building members, etc., immediately after the earthquake, utilizing the observed response information using vibration sensors located at various places in the building.

Structural designs normally take earthquakes into account, as do designs to some extent for main building equipment [3]. Although agreement cannot be guaranteed between the damage due to the design earthquake and the actual one, if design criteria are used as the basis of the estimate as one of references, it should be possible to immediately estimate building soundness to some degree of accuracy. This method is particularly effective where a primary early estimate in a severe earthquake is required. Another soundness estimating method is to utilize the various fragility curves proposed to date [e.g. 2, 37]. Such early soundness estimates, although rough, would play a significant role in initial *immediate-post-earthquake* actions.

Analysis with real-time simulation can be carried out for *mid-earthquake* conditions using a control computer [24]. This uses an analytical model that accurately simulates building response. It can grasp the parameters that cannot be immediately determined only from the observation with the vibration sensors. The parameters are, for example, story deformation, forces in structural members, forces and deformation in structural control devices. Comprehensive evaluation of these results together with the above estimates can improve soundness estimate accuracy in *immediate-post-earthquake* actions. This is one of the significant merits of the proposed system, although it needs severe real-time performance.

Detecting soundness conditions of building equipment and comprehensive disaster mitigation measures

Recently developed automated building equipment has enabled monitoring of operation conditions and central management of complicated facilities. However, in most cases, their main functions are limited to surveillance and operation management of equipment under everyday conditions in loose real-time. In a few cases, control functions are designed for maintenance of building functions and early damage recovery after an earthquake. Here, improved disaster mitigation functions utilizing a control computer are presented from the viewpoint of safe emergency evacuation, early recovery, etc., in the *immediate-post-earthquake*. The control computer monitors the conventional equipment, checks the soundness of various equipment, and carries out advanced comprehensive analysis and judgment concurrently and totally. Several examples are given as follows.

One method is to facilitate safe emergency evacuation by detecting irregular building conditions. The control computer instantaneously judges whether the route is usable or unusable for evacuation, based on the image information from monitoring cameras regularly used for security and data on soundness of the building members estimated in the above section. Furthermore, the evacuation simulation would be carried out in a real-time manner based on the same information. The simulation may thus achieve real-time instruction for evacuation that has higher instantaneousness and reliability.

A similar example is shown by management of cases where functions remain working even though equipment is partially damaged. If there is a damaged water supply route, a possible emergency plan is to detach the damaged route and switch it to an undamaged one. This is a rearrangement of the water supply system to ensure the water supply. It also becomes possible to automatically draw a plan for recovery to enable efficient early restoration of equipment depending on the damage severity.

Furthermore, earlier re-start of elevator operation after an earthquake is expected by utilizing the observed data with vibration sensors, as described in the above section. This can be accomplished by quickly estimating the soundness conditions of the building and the elevator equipment based on the data captured in *mid-earthquake*. In the past, once an elevator function was stopped by the elevator seismic system trigger, immediate re-start was impossible in most cases before completion of the manual inspection by the specialized engineer. This has been a large factor in obstructing early recovery in *post-earthquake*. However, this problem may be partially solved by the actions described above.

Notification (information conveyance)

Earthquake and disaster information greatly influences activities and judgments of earthquake victims. However, enough information often cannot be obtained. The information gained as described above is conveyed to building administrators and occupants in the most efficient manner using various information conveying means such as cellular phones, PHS, the Internet, bulletin boards, wireless, etc. Information is also conveyed to the system administrator in the remote office.

As a result, building administrators can obtain *immediate-post-earthquake* information on whether or not there is any damage to a building and equipment and how severe the damage is. If necessary, they can take action for early function recovery based on the measures stated in the above section. Furthermore, information on the building conditions is quickly provided to the occupants, who can get safety information when there is no damage, thus avoiding unnecessary confusion. In an emergency where evacuation becomes necessary, information for safe evacuation is provided and actions can be taken for quick evacuation. Furthermore, information about the building is simultaneously provided to the system administrator in the remote office. It thus becomes possible to move forward to the initial phase of activities such as supporting early recovery of the building, etc. For example, if several companies' branch offices are distant from the head office and the one is damaged by a natural disaster, the other offices can take early recovery action for the damaged building according to the judgment by the system administrator.

If information conveyance as above spreads over plural buildings, it leads to advanced district prevention measures with joint information between buildings in an urban area.

