WEB BASED ONLINE MONITORING AND DATABASE SYSTEMS FOR DYNAMIC RESPONSE OF STRUCTURES AND GROUND

JUN TOBITA[1)], HIROAKI KOJIMA[2)] and NOBUO FUKUWA[3)]

[1)] Department of Environmental Studies, Nagoya University, Nagoya 464-8601, Japan
Email: tobita@sharaku.nuac.nagoya-u.ac.jp
[2)] Department of Environmental Studies, Nagoya University, Nagoya 464-8601, Japan
Email: hiroaki@sharaku.nuac.nagoya-u.ac.jp
[3)] Department of Environmental Studies, Nagoya University, Nagoya 464-8601, Japan
Email: fukuwa@sharaku.nuac.nagoya-u.ac.jp

ABSTRACT

Online systems for earthquake response records and various kinds of vibration experiment results for building structures and ground are developed. Vibration data with specifications on earthquakes, ground conditions of observation sites, buildings and observation equipments are available via the Internet by use of Web based interface. First, the web system for observed records on structures is discussed. On-line monitoring system is developed for spatial response of a building, with live camera views and triggered video images under earthquake shaking. For many buildings in Nagoya University campus with vibration observation sensors, a web site has also been constructed to publish observed records, soil data and structural data in order to encourage the use of seismic data. Next, the web system for observed seismic ground motion is described. A super-net of seismic observation networks deployed by multiple institutions has been constructed in the Tokai region in Japan in order to collect and publish a unified, on-line set of seismic data. Comprehensive analysis of abundant data recorded over a large observation area have lead to a better understanding of the dynamic characteristics of the soil throughout the region. The 3-D web system for ground-structure survey is also developed.

INTRODUCTION

By the latest development of a data transmitting network and web interface technology, a large amount of data is transmitted and stored promptly in easy treating form without special software. The benefit of such technology is important in accumulation and use of observed dynamic response records of structures and ground. In this paper, the system for earthquake response of structures and ground is developed, which has the feature of on-line, real time, web interface, etc.

There are not many examples of high-quality earthquake observation of low- and medium-rise buildings. Ordinary buildings have specific structural features, thus, the observed data on each building is very important. Since many of buildings with earthquake observation instruments are private sector buildings, it is rare in Japan to exhibit observation results and building specifications. Moreover, the number of engineer who can do analysis of observed data is not enough. Therefore, if the obtained dynamic data is collected efficiently via network and is arranged with the information on the building and ground by using the web interface, the utility value of data will increase. If data is exhibited via the Internet, many researchers and engineers can use it for their research and structural design of buildings. This paper first describes development of the on-line vibration monitoring system of a building with web camera image and meteorological data. Furthermore, the system for efficient arrangement of data for public use by the internet with web interface is also described.

The observed seismic data on ground surface and underground is now released via the Internet, for example, by the National Research Institute for Earth Science and Disaster Prevention (NIED) in Japan. High density seismograph network, such as K-net and KiK net, cover whole country by over thousand sites at 20-30 kilometers interval. However, when considering the special character of seismic ground motion, such as “the disaster belt” appeared during the 1995 Kobe earthquake, more high-density seismic observation is required. For that, it is effective to collect and arrange many organizations' seismic observation data. Such so-called “super network” has been developed by Nagoya University connecting many organizations' system by use of various types of devices, lines and software. In addition, the database system for deep underground structure which displays the results of investigation in a plain scale in three dimensions is described.

ON-LINE MONITORING OF DYNAMIC BEHAVIOR OF A BUILDING

In this section, the building of Nagoya University graduate school of environmental studies is discussed with newly developed on-line observation system for spatial vibration with web camera image and meteorological data. This 7-story building has the PHC piles with over 30m length, and pre-cast pre-stressed concrete (PCaPC) superstructure. The shape of floor is simple rectangular with 49.5 x 16m, with almost no eccentricity. Fig.1 shows appearance of the building. There are some reinforced concrete earthquake resistant walls in the transverse direction.

