Online Monitoring for Dynamic Response and Environmental Conditions of Buildings with a Web-based Interface and Database

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ABSTRACT:

Development of an online real-time monitoring system for the dynamic response of buildings is presented. This system, composed of a series of systems, integrates video images and various kinds of environmental sensors, such as those measuring the temperature and energy consumption in a building. There is also a Web-based interface, equipped for monitoring and storing data in a database. An example is shown of a seven-story building on the Nagoya University campus. Observation of high-density vibration is conducted on the superstructure, in the piles and on the surrounding ground for detection of the spatial vibration characteristics and soil-structure interaction (SSI) effect. At Nagoya University, other buildings are equipped with accelerometers, Web cameras and other sensors. Such a monitoring system is effective not only for structural health monitoring of a building, but also for disaster mitigation and crime prevention in the building, in the campus and in the surrounding neighborhood.

INTRODUCTION

There are not many examples of high-quality, earthquake response observations of low- and medium-rise buildings. Even ordinary buildings have specific structural features; thus, the data observed for individual buildings are very important not only for structural health monitoring of a building, but also for building a database of structural designs and damage evaluations after destructive earthquakes.

This paper describes the development of online vibration observations, as well as a monitoring and database system of buildings using networks (LAN and the Internet) with a Web-based interface. The system also monitors video images of buildings with Web cameras, and various kinds of environmental conditions, such as meteorological data and energy consumption in and around a building. By using this system, it is possible to observe the ambient vibration and earthquake response of a building with many vibration sensors; this information can be used to show complex vibration characteristics, including

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the spatial vibration of a superstructure and the soil-structure interaction effect [1]. A network connection and database with a Web-based interface reduce the long-term monitoring load of engineers. Video images with vibration data are effective for monitoring the structural and non-structural damage process of a building under earthquake excitations. Meteorological data, such as wind velocity and temperature is also important for precise evaluation of the dynamic characteristics of a building, especially the change of natural frequency for monitoring the reduction of structural stiffness. The observed data of the building and ground are stored and arranged in a detailed database.

Video images and environmental data are effective not only for structural monitoring but also for environmental and safety monitoring for building users. Because this system is made of common network components, it is possible to use various kinds of sensors and data for the integrated monitoring of the building.

ONLINE MONITORING OF DYNAMIC BEHAVIOR OF A BUILDING WITH ENVIRONMENTAL CONDITIONS

Outline of the building

In this section, the building of the Nagoya University graduate school of environmental studies is discussed as an example of the developed monitoring system. This seven-story building is a pre-cast, pre-stressed concrete (PCaPC) superstructure with 92 pre-stressed high-strength concrete (PHC) piles more than 30 m in length. The shape of the floor is a simple rectangle 49.5 x 16 m, with almost no eccentricity. There are some reinforced concrete earthquake-resistant walls in the transverse direction. Fig. 1 shows an outline of the building.

Online monitoring of spatial vibration

A high-density vibration observation is conducted at the building, in the piles and on the surrounding ground for detection of the spatial vibration characteristics and soil-structure interaction effect of the building. The locations of the sensors, shown in Fig. 1(c), include 16 points with 39 components in all. The servo-type acceleration sensors shown in Fig. 2(a) are used. It is important to install the acceleration sensors in two piles to show the soil-pile interaction. There are two data recorders that have 19 bit A/D converters with 100 Hz sampling and a GPS clock adjust. Recording of the response data during an earthquake is controlled by an event trigger signal. For real-time monitoring, the signals of 12 components are directed into the recorders with the network interface (Fig. 2(a)). The recorder has four-channel analog inputs, which are digitized by 24 bit A/D converters with 400 Hz sampling. After anti-aliasing finite impulse response (FIR) filtering and re-sampling into 100 Hz, digital data packets at one-second intervals are provided directly to the network.