System merits under normal conditions

The proposed system can control the surveillance function of the building equipment under normal conditions. If information on normal operating conditions is collected, an energy management function of the building equipment can be easily added to the system. Furthermore, the additional function enables the implementation of commissioning such as detection of wrong settings in the construction of building equipment. This leads to correct setting of management parameters and improves the operations, indicating that the system is applicable not only to *mid-earthquake* measures but also to *pre-earthquake* measures under normal conditions, thus greatly increasing the practical value of the proposed system.

The operating conditions of the structural control system can be remotely observed and operated by the system administrator in the remote office.

TRIAL APPLICATION OF REAL-TIME DISASTER MITIGATION SYSTEM TO ACTUAL AVS SYSTEM

It is important to realize the proposed RDMS with an actual structural control system. A partial application of the RDMS concept has been tried with an actual AVS system that has been in operation for the thirteen years since 1990 [12]. This AVS system actively controls the structural stiffness of the building to establish a non-resonant state against earthquake excitations, thus suppressing the building's response. A variable stiffness device (VSD for short) consumes a small amount of energy, making it possible to effectively control the building against large earthquakes. The control computers of the AVS system were renewed twice, in 1994 and 2002, since its completion, because of the superannuation of the computers [23, 24, 26]. The latest renewal was carried out using recent rapidly advanced communication