On-line monitoring of Spatial Vibration

High-density earthquake observation is continued at the building, in the piles and on the surrounding ground for detection of spatial vibration characteristics and the soil-structure interaction (SSI) effect of the building. Location of sensors is shown in Fig.2 including 15 points with 36 components in all. The servo-type acceleration sensors are used. It is the important feature to have installed the acceleration sensors in two piles to show soil-pile interaction. Two data recorders (FlexSysALTUS) have 19bit A/D converters with 100Hz sampling and GPS clock adjust. Recording of response data during earthquake is controlled by event trigger signal. For the real-time monitoring, signals of 12 components are branched into the Internet Seismic Recorders. The recorder has 4ch analog inputs, which digitized by 24bit A/D converters with 400Hz sampling. After anti-aliasing FIR filtered and re-sampled into 100Hz, digital data packets of every second are provided directly on the network.

For displaying the on-line data, Java C applets are developed as applications for web browsers on ordinary PC. Fig.3 shows monitoring window displaying real-time spatial vibration of the building in left-hand side, with various environmental monitors in right-hand side. Acceleration vibration data from sensors are numerically integrated into displacement data and low-cut filtered by the FIR digital filter of 1Hz (lowest natural frequency of the building is approximately 2 Hz.) Wire-frame model of the building is made by the observed 12 components. 3-D view of vibration is made by VRML (Virtual Reality Modeling Language) and thus it can see from various viewpoints. Fig.4 shows another example in which torsion vibration mode of the superstructure clearly appears. By viewing this monitor, variation of spatial vibration under ambient excitation is clearly observed, and torsion mode predominates in some time although the building has almost no eccentricity. This shows the importance of more detailed analysis of ambient vibration characteristics comparing with seismic response. Thus the on-line 3-D view is not only for intelligible view but for acquisition and discovering new knowledge of structural vibration.

On-line monitoring of Environmental Data, Video Image and Earthquake Warning

Following on-line environmental data is also shown for recent two days in the monitoring window in Fig.3: temperature, humidity, solar irradiation, rainfall amount, wind velocity, atmospheric pressure, the amount of electric and gas consumption, the maximum acceleration of environmental vibration, and CO2 emissions of the building. This window can be displayed with ordinary PC via the network (the University LAN and the Internet.)

Fig.5 shows another example of real-time vibration monitoring display on a web browser window for three components of a point in a building, together with the simultaneous video image of the building obtained by the network live camera. Waveforms are shown in every second in the window. The video image of every second is transferred to the server for web view. When the earthquake occurs, the image data of 15 frames per second (fps) is also saved in on-site micro PC simultaneously with earthquake response record by a seismograph trigger operation. System operation during earthquake shaking is performed for dozens of minutes with an uninterruptible power supply (UPS) in the time of a power failure. By Then the data is transferred to the server computer. During the usual time, the system can be used as environmental vibration monitoring and crime prevention monitor camera (Fig.6.)

As a kind of early warning system, the Japan Meteorological Agency has been examining a system for issuing warnings immediately before an earthquake hits, based on data from measurements taken near epicenters (Tobita and Fukuwa, 2004.) The earthquake alarm system has developed by use of the information from JMA together with the data of the original observation sites at Shizuoka and Wakayama prefecture considering the occurrence of Tokai and Tonankai earthquakes. On-site micro PC for vibration and video system receives an alarm signal from the server via network, and tells it to signal tower blink and alarm sound (Fig.7.)

Application to Inter-University On-line Disaster Monitoring System

Fig.8 is the web based system showing connection between some universities in Chubu area using above mentioned systems. As a mutual situation can always be checked by the video image and vibration, the system is not only for observation and monitoring but for a kind of on-line disaster emergency response system for researchers of universities in this region. Not only using the system, it is important to establish some organization for collaboration of disaster mitigation activities in the area (Tobita et al. 2004).