For displaying the online data, Java C applets are developed as applications for Web browsers on an ordinary PC. Fig. 2(b) shows the monitoring window displaying the real-time spatial vibration of the graduate school building. The acceleration vibration data from the sensors are numerically integrated into the displacement data and low-cut filtered by a FIR digital filter of 1 Hz (the lowest natural frequency of the building is approximately 2 Hz). A wire-frame model of the building is made with the observed 12 components. The 3-D view of the vibration is made by using VRML (Virtual Reality Modeling Language), and thus the building can be seen from various viewpoints. In Fig. 3, the torsion vibration mode of the superstructure clearly appears. By viewing this through the real-time 3-D monitor, the variation of the spatial vibration under ambient excitation is clearly observed, and the torsion mode predominates under a strong wind condition, although the building has almost no eccentricity. Figure 2(c) shows the transfer functions between the top and bottom of the building for the observed earthquake response. The peak for the torsion mode is not as clear. This shows the importance of more detailed analyses of the ambient vibration characteristics in comparison with the seismic response. Thus, the online 3-D view is important for the acquisition and discovery of new knowledge of structural vibration. Another important aspect in Fig. 2(c) is the significant effect of the rocking motion in the transverse (NS) direction, which is also observed clearly in the 3-D view of Fig. 2(b).

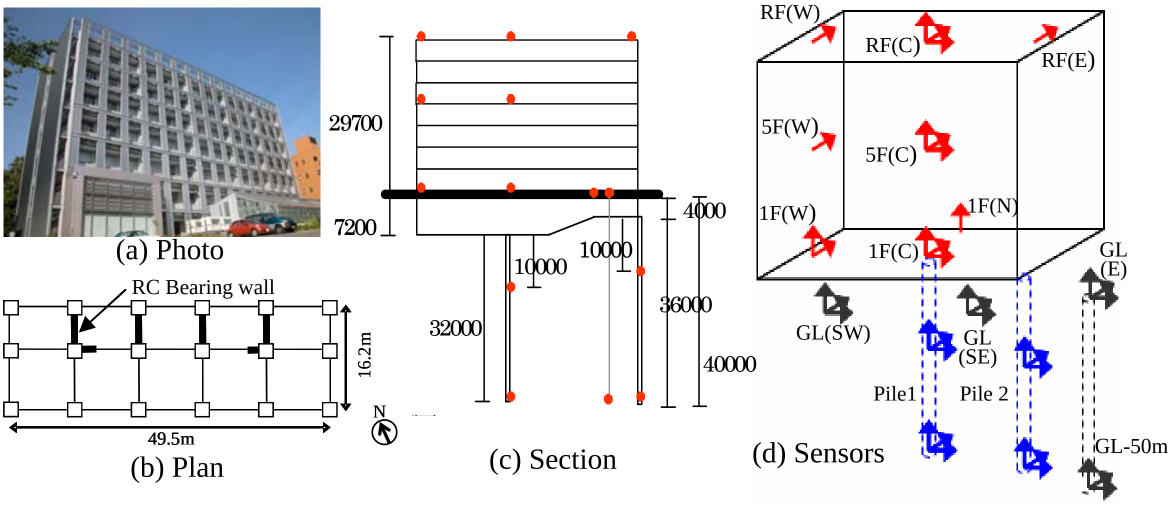
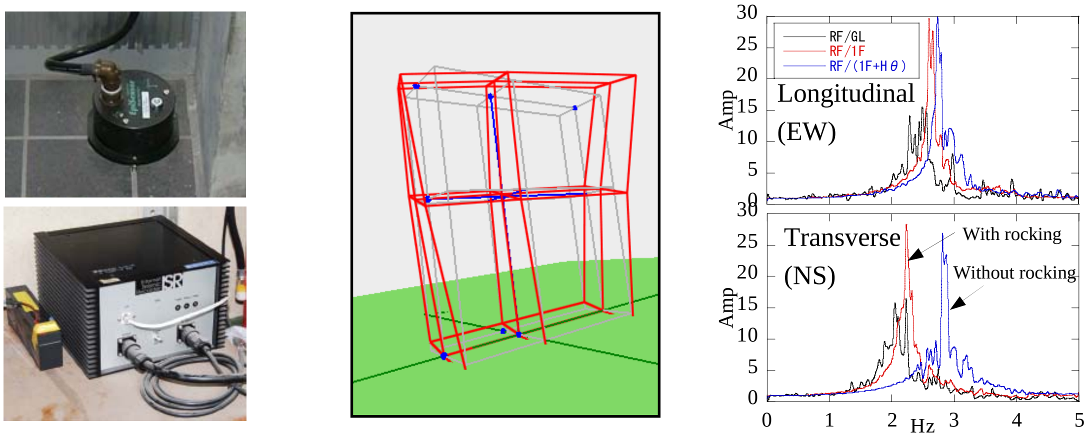


Figure 1: Outline of the PCaPC seven-story building and locations of vibration sensors.