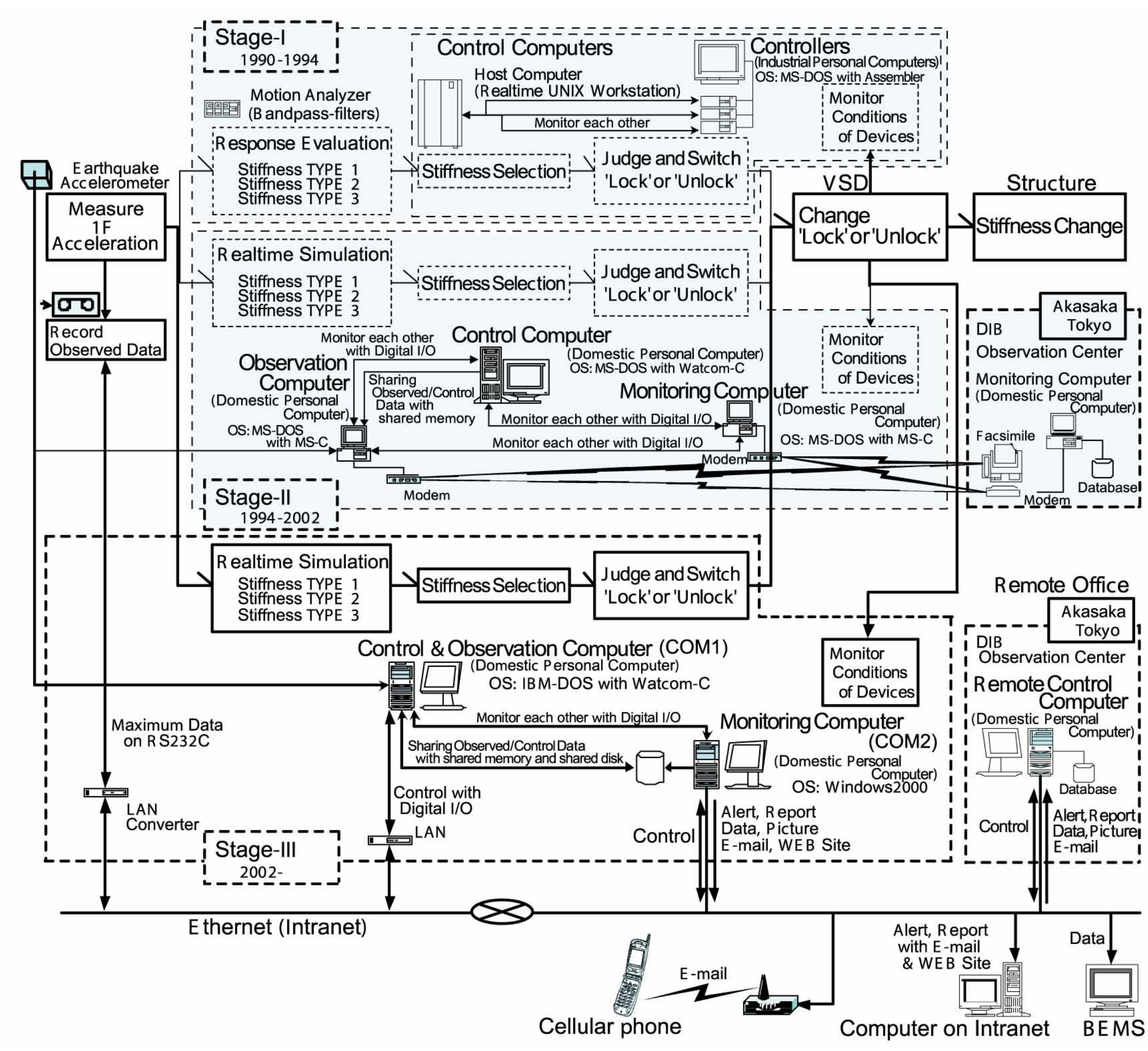


Figure 2 Outline of the control system of the AVS system

network technology in order to decrease system maintenance and increase system reliability. At the renewal, the first construction of the RDMS was implemented. The outline of the latest renewal and a trial application of the RDMS to an actual building with an AVS system are described here. Figure 2 shows the outline of the control system of the AVS system. These new functions are only a part of the proposed RDMS, and it is only a trial. However, this should be beneficial for data accumulation aimed at practical use for the RDMS. The trial application of the RDMS is discussed in the latter half of this section.

Outline of latest renewal

The control system had to be renewed in order to maintain its functions, enable advanced research results and utilize new technologies. The original AVS system is called Stage-I control system (Stage-I for short) [12], the system renewed in 1994 [23, 24] is called Stage-II control system (Stage-II for short) and the system renewed in 2002 [26] is called Stage-III control system (Stage-III for short).

Stage-I in 1990 was composed of a real-time UNIX workstation with three CPUs in order to execute appropriate stiffness judgment in real-time and three industrial personal computers to operate six VSDs. Because the real-time evaluation of the responses of three selective stiffness types with real-time simulation was impossible in those days, a motion analyzer with several band-pass-filters was used. The workstation and computers monitored each other and the computers monitored the conditions of the controlled devices. These warnings in monitoring were shown on the CRT of the workstation and computers simultaneously and some recorded voice warning messages were sent by a telephone line. For the system administrator (S.A. for short) in the remote office, the only way to detect the detail of the warning was to go and get them directly from the control console.

Stage-II in 1994 was composed of three domestic personal computers. The remarkable result of the system was that it realized simulation of the responses of the three selective stiffness types with observed seismic data in real-time using analytical models. It also sensed unusual changes, some observed seismic data and building responses, as well as some operating and control information of the system. The three computers monitored each other and reported by facsimile in cases of some unusual conditions. The system could deliver an alert to the S.A. in the remote office by facsimile. Then, he could get the observed data using a telephone line and a modem. The S.A. in the remote office could thus get the detail of the system at his desk. This was a prototype of the information function of the proposed RDMS.

Stage-III is now in operation, and it uses a recently developed rapidly advanced communication network technology, in order to decrease system maintenance and increase system reliability. Two domestic personal computers were employed for control and observation, and for monitoring, as shown in Figure 2, because of their purposes and required real-time execution performances. The control and observation computer (COM1 for short) detects seismic data and controlled building responses, simulates the responses of three selectable stiffness types, judges the appropriate stiffness type, and sends the commands to the VSDs in severe real-time. Thus, high reliability and performance for severe real-time execution within a few msec is required. The monitoring computer (COM2 for short) gets the observed earthquake and response data of the building from the COM1 immediately after the earthquake, observes the operation state of the COM1 with a Digital I/O interface and the flow quantity of the water supply pipeline described later with a pulse counting device every 100msec, records the oil pressures of all oil rooms of all VSDs, detects unusual symptoms from recorded data to compare it with regular data, and delivers these data and alert to the S.A. in the remote office using the Intranet in *immediate-post-earthquake*. The requested real-time execution performance for the COM2 is a little looser than that for the COM1. However, some communication interfaces and high performance for the multi-tasking are required for the COM2. The functions of the RDMS described below do not need high real-time execution performance. Thus, they are achieved by the COM2. The trial RDMS has been under way since September 2003.