Fig.1 Appearance of PCaPC 7 Story Building

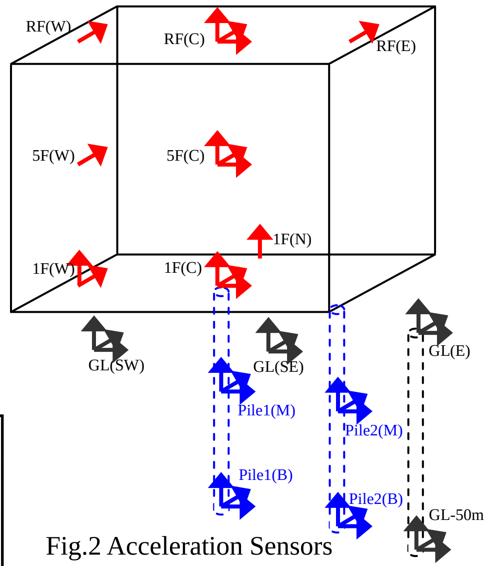


Fig.2 Acceleration Sensors Location

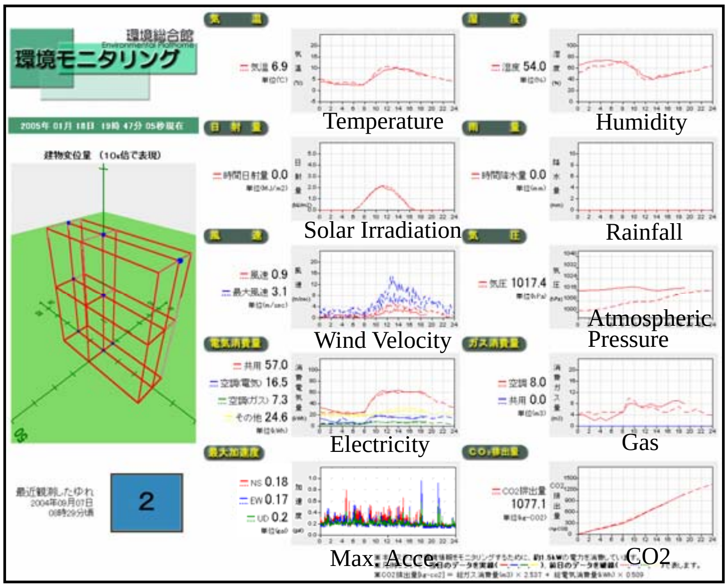


Fig.3 Monitoring Window Displaying Real-time Spatial Vibration of the Building with Various Environmental Monitors

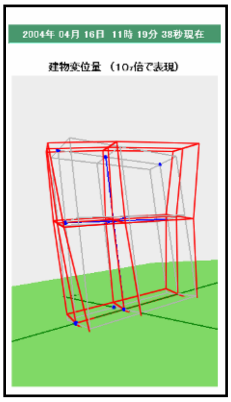


Fig.4 Spatial Vibration Mode when Torsion Mode is Predominant

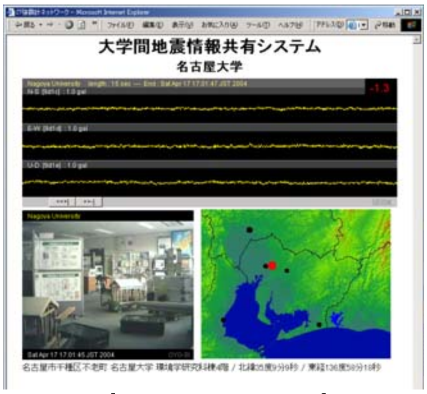


Fig.5 Vibration Monitor with Video Image of Live Camera

Fig.6 Video Image of Live Camera In Nagoya Univ. Campus

Fig.8 Live Video Image of Univs. In Chubu Area

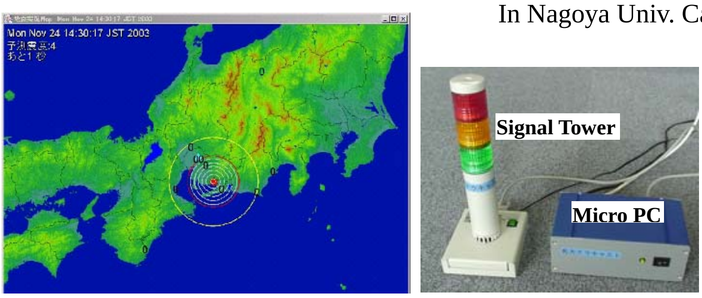


Fig.7 Display and Signal Tower of the Earthquake Alarm System

Fig.9 UPS, Live Camera and Micro PC

WEB BASED DATABASE FOR OBSERVED RESPONSE OF BUILDINGS

Earthquake response observation of various kind of low- and medium-rise buildings are conducted by Nagoya University (Kojima et. al, 2005). They are planed to analyze the influences of various factors in building vibrations, including structure height, structural type, soil conditions, the effect of eccentric masses in the structure and the effect of close neighboring structures. The actual response behavior of the structures and the forces acting on the structures under earthquake excitations are not sufficiently understood even if we can use current analytical methods. Especially for low- and medium rise buildings, they have various shapes and complicated response modes, the effect of non-structural members and the influence of ground. The effect of soil-structure interaction (SSI) is one of the most important factors. In order to clarify these influences, observation of actual building is required.

