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ACTUAL APPLICATION OF REAL-TIME DISASTER MITIGATION SYSTEM TO HIGH-RISE BUILDING

Motoichi Takahashi
Kajima Technical Research Institute, Japan

Yutaka Uchimura
Kajima Technical Research Institute, Japan

Hajime Hagiwara
Kajima Technical Research Institute, Japan

Tadashi Nasu
Kobori Research Complex, Japan

Yuichi Watabe
Kajima Design, Japan

Abstract

The real-time disaster mitigation system (RDMS) is aimed at mitigating earthquake disasters by utilizing real-time information under seismic events (pre-earthquake, mid-earthquake, and immediate-post-earthquake). This paper presents an actual application of the RDMS to a 22-storey high-rise building with multiple functions. The system is designed to function mainly under immediate-post-earthquake conditions. The seismic risk of the facility (building and equipment) is evaluated from earthquake observations obtained from vibration sensors placed in the building and from immediate simulation analysis in the post-earthquake period. This is then used to provide building administrators with an inspection procedure for the building. The RDMS server in the disaster prevention center of the building manages all the system functions. The RDMS supports quick actions in the immediate-post-earthquake period to mitigate secondary damages and enable early recovery of building functions. It also leads to rational building management for earthquake disaster mitigation and business continuity. Since its installation, the system has been verified under an actual earthquake.

INTRODUCTION

With the rapid progress of information technology and intelligent buildings in recent years, building functions, especially in urban areas, have become more complex and sophisticated. It is thus becoming increasingly difficult to estimate all aspects of earthquake disasters, thus complicating disaster mitigation measures. With the prediction of near-field earthquakes in urban areas, new earthquake countermeasures are required to mitigate future earthquake disasters.

Thus, the real-time disaster mitigation system (RDMS) has been proposed [1] [2]. The RDMS is aimed at mitigating earthquake disasters by utilizing real-time information under pre-, mid-, and immediate-post-earthquake conditions. The concept of the RDMS is shown in Figure 1. It is based on a broad concept including seismic response control [3]. Specifically, it is based on vibration reduction by seismic response control (hardware measure) and on disaster mitigation by utilizing real-time information (software measure), and functions as a comprehensive disaster mitigation system using recent information technologies. A prototype of the RDMS has been implemented in an actual 3-storey building, and its effectiveness has been verified by actual earthquakes.

Pre-arrival earthquake information (earthquake early warning) has been distributed on trial to restricted facilities by the Japan Meteorological Agency (JMA) since February 2004. The authors have utilized this information on building construction sites to ensure worker safety [4]. A general service of the earthquake early warning from JMA will soon start, so remarkable development can be expected in the near future.

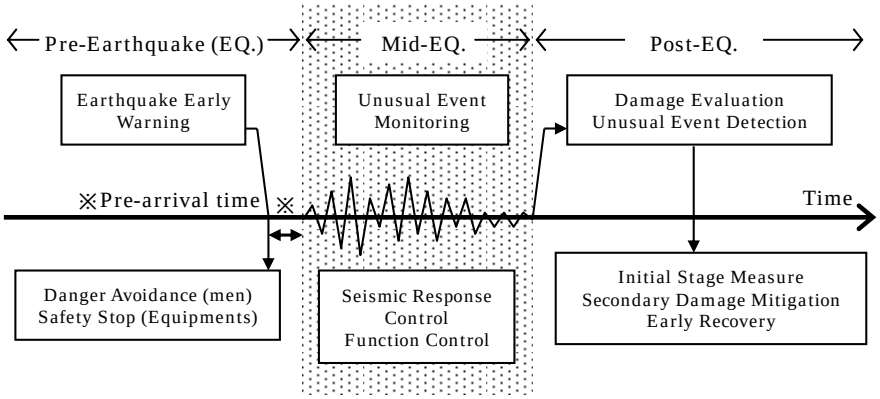

Figure 1. Concept flow of RDMS.

This paper introduces an application utilizing real-time information during the immediate-post-earthquake period. This is the first application to an actual commercial building. Real-time information on the building and its equipments in the immediate-post-earthquake period is supplied immediately to the building administrator. This information is utilized to establish an accurate initial stage measure, secondary damage mitigation, and early recovery of building function. The system is described and verification with an actual earthquake is also discussed.

SYSTEM APPLICATION

Object Building

An outside view of the object building is shown in Japan. It comprises 22 floors of structural steel above ground and 3 floors of reinforced concrete under the ground, and has a total floor area of 160,000 square meters. It is a high-rise building with multiple functions, occupied by various tenants for offices, stores, etc.