Example of control function in *mid-earthquake* (water supply control)

Water supply control is an example of a control function in the *mid-earthquake*. It is carried out in the *mid-earthquake* as well as in the *pre-earthquake* (*always*) in the following two ways, as shown in Figure 3. One way is that the COM2, including the *mid-earthquake*, always monitors the water flow quantity using the flow meter on the water supply pipeline. The flow meter detects the flow quantity and sends its increment by a pulse signal. The COM2 detects the flow quantity from the pulse signal counted with the pulse counter board in real-time and records it every 30sec. The COM2 judges the occurrence of unusual water leaks by comparing the actual flow quantity with the allowable flow quantity fixed in advance on the basis of the regular flow quantity. The other way is that the COM2 judges the soundness of the water supply equipment by comparing the observed acceleration on all floors sent from the COM1 with the allowable acceleration of the water supply equipment. In the event of unusual water leak or too much acceleration, the computer sends the alert to the building administrator (B.A. for short), the S.A. in the remote office and the occupants (Occ. for short) by means discussed later. In such a case, the COM2 controls the functions of the controllable valve to stop the water supply (check 1, refer to Figure 3). In particular, all information about the flow quantity that will be useful for the analysis of the reason for the leak will be sent to the S.A. (report 1, refer to Figure 3).

Prototype of immediate soundness estimate in *immediate-post- earthquake*

During the earthquake, the COM1 measures the earthquake acceleration and the building responses with accelerometers located in the building, simulates the building responses in real-time from the detected earthquake acceleration record, and writes these results onto the shared disk every 10msec in the *mid-earthquake*. In the *immediate-post-earthquake*, the COM2 gets these data from the shared disk, calculates the story drift angles and the floor response spectra of all floors, and estimates the soundness of the structure, building equipment and members based upon the comparison with the calculated results and the design criteria (check 2, refer to Figure 4). After the soundness estimate, the results are delivered to the B.A., the S.A. in the remote office, and the Occ., by means discussed later according to their urgency, their privilege and their need (report 2, refer to Figure 4).