Outline of Web Based Database for Observed Response of Building in Nagoya University

Earthquake observations are currently being carried out or are scheduled to begin soon at over 20 buildings by Nagoya University. Many of them are on the Higashiyama campus in Nagoya City. In order to use effectively the data observed in these buildings, on-line data collection is done by use of the university LAN and the Internet as shown in the previous section. It is also important to arrange and provide precise information on the structure, soil and observation sensors, to use observed dynamic data of earthquake response and microtremor appropriately in the research and structural design. For this purpose, the web-based database on the dynamic observation of buildings has been developed (Kojima et al. 2003).

Fig.10 is the examples of web window of the system, which showing buildings in Higashiyama campus. Following items are stored in the system:

(1) Building data
- Site map : location of seismic observation buildings
- List of Buildings : table for observed buildings and its outline
- Specific data on each building : building features, structural features
- Structural drawings : for modeling of structural analyses
- Sensors location : for earthquake response observation (fixed sensors)
- Photos : photos including under construction situation

(2) Soil and ground data
- Geological, geographical and topographical data on the site
- Deep and shallow soil structures : boring exploration, PS logging, microtremor survey, landfill and excavation distribution, and other soil data

(3) Observation instruments
- Specification of sensors and recording instruments : seismic observation, ambient vibration

(4) Observed records
- List of observed records : table for earthquake response, ambient vibration and various vibration tests with outline of results
- Digital data for download : confirmed data only for registered users
- List of earthquakes : Specification and intensity distribution map for each earthquake
- Video images

(5) Home page, introduction, user guide, references, contact, etc.

It is important that various data is classified for every category for easy access of users, and that the data should be separated into category with and without changes as the earthquake occurs for easy data management for web and database managers. In the above-mentioned classification, the 4th is data which is added and changed as the new earthquake occurs, and as the new experiments are conducted. Others do not change except the case of new building construction, new soil exploration, etc. When users search for data which they wish to have, there are roughly two routes : search from building list and earthquake (or experiment) list.

Downloading Digital Data

Digital data downloading is now considered only for the data which are checked and confirmed by our laboratory. The downloading is now limited for registered users. Digital data is accumulated by using the common format. Data correction filter for difference of sensors' characteristics is not used except only the base-line correction of acceleration waves, because the original data is more important than corrected data. The user is able to do correction procedure, if needed, considering provided characteristics of sensors and procedures.

The HTML programs of the web system are also available. By using such a system, researchers and engineers who have not enough time to arrange and use many recorded data receives a great benefit. It is also expectable to give the cause to provide their data for public use. As many buildings' data is prepared for public use, it is very useful for research and structural design of low- and medium rise buildings.