Figure 2. A view of the building.

Application Purpose

The RDMS, utilizing real-time information on immediate-post-earthquake conditions, was applied to mitigate disasters and confusion of building occupants during an earthquake. The System not only rationalizes building management during an earthquake disaster but also supports secondary damage reduction and early recovery of building functions. It is designed to ensure the safety of various equipment that plays an important role in building functions, such as electrical, communications, energy supply, water supply, and drainage equipment.

It is generally said that self-assistance, mutual-assistance, and public-assistance are essential to mitigate earthquake disasters. The system introduced here aims at “self-assistance” that help the building to save itself.

System Outline

Figure 3 shows the building outline and the system layout. Six vibration sensors are placed in the building to measure a total of fifteen channels of vibration data in the horizontal and vertical directions. The measurement data are sent via cables to a disaster prevention center on the building’s first floor, and the RDMS server processes the flow as shown in Figure 3, thus supplying disaster mitigation support information to the building administrator in the immediate-post-earthquake period.

The system functions as follows:

(1) When an earthquake occurs, the vibration sensors measure the building vibrations, and the RDMS server records the earthquake information. The seismic response load of the building and equipment are thus estimated employing real-time simulation analysis.

(2) The risk levels of the building and equipment are thus evaluated, and an inspection class is determined taking account of the seismic level and equipment importance class. This takes only a few tens of seconds.

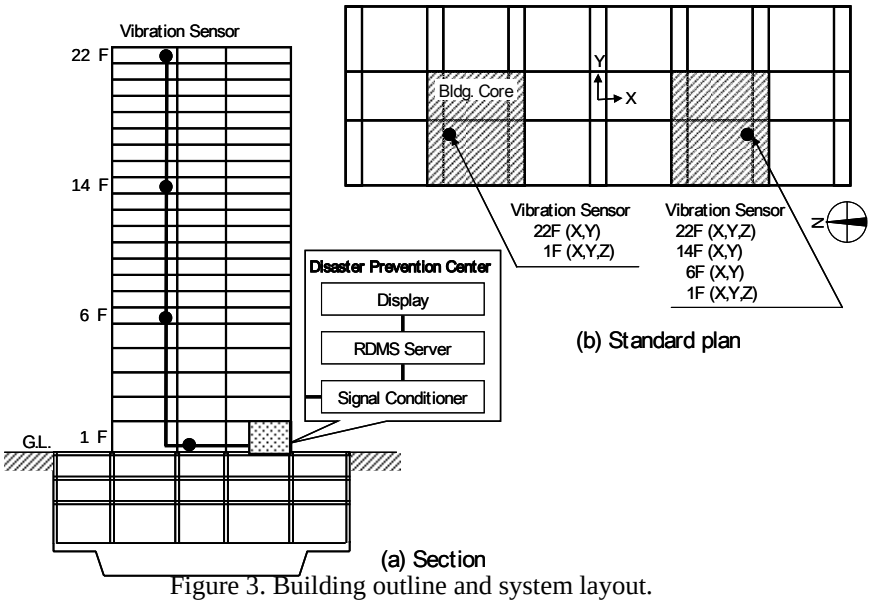

Figure 3. Building outline and system layout.