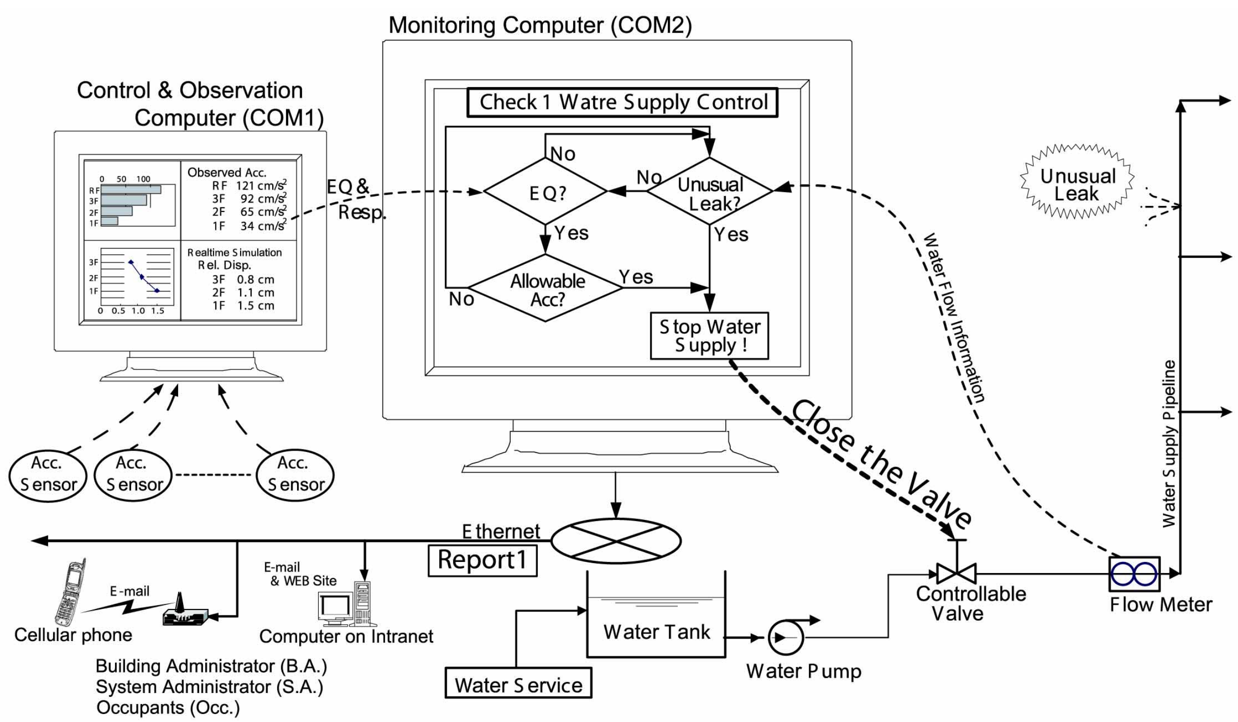


Figure 3 Outline of Water Supply Control in *mid- & pre- earthquake*

Trial of evacuation support for occupants in *immediate-post- earthquake*

In the trial, two methods were provided for the evacuation support. One was to supply the results of the immediate soundness estimate in the *immediate-post-earthquake* to support the evacuation of underground occupants. Because of their high urgency, especially for underground occupants, a summary of information on the soundness of the building is shown on a display panel hanging on a wall in the underground from the COM2 to help them to make a judgment. The other way is to detect the building condition from camera images. In this building, a video camera set on the wall in the AVS control room (on the 3rd floor) shows a picture of the room (Figure 5). Unusual symptoms will be detected by comparing the reference image detected before. The accuracy of the judgment algorithm is being improved.

Prototype of cooperation with crime prevention system and RDMS

The COM2 always searches for invaders in the AVS control room with an infrared human sensor on the ceiling near the room entrance. In the event of an invasion, the ceiling light is turned on (check 3, refer to

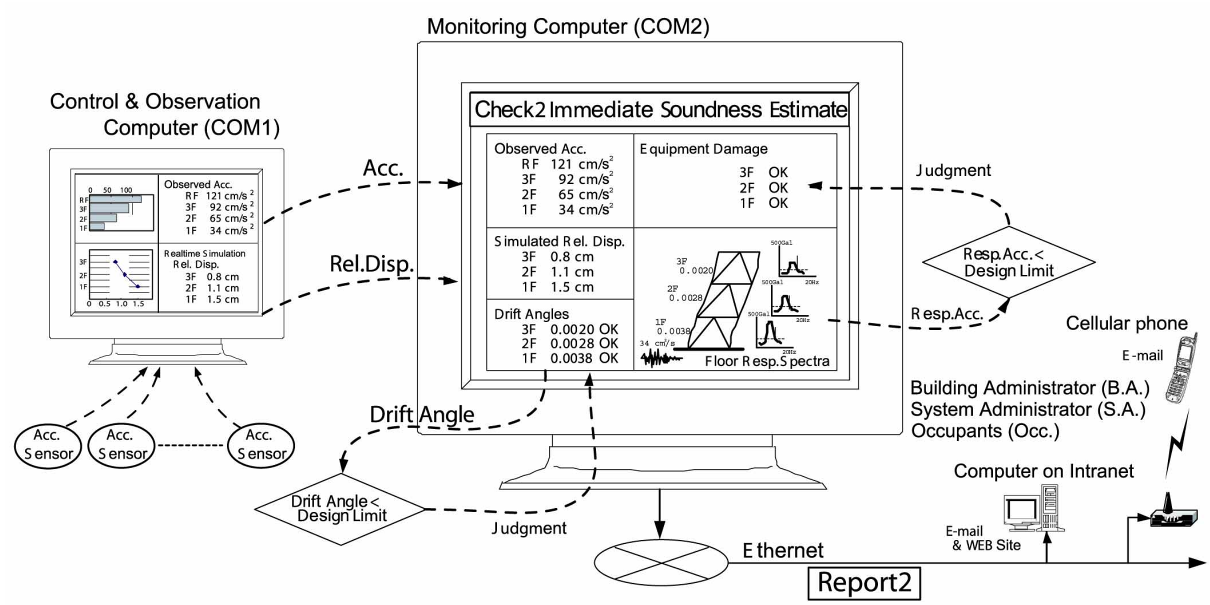


Figure 4 Outline of Immediate Soundness Estimate in *immediate-post-earthquake*

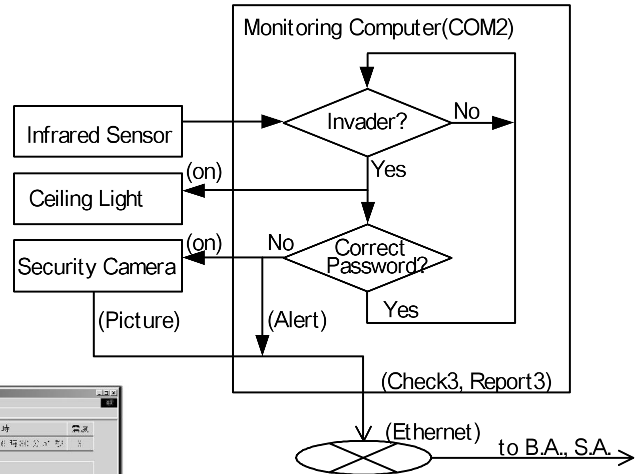
(a) detected picture in AVS control room (b) trial for detecting unusual symptom