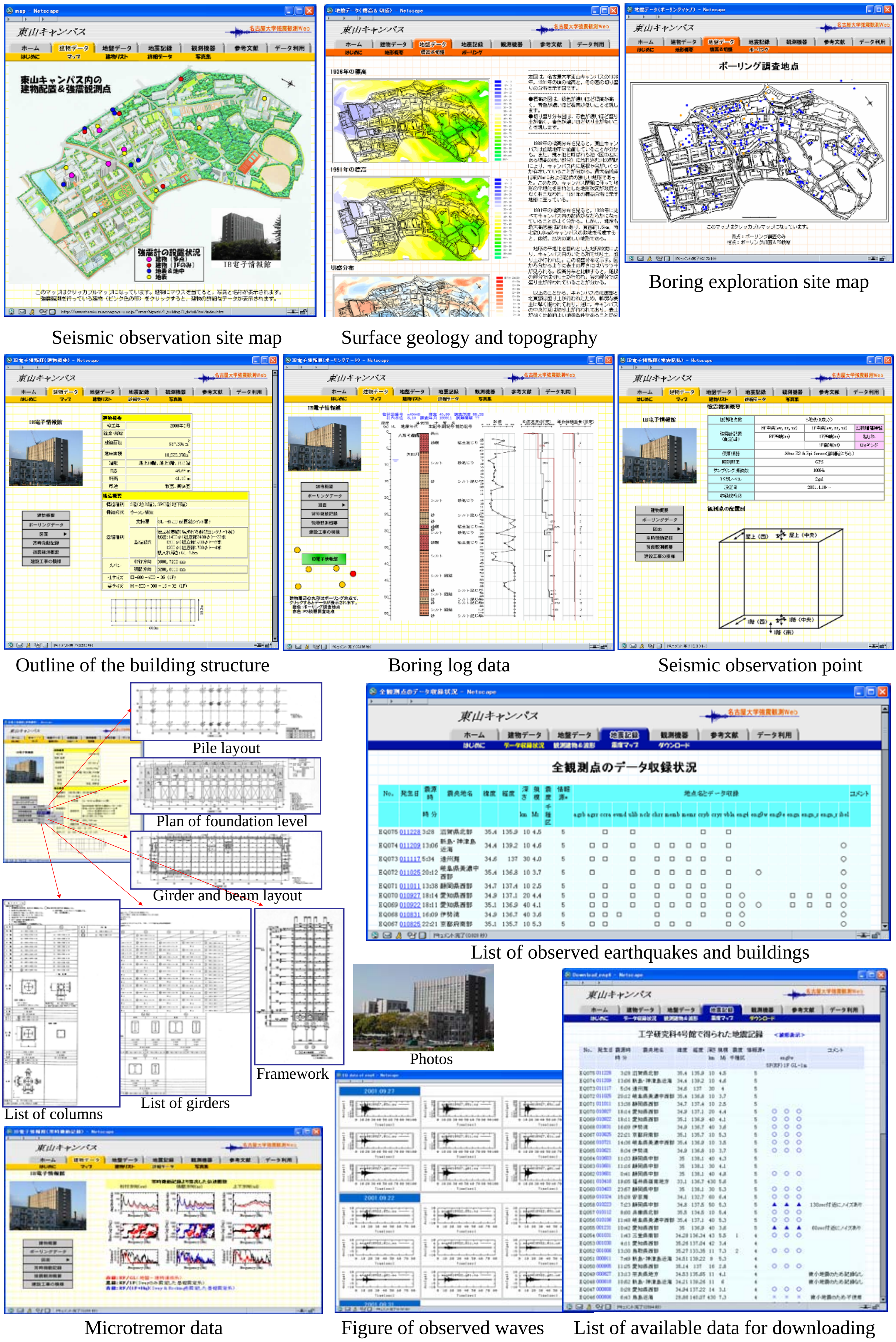


Fig.10 Web System for Publishing Structure-soil Seismic Response Data in Nagoya University

STRONG GROUND MOTION OBSERVATION NETWORK IN TOKAI AREA

"Super Network" of Strong Ground Motion Observation

It is essential to clarify the characteristics of strong ground motion in each region for the seismic design of buildings. The Tokai region is the third largest metropolitan region in Japan with 10 million inhabitants on the several large-scale plains. Organizations of many authorities are carrying out earthquake ground motion observations in this region, including several local political bodies, one electric power company, one gas company, one public corporation operating the expressways, several universities, and others.

If it can use all the observed data of such organizations' networks, more high-density observation can be developed. Such a "super network" of seismic observation networks deployed by multiple institutions has been constructed in the Tokai region in order to collect and publish a unified, on-line set of observations of seismic data. As each organization has developed their own earthquake observation network and database separately in accordance with its own purposes, such systems have different hardware, software and network connection for data collection system, and it proved to be no easy task to unify data. Wave data itself is the most important information for structural engineering and earthquake disaster mitigation, however, the systems of prefecture governments were established only for reporting seismic intensity. Thus the network connection systems and their interfaces were developed in various ways considering situations of each organization such that no changes to system operation were necessary in order to connect to the super-network. It was agreed that sending data is performed in the midnight, at least half a day after the occurrence of a seismic event so as to minimize disruption to the organizations' operations.

The super-network initially combined seismic observation networks managed by 3 prefectures, 2 cities, 3 companies and 3 universities. As shown in Fig.11, it was comprised of over 300 data collection points. It began operation as a super-network in 2000 (Fukuwa et al. 2000, Tobita et al. 2001). Other organizations have joined the network since then.

Web System for Observed Strong Ground Motion

Collected wave data is stored for every earthquake event, with various kinds of information. Fig.12 shows examples of the web pages displaying seismic intensity map for observed ground motion records, observed waveforms and its response spectra, geology and soil data, seismometer installation and instruments' specifications, etc. Digital data downloading is also provided, however, the access is now limited for registered users.

Comprehensive analyses of abundant data recorded over a large observation area have lead to a better understanding of the dynamic characteristics of the soil throughout the region. This represents valuable information for the design of high-rise buildings and base-isolated structures.

WEB SYSTEM FOR GROUND STRUCTURE SURVEY

Understanding and estimation of surface layers based on observed exploration data is important for consideration of dynamic behavior of soil. Various kind of subsurface exploration have conducted, however, they are difficult to understand and to use practically. Modeling of surface layers is not an easy task for ordinary engineers.

A on-line Geographic Information System with Web interface (WebGIS) to estimate the dynamic soil model in the sedimentary plain is constructed (Fig.13). The system conjugates maximally all of the existing subsurface exploration data in the large sedimentary plain in Tokai area, which are the Nobi plain, the Ise plain, the Okazaki plain and the Toyohashi plain. The data is obtained from the report of Aichi and Mie prefecture on the depth of upper boundary of each layer, together with various exploration data like reflection and refraction survey, microtremor array exploration, deep boring, P-S logging, gravitational anomalies, etc. The system estimates shear wave velocity and density of layering soil structure along an arbitrary section line and evaluates the soil amplification at an arbitrary site. The 3-dimensional subsurface structure is drawn in a web window using Java and Matrix Engine which make possible to visualize complex surface layers from arbitrary point of view only using ordinary browser software (Fig.14).

The system is developed for engineers of building structure and disaster mitigation to understand subsurface exploration data of large-scale sedimentary plain. Users are able to consider subsurface soil layer structure data in surface layer modeling for evaluation of dynamic ground response. Visual 3-D display is helpful for suitable 3-D modeling of sedimentary basin which is important to know the effect of 2-D and 3-D subsurface structures on characteristics of seismic wave amplification like "the disaster belt" appeared during the 1995 Kobe earthquake. There is a remarkable level difference of seismic bedrock caused by the Yoro fault at western edge of the Nobi plain. This can be understood from enlarged 3-D view in Fig.14, in which the shape of upper boundary of seismic bedrock is shown as yellow surface.

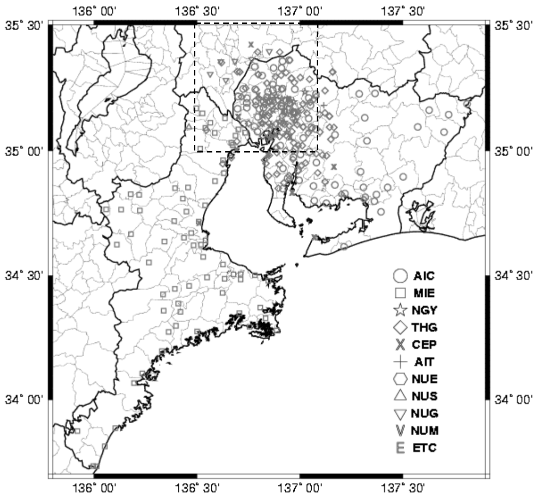
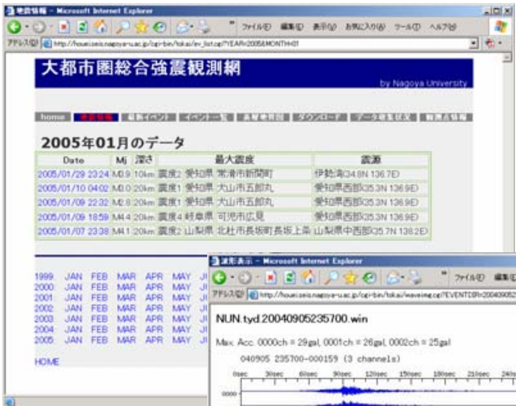
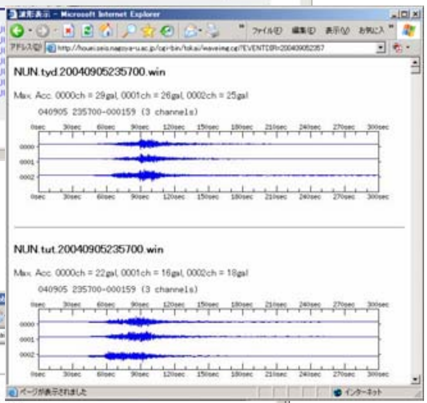


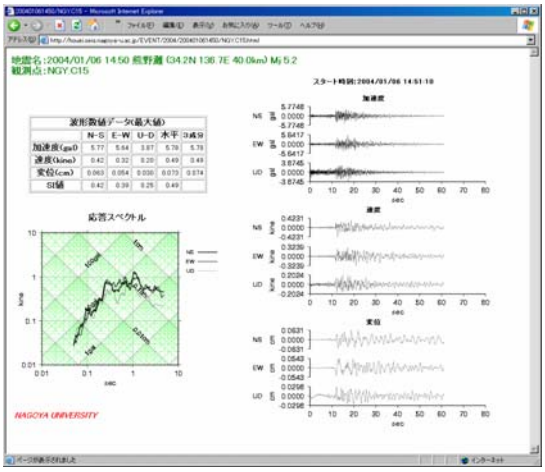
Fig.11 Seismic Observation Sites in Tokai Area



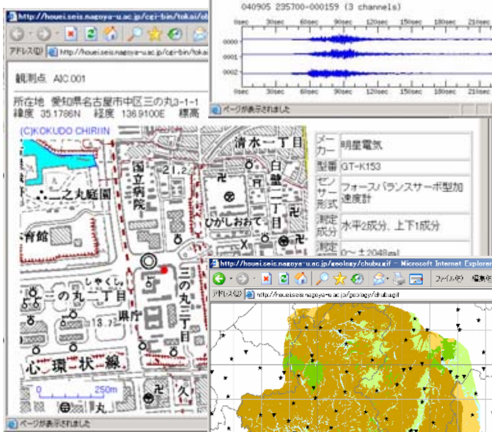
Earthquake List



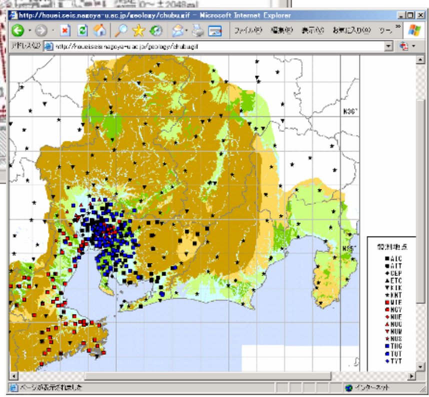
Waveform List



Waves (acce., vel, & dis.),
Maximum Values and Intensity,
Response Spectra

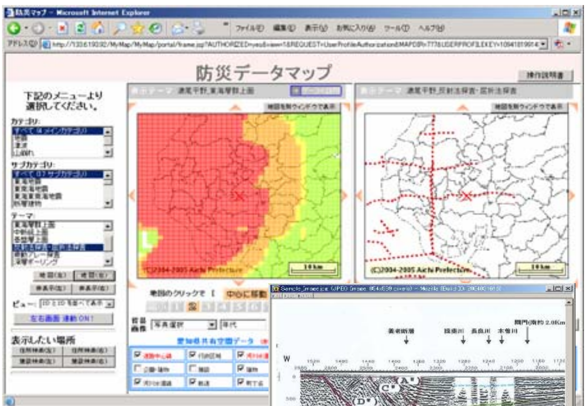


Site Map and
Specification of
Seismometer

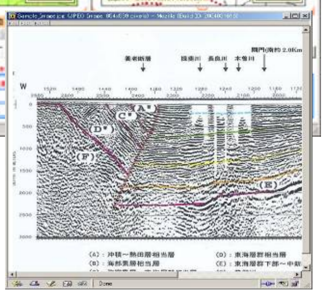


Geological Map

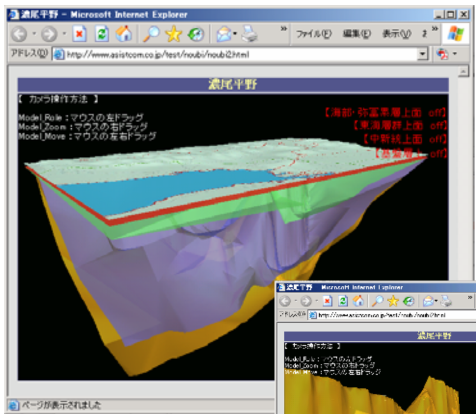
Fig.12 Web System for Publishing Seismic Observation Data



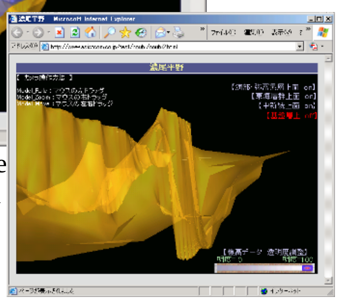
WebGIS for Various
Soil Exploration and
Soil Structure



Reflection Survey



3-D View of Subsurface
Layers in the Nobi Plain



Upper Boundary of
Seismic Bedrock

Fig.13 Web GIS for Deep Soil Structure

Fig.14 3-D View of Subsurface Soil Structure

CONCLUSION

Some examples on development of web-based online observation, monitoring and database systems for earthquake response of buildings and ground are described in this paper. It is shown that the data collection and information connection through networks are effective not only in quick data collection but in common use of the data by many researchers, engineers and organizations. As data is arranged by web-based systems, users are able to access the observed information by using a browser on ordinary PC without any special software. Such an easy accessibility promotes effective use of data. If discussions are made about the common format with which such a database should be equipped in the future, utilization of observation / experiment record will progress and it leads to effective practical use of observed data.

Considering building damage in 1995 Kobe earthquake, most of low-rise R.C. buildings suffered slight damage under severe shaking of intensity VII which is not considered in structural design. Thus, our understanding of building behavior during earthquakes has proven to be inadequate especially for low- and medium-rise buildings. For the performance-based design of structures, actual response characteristics and seismic performance of buildings have to be clarified by progress of observation and observed database.