(a)Sensor & network interface (b)Spatial mode with torsion (c)Transfer functions for EQ data

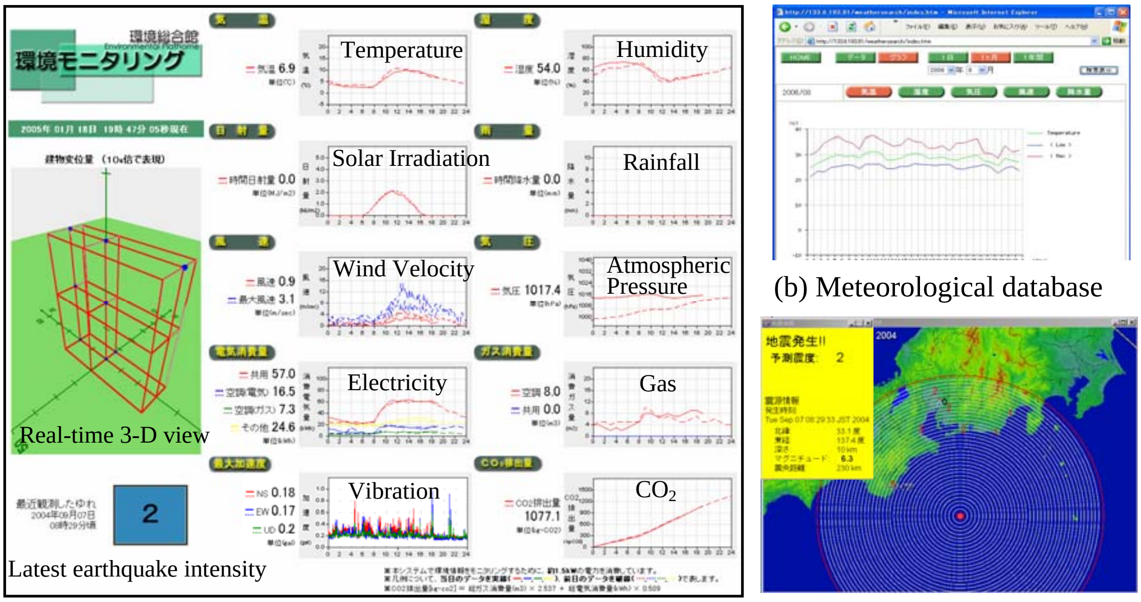
Figure 2: Observation equipment, real-time 3-D view of ambient vibration under a strong wind condition, and observed earthquake (EQ) response characteristics.

Online monitoring of environmental conditions and other information

The online monitoring display for the real-time spatial vibration of the building with various environmental data is shown in Fig. 3(a). The following measurements are shown for a recent two-day period: the temperature, humidity, solar irradiation, rainfall amount, wind velocity, atmospheric pressure outside the building, and the amount of electric and gas consumption, maximum acceleration of environmental vibration, and CO_2 emissions of the building. This window is shown in an ordinary Web interface with a full-screen Web browser and thus can be displayed on an ordinary PC connected to a network (a LAN in the university campus and the Internet.) An online meteorological database is also available, as shown in Fig. 3(b). The large-size LCD showing this monitoring window is now set up at the entrance hall of this building, and building users are able to understand and are interested in the environmental and structural conditions of the building.

Figure 3(c) is an example of a monitoring window added for earthquake warnings. The Japan Meteorological Agency (JMA) has been examining a system for issuing warnings immediately before an earthquake hits, based on data from measurements taken near epicenters [2]. The system proposed in this paper has been developed by using the information from JMA together with data of the original observation sites at Shizuoka and Wakayama prefectures, with consideration of the occurrence of the Tokai and Tonankai earthquakes. When an earthquake occurs, a window in Fig. 3(c) appears and shows the estimated arrival time and intensity of earthquake shaking with an alarm sound.