Figure 5 A trial of evacuation support for occupants

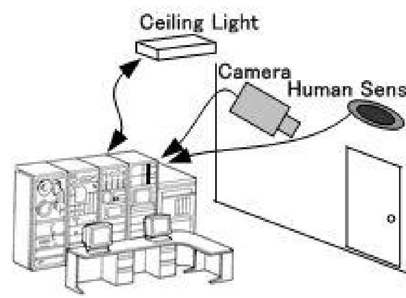
Figure 6). The COM2 sends an alert to the B.A. and the S.A. in the remote office using a means discussed later. Moreover, the detected digital camera picture is always served using the Intranet by the COM2 as described later (report 3, refer to Figure 6).

Prototype of urgent report function

The COM2 sends an unusual water leak alert (check 1), a summary of the immediate soundness estimate (check 2), and an invader alert (check 3) to the B.A.



(a) Outline of algorithm



(b) Outline of settings

Figure 6 Outline of crime prevention system

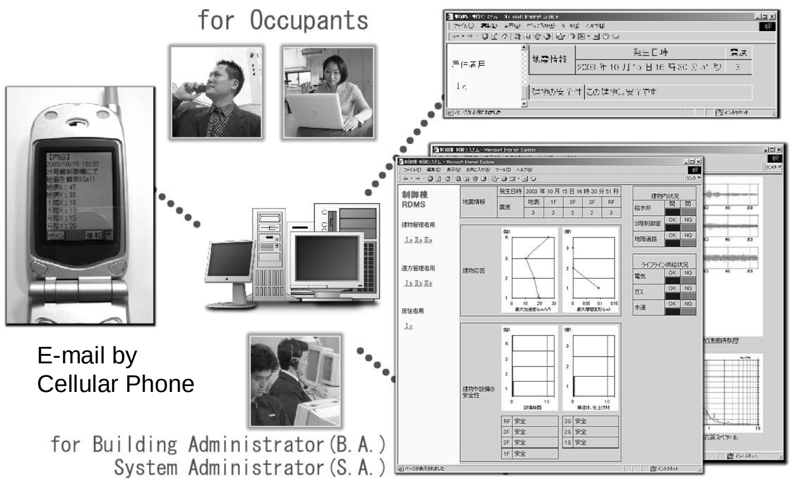
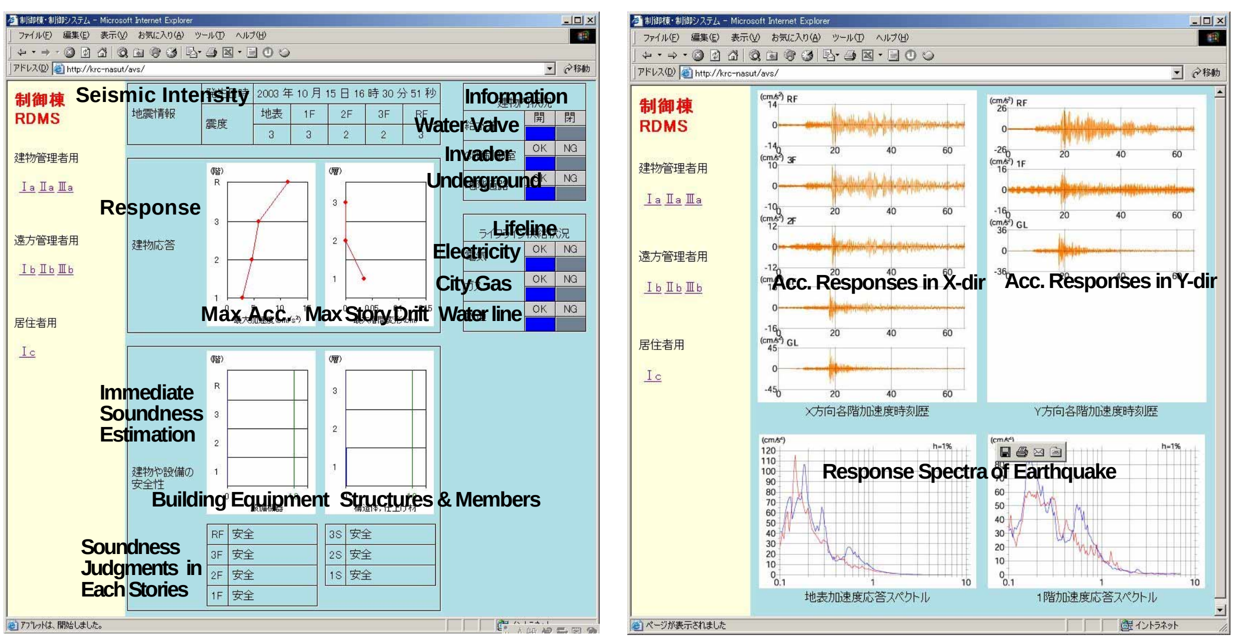