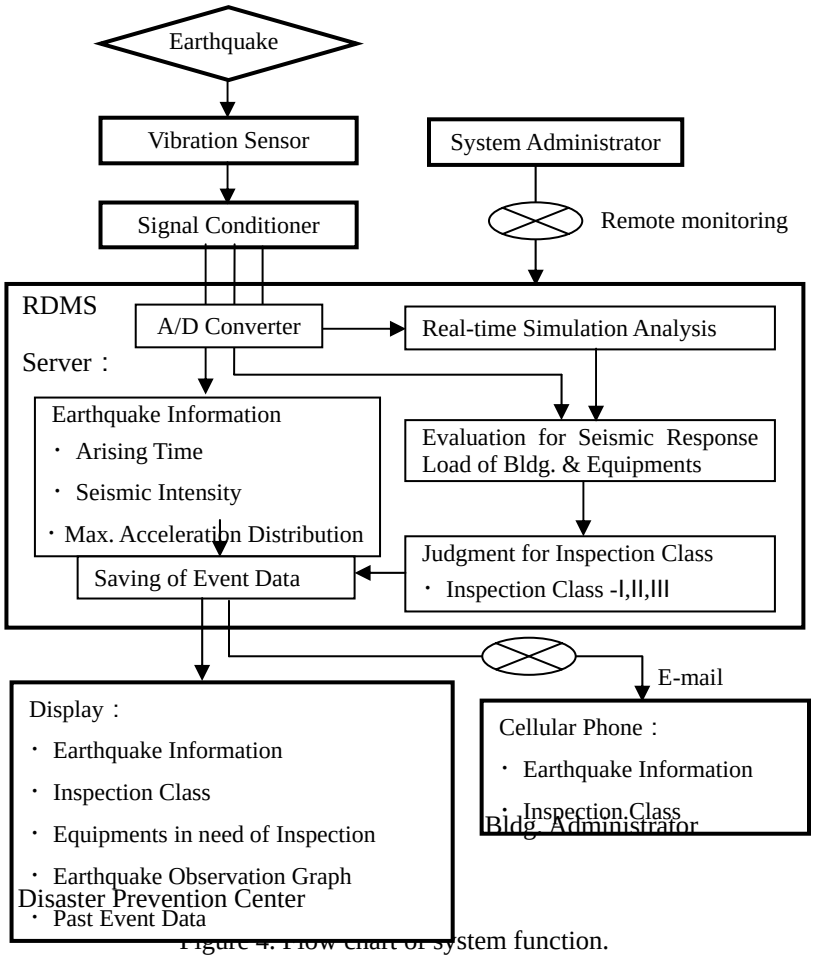

Figure 4. Flow chart of system function.

(3) Through a display, the building administrator instantaneously picks up the following information: earthquake information, inspection class, inspection object, earthquake observation data, etc. This enables quick and efficient initial stage action. It also enables not only secondary damage mitigation, but also early recovery of building functions based on quick confirmation of unusual events. The earthquake observation records (past event data) can be utilized for building management data in a lifecycle (seismic health chart).

(4) At the same time, the information abstracted from above is sent outside to the building administrator by cellular phone e-mail. This can be employed as an emergency call to the administrators' pool late at night and on days off, thus facilitating quick action in an emergency.

(5) Giving such information to the occupants as an information service avoids confusion and assists peace of mind.

Figure 4 shows the display in the disaster prevention center. Figure 5 shows a picture example of the display and cellular phone.

Figure 4. Display view in disaster prevention center.

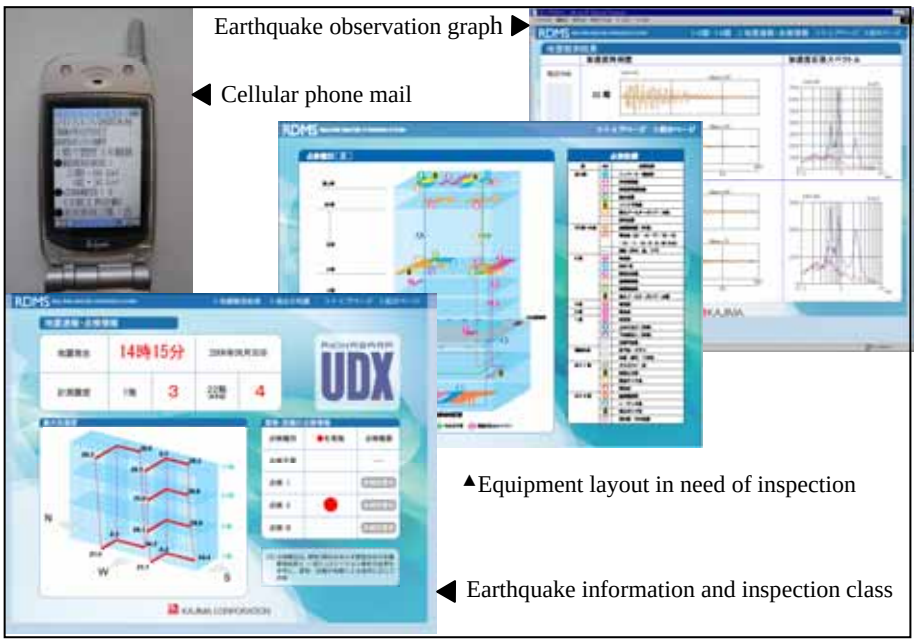

Figure 5. RDMS display.

Table 1 shows four inspection classifications. They are determined carefully in discussion with the building administrator. The classifications are based on design criteria of the building and equipment [5], taking into account the building's seismic design earthquake analysis results. For small earthquakes (Inspection class 0), only earthquake information is provided and no inspection is necessary. Inspection class corresponds to a seismic response level-1 derived from earthquake response analysis in the Japanese design standard for high-rise buildings.