Such an "integrated monitoring" system is effective for educational aspects as well as engineering purposes.



(a) Monitor window (c) Earthquake warning window

Figure 3: Monitoring for vibration with environmental and earthquake information.

VIDEO IMAGES AND OTHER APPLICATIONS

Online video image monitoring with vibration data

Figure 4 shows another example of the real-time vibration monitoring display on a Web browser window for three components of a point in another building, together with simultaneous video images of the building obtained by the network live camera. Waveforms are shown at one-second intervals in the window. The video images at every second are transferred to the server for the Web view. When an earthquake occurs, image data at 15 frames per second (fps) are also saved in an on-site micro PC simultaneously with the earthquake response recorded by a seismograph trigger operation. System operation during earthquake shaking is performed for dozens of minutes with an uninterruptible power supply (UPS) in the case of a power failure. Then the data are transferred to the server computer. In normal conditions, the system can be used as an environmental vibration monitoring and crime prevention monitor camera (Fig. 5(a)).

Application to inter-university online disaster monitoring system

Figure 5(b) is the Web-based system showing the connection between other universities in the Chubu area using the abovementioned system. Because mutual situations can always be checked by the video images and vibrations, the system is not only for observation and monitoring but also for an online disaster emergency response system for researchers at the universities in this region. However, it is important to establish some organization for the collaboration of disaster mitigation activities in the region [3].

(a) Web camera and recorder PC

(b) Monitoring window

Figure 4: Video image monitoring and vibration of a building.

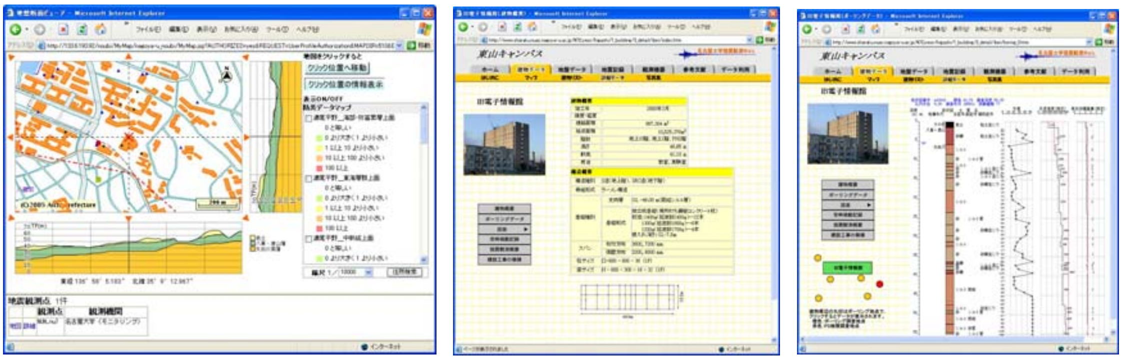
(a) Buildings in Nagoya University

(b) Buildings in some universities in Chubu region

Figure 5: Video image monitoring at multiple buildings and sites.

WEB-BASED ONLINE DATABASE OF SITES AND BUILDINGS

Together with the online monitoring system shown in the previous section, it is also important to arrange and provide specific information about the building, soil and observation systems. Fig. 6 shows examples of a Web window which shows the soil condition and building structure on a Web-GIS site map.



(a) Web-GIS sitemap (b) Building specifications (c) Soil specifications

Figure 6: Web-GIS system for building, site and monitoring specifications.

CONCLUSIONS

Some examples of the development of a Web-based online observation, monitoring and database system for buildings and ground are described. It is shown that observations and monitoring through networks are effective not only for quick data collection but also for accumulation and shared use of the data. Because data is arranged by a Web-based system, users are able to access the observed information on an ordinary PC by using a browser without any special software. Such easy accessibility promotes the effective use of the data by many researchers, engineers, and building users. By integrating various kinds of information such as meteorological data, earthquake warnings and video images, it is useful not only for structural and environmental monitoring, but also for educational and disaster mitigation activities.

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