Figure 7 Outline of urgent report function



(a) Seismic intensity, water supply check & Immediate Soundness Estimation

(b) Observed earthquake & observed response of the building

Figure 8 A Example of automatically created WWW site (15 Oct, 2003, N.W. Chiba Pref. EQ) and the S.A. in the remote office by e-mail via the Intranet (report 1,2,3). In addition, the COM2 sends an alert of check 1 & check 2 to the cellular phones of the Occ. (Cellular Phone).

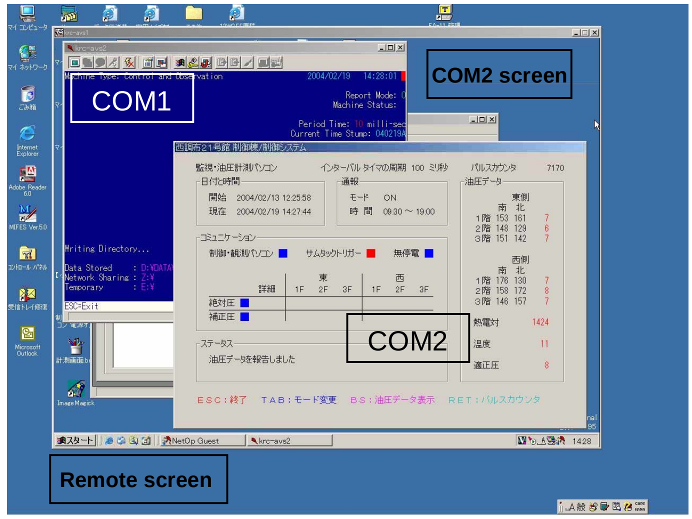
The COM2 also serves the automatically created World Wide Web site showing the data discussed above on the Intranet including the consoles of the B.A., the S.A. and the Occ. Each has a different password, and different data are made available to them depending on the password. For the Occ., to see the site that summarizes the immediate soundness estimate on each floor without detail is allowed, while the B.A. and the S.A. can obtain all detailed data from the site. An outline of the urgent report function is shown in Figure 7.

Figure 8 shows the automatically created WWW site for the S.A. for a real seismic event on 15 Oct 2003. The WWW site will be automatically provided ten seconds after the termination of the seismic event.

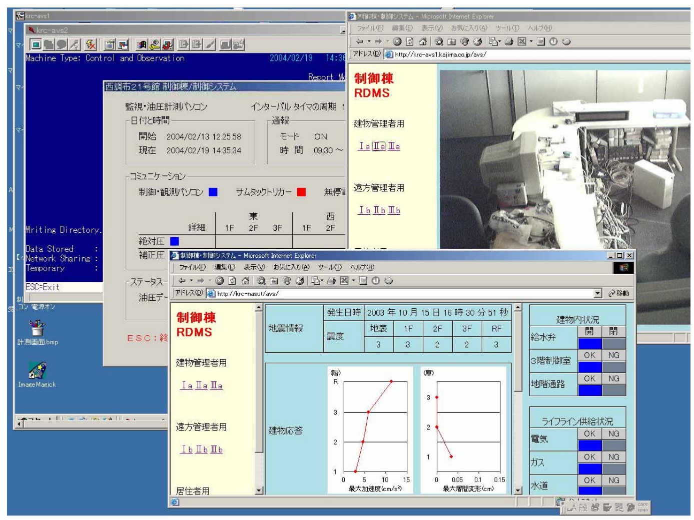
Remote control function of system

The S.A. in the remote office can control the COM1 and the COM2 directly with remote control software via the Intranet as shown in Figure 9. Furthermore, the S.A. can control the control and observation computer directly with a digital I/O interface via the Intranet and indirectly with the remote controlled COM2 with the other remote control software. Because of this, as well as a lot of data sent from the control system to the S.A. as mentioned before, he can judge system health, fix timing to maintain some parts of the control system at the most suitable moment, and improve the control algorithm, as if he were in the control room.