Real-Time Simulation Analysis

In immediate-post-earthquake, real-time simulation analysis is carried out by putting the input motion observed on the first floor into the simulation analysis model. This enables estimation not only of the building's local response, which is unobtainable from observation, but also of building deformations.

The simulation analysis model is a three-dimensional multi-coupled bending and shearing model fixed on the first floor. The model's stiffness is estimated from the structural steel frame under large deformation amplitude, taking account of secondary building materials under small deformation amplitude. The stiffness under small deformation amplitude is determined from a micro-tremor test on the building. The elasto-plastic characteristic of the stiffness is evaluated, considering nonlinearities for each stiffness element. The damping factor is determined by referring to previous observation data for actual high-rise buildings [6]. The simulation analysis model will be identified based on earthquake observations, thus maximizing its accuracy.

Table 1: Inspection classification.

Inspection Class		0	I	II	III
Response Level*1	Max. Acceleration*2	~ 15cm/s^2	15 ~ 30cm/s^2	30 ~ 200 cm/s^2	200cm/s^2 ~
	Max. Story Drift Angle*3	~ 1/200		1/200 ~	
Equipments in need of Inspection		None	Important Equipments in RF, 5F,and B3F	Equipments in all of the Floor	Equipments in all of the Floor, Important Life-line Pipe

Notes: *1 Response level is determined based on structural design earthquake response analysis and design criterion of the facilities.
*2 Horizontal acceleration obtained from observation in all of the floor.
*3 Story drift angle obtained from simulation analysis is adopted to evaluate the inspection class only when the max. acceleration difference between observation and simulation analysis is within 20%.

OPERATION UNDER ACTUAL EARTHQUAKE

The system began operation in July 2006, and an earthquake occurred just after that on August 31, with its epicenter in Tokyo Bay and magnitude 4.8, and the system operated as expected. An example of a display picture is shown in Figure 6 and the maximum response of the building is shown in Table 2. The maximum acceleration is about 10cm/s^2 (seismic intensity 2) at the first floor and 6~9cm/s^2 at the 22nd floor. Because it was a small earthquake, inspection class 0 was determined, so the building administrator was informed that no inspection was necessary.

As above, the RDMS judges on the basis of its own data obtained from actual building states, thus establishing adequate and rational support for building disaster mitigation management.

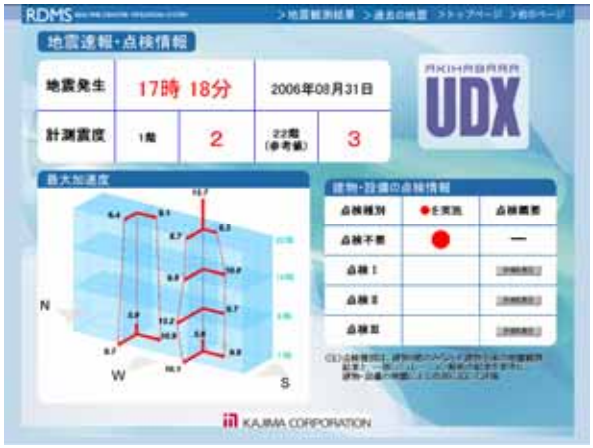

Figure 6. Display picture due to the earthquake on August 31 in 2006.

Table 2: Maximum response of building due to the earthquake.
(Northern part of building)

Direction		X	Y
Max. Acceleration (cm/s^2) -Observation-	22F	6.3	8.7
	14F	10.0	9.8
	6F	9.7	13.2
	1F	9.9	10.1
Max. Story Drift Angle (rad.) [Arising Story]*		1/11700 [22]	1/17000 [22]
Note: *Reference data obtained from simulation analysis			

CONCLUSIONS

The RDMS is proposed for mitigation of earthquake disasters with real-time information under pre-, mid-, and immediate-post-earthquake conditions. This paper has reported the actual application of an RDMS to a 22-storey high-rise building with immediate-post-earthquake information, where the system was used for building disaster mitigation management. System verification was also demonstrated through an actual earthquake.

This paper shows only one application example. The RDMS can be applied to various kinds of buildings and facilities according to the needs of building management. It also contributes to business continuity management (BCM), which has recently become a concern for measurement under emergency situations. When the pre-, mid-, and immediate-post-earthquake information through the event is utilized comprehensively, the RDMS will be a useful disaster mitigation measure for future society.

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