ACKNOLEDGMENTS

The authors wish to thank Mr. T. Hara, Mr. E. Koide and Mr. T. Ito of OYO S.I. co. ltd., Mr. Y. Furuse of Falcon corporation for their cooperation in development of systems shown in this paper.

REFERENCES

Fukuwa, N., Tobita, J., Nakano, M., Takahashi, H., Iida, M. and Ishida, R. (2000). “Compilation of data of soil, seismic ground motion and microtremor, and grouping of dynamic ground properties in Nagoya city area.” *AIJ J. Technol. Des.* 10, 41-46 (in Japanese).

Kojima, H., Fukuwa, N., Tobita, J. and Nakano, M. (2003). “Development of web system to open seismic observation data of buildings.” *AIJ J. Technol. Des.* 17, 553-558 (in Japanese).

Kojima, H., Fukuwa, N., and Tobita, J. (2005). “Strategic observation program for dynamic response of buildings.” *Proc. of the The First International Conference on Advances in Experimental Structural Engineering (AESE2005)*, Nagoya, Japan.

Tobita, J., Fukuwa, N., Nakano, M. and Yamaoka, K. (2001) “Development of on-line data acquisition system for strong motion seismic records and its application to existent observation systems.” *AIJ J. Technol. Des.* 13, 49-52 (in Japanese).

Tobita, J. and Fukuwa, N. (2004). “Emergency Response Systems.” *Telegeoinformatics – Location-based Computing and Services* (ed. Karimi & Hammad), CRC Press LLC, 263-286.

Tobita, J. and Fukuwa, N. (2004). “Systems and programs for community disaster mitigation activities.” *Proc. of the 13th World Conference on Earthquake Engineering (13WCEE)*, Vancouver, B.C., Canada.

Tobita, J., Fukuwa, N. and Nakano, M. (2004). “Development of information systems and base for collaborative activities in disaster mitigation.” *AIJ J. Technol. Des.*, 20, 367-370 (in Japanese).