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Seismic Observation Systems in Nagoya University and Publication of Data

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This paper reports the current situation of the seismic monitoring program conducted by Nagoya University. First, the system for observing seismic ground motion in the Tokai Region is described. This is a super-network combining existing seismic ground motion observation networks deployed by multiple institutions and connected by the Internet. The network was established with the purpose of obtaining the characteristics of seismic ground motions over a wide area. Next, the network for observing the earthquake response of the structure-soil system is described. Buildings on the Nagoya University campus were chosen with the objective of clarifying their dynamic response characteristics to seismic excitation, and the observation results are published on a web page. A newly proposed seismic observation system is then discussed. An inexpensive seismic observation system based on acceleration sensors used at present for automotive air-bag systems has been built. Sensors have also been combined with warning light towers and PCs and connected to the Internet to create a system capable of transmitting raw, real-time seismic data for recording as well as signals for emergency alarm systems. The design also allows expansion of the system to allow for multiple uses. Other components could be meteorological sensors, live cameras, etc., for disaster prevention, ordinary crime prevention, environmental monitoring, education, or other purposes.

INTRODUCTION

More knowledge about the dynamic behavior of buildings is needed to widen the use of seismic design based on dynamic analysis. Data must be taken during major seismic events in order to learn more about the nature of seismic ground motions acting on buildings and the nature of dynamic soil structure interaction. Currently, however, an entirely inadequate

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number of buildings have been instrumented, and the data is of dubious quality. Furthermore, little of this valuable observation data has been published. This field desperately needs a large increase in the number of observation locations, improvements in the quality of measurements, and publication and dissemination of information that has already been recorded. In the 2nd UJNR Workshop on Soil-Structure Interaction (SSI) held at Tsukuba, Japan in 2001, researchers discussed how important it is in both nations to collect more observation data and to make that data available. This report is part of the effort to improve this situation by describing the system deployed at Nagoya University for gathering and disseminating seismic observation data is also described. A newly developed system employing inexpensive seismometers, which is expected to make it possible to increase the number of observations. The system was developed with the goal of allowing multiple uses besides earthquake engineering.

The data collection/publishing system developed by the authors consists of the Tokai Area Strong Ground Motion Observation Network System (TAS-Net) and the Nagoya University Soil-Structure Seismic Response Observation Network System (NUS-Net). TAS-Net is a super-network composed of multiple networks controlled by several authorities in the Tokai region, the third largest urban area in Japan, recording soil subsurface and underground seismic waveforms and publishing the data in a unified database accessible over the Internet.

NUS-Net records a wealth of seismic response data from multiple buildings and soil sensors on the Nagoya University campus over the campus LAN. In addition to waveform data, this system also publishes detailed data on building structures, soil geological data, and other material. A strategy was conceived for choosing the buildings to be observed in order to obtain the best illustration of the factors affecting the behavior of buildings during earthquakes.

As an example of an approach to creating a much larger earthquake observation network, the authors also developed inexpensive seismometers by using automotive air bag acceleration sensors and constructed a simple model network connected by a LAN and cellular telephones. In order to motivate more would-be users to install real-time seismic alarm systems and earthquake damage data transmission systems, the network readily allows for expansion through the use of components that are not typically used in earthquake engineering. The system is designed for multiple uses, for crime prevention, environmental monitoring and science education, by incorporating Internet cameras and meteorological sensors.

TAS-NET: TOKAI AREA STRONG GROUND MOTION OBSERVATION NETWORK SYSTEM

It is essential to understand the characteristics of strong ground motions in each region in order to ensure the rational seismic design of buildings. This data must be recorded during earthquakes. The Tokai region, the third largest metropolitan region in Japan and home to 10 million inhabitants, encompasses a number of plains: the Nobi Plain, the Ise Plain, the Okazaki Plain and the Toyohashi Plain. Organizations of many authorities are carrying out observations of seismic ground motions in this region, including several local political bodies, an electric power company, a gas company, a public corporation operating the expressways, several universities, and others.