The renewal reflecting the RDMS concept described above is summarized in Table 1.



(a) Remote control of COM1 & COM2



(b) Browsing a WWW site and controlling the COM1/2

Figure 9 Screen shot of the remote control of Stage-III by the S.A. in remote office

CONCLUSIONS

This paper has proposed a real-time disaster mitigation system (RDMS). During an earthquake (*mid-earthquake*) and after an earthquake (*immediate-post-earthquake*), the RDMS functions as an intelligent real-time disaster mitigation system that cannot be accomplished with structural control systems only. The control computer manages building disaster mitigation synthetically based on vibration observation data obtained from vibration sensors in the structural control system and operation data of

Table 1 Function list of the RDMS

	Function	State	(Action No.) Notification	Building. Administr-ator (B.A.)	Occupant (Occ.)	System Administr-ator (S.A.)
RDMS	Water Supply Control	Mid-EQ. & Pre-EQ.(Always)	(Check1) Unusual Water Leak	C	C	C
			(Report1) Water Flow Data *1	W1	-	R
	Immediate Soundness Estimate	Immediate-Post-EQ.	(Check2) Outline of Result	C	C	C
			(Report2) Estimate Result	W1	W2	R
	Evacuation Support	Immediate-Post-EQ.	(Indication1) Soundness of Bldg.	-	D	-
	Co-operation with Crime Prevention System	Pre-EQ.(Always)	(Check3) Invader Detection	C	-	C
			(Report3) Picture	W1	-	R
Existent Function	Control System Monitoring	Immediate-Post-EQ.	(Check4) Unusual Occurence	C	-	C
	Variable Stiffness Device Monitoring	Pre-EQ.(Always)	(Check5) Unusual Occurence	C	-	C
			(Report4) Acquisition Data *2	W1	-	R
	Control & observation Data Acquisition	Immediate-Post-EQ.	(Report5) Acquisition Data *2	-	-	R

(Note1) All functions are achieved by the monitoring computer.

(Note2) Abbreviation in the table means as follows.
C=Cellular phone, W1,W2=WWW site (Intranet) for B.A. and Occ.,
R=Remote office (Ethernet) for S.A. in the remote office, D=Display panel

(Note3) S.A. in the remote office can remotely control the system.

(Note4) Data indicated from *1 & *2 are automatically acquired and utilized as follows.
*1 for analyzing the cause of water leak,
*2 for judging system health and maintenance timing etc.

various building equipment, utilizing the recently provided open network. In addition, information on the event of an earthquake is immediately conveyed to building administrators, occupants and system administrators in remote offices in the most efficient manner using various means of communication. The RDMS is also utilized under normal conditions (*pre-earthquake*), when it observes regular operating conditions of building equipment, thus greatly increasing the practical value of the system.

The paper has also presented a trial application of the RDMS to an AVS system operating in an actual building for the thirteen years. This trial was executed at the latest computer renewal of the AVS system in 2002. The trial system has some prototype functions of the RDMS concept. The trial RDMS checks for water leakage, and invaders in the AVS control room and lifeline everyday. In the case of a seismic event, the trial RDMS executes immediate soundness estimation of structures, building equipment and members, damage detection of the control room and some evacuation support for the underground occupants, as well as earthquake observation and structural control. All information and alerts are sent to the building administrator, the system administrator in the remote office and occupants with the automatically created WWW site and e-mail using the Intranet and cellular phone. This RDMS trial has been in operation since September 2003.

There remain several subjects that should be resolved for practical use of the RDMS, and a performance verification process is also needed. However, the RDMS will deeply integrate the structural control system into buildings, thus realizing not only improvement of the operation rate of buildings by earthquake disaster mitigation and quick recovery but also economic advantages from the viewpoint of building life cycle. The RDMS proposed here enables new building performance not previously possible and will become a crucial tool for future performance design of buildings.

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