Each organization places its observation network on-line and creates an environment permitting access to all the observation data to facilitate effective exploitation of the data. As each organization had established its database in accordance with its own purposes prior to the merger, many were required to re-create the data storage system to comply with the merger while continuing to meet the original purposes of the observations. Further, each organization had a different transmission system and different server for data collection, and it proved to be no easy task to unify data display. It was agreed that this super-system would send data requests to the organizations in the middle of the night, at least half a day after the occurrence of a seismic event so as to minimize disruption to the organizations' operations. Each

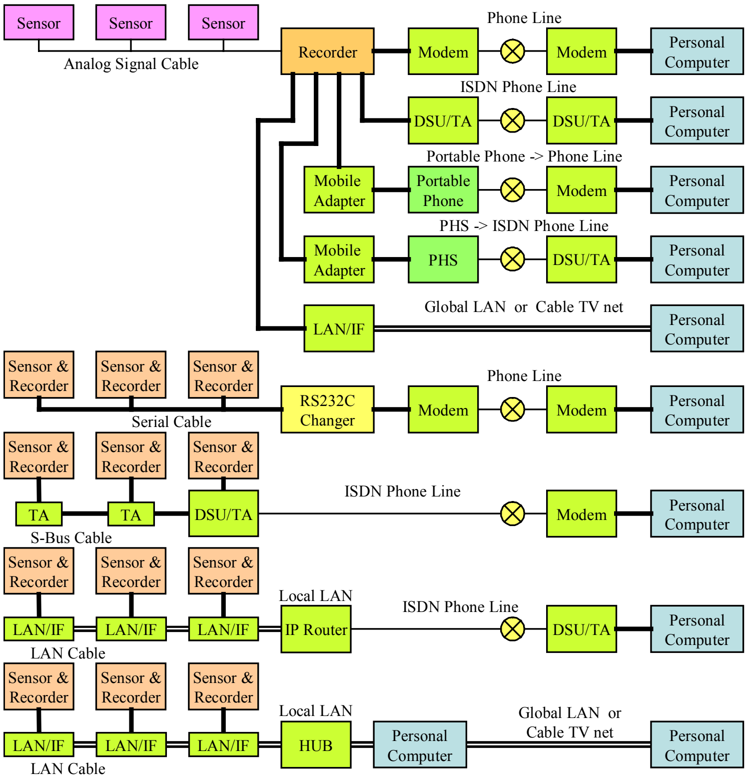
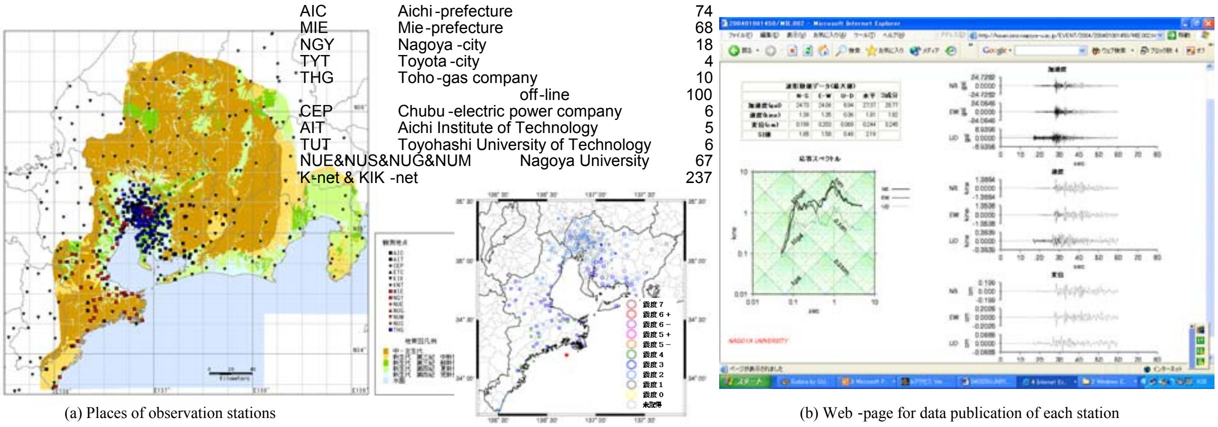


Figure 1 Interface for connections between institutions in the strong ground motion observation network

organization established an interface like that shown in Fig. 1 such that no changes to systems were necessary in order to connect to the super-network.

The super-network initially combined seismic event observation networks managed by 2 prefectures, 2 cities, 3 companies and 3 universities. As shown in Fig. 2, it was comprised of over 600 data collection points. It began operation as a super-network in 2000. Other organizations have joined the network since then. The data records consist of seismic intensity, wave forms and response spectra, as indicated in Fig. 2, as well as seismometer installation, soil data, and seismometer specifications. This information is published on the web.



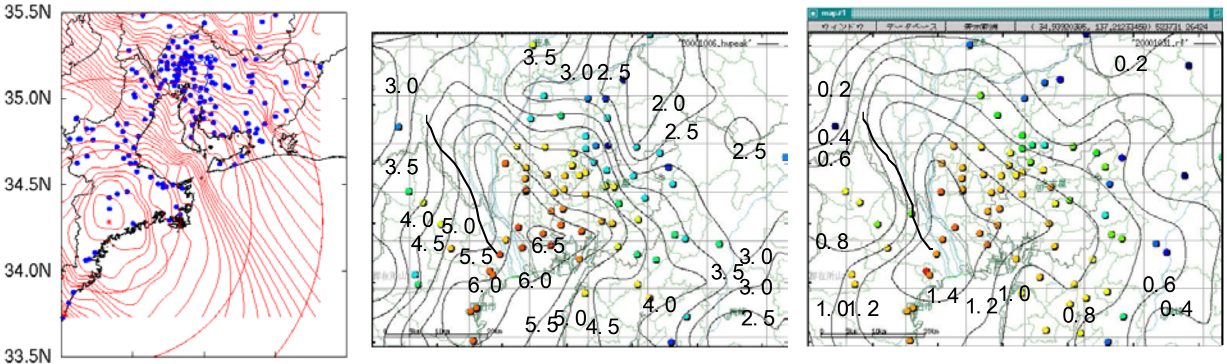
AIC	Aichi-prefecture	74
MIE	Mie-prefecture	68
NGY	Nagoya-city	18
TYT	Toyota-city	4
THG	Toho-gas company	10
	off-line	100
CEP	Chubu-electric power company	6
AIT	Aichi Institute of Technology	5
TUT	Toyohashi University of Technology	6
NUE&NUS&NUG&NUM	Nagoya University	67
K-net & KIK-net		237

(a) Places of observation stations

(b) Web-page for data publication of each station

Figure 2 TAS-Net Web system for displaying earthquake observation locations and publishing observation records

Comprehensive analysis of abundant data recorded over a large observation area has lead to a better understanding of the dynamic characteristics of the soil throughout the region. Figure 3 shows the arrival times when the shear waves reached the sensor, the predominant



(a) Distribution S-wave arrival time in 2000 Mieken-chubu earthquake

(b) Distribution of predominant period due to H/V spectrum in 2000 Tottoriken- seibu earthquake

(c) Distribution of P-PS time in 2000 Mieken-chubu earthquake

Figure 3 Examples of analysis of extensive strong ground motion records period given by the H/V spectrum, and the PS-P time distribution given by the receiver function. These results correspond well with existing data for the distribution of gravitational anomalies and were proven to be caused by surface geology. This represents invaluable information for the design of super high rise structures and base-isolated structures

NEED FOR STRATEGIC OBSERVATIONS OF SEISMIC STRUCTURE-SOIL RESPONSES

Many theoretical reports have pointed out the need for more intensive investigation of soil-structure interaction (SSI). Regular structural engineers lack sufficient awareness of the importance of SSI because of the dearth of systematically gathered experimental data. There is a real need for seismic response observation systems capable of distinguishing the effects of parameters controlling SSI. An ideal list of capabilities of such a system would include the following kinds of analyses, among others: 1) period-lengthening and damping effects of SSI; 2) difference between foundation input motion and effective input motion; 3) different soils beneath buildings of the same structural type and height; 4) SSI in buildings with the same structures and soil conditions but different heights; 5) differences between buildings with the same height and soil conditions but different structures in order to study the effect of structural type on SSI; 6) three-dimensional structural dynamic behavior due to eccentricity in the upper structure; and 7) structure-soil-structure interaction due to neighboring structures.

In order to better understand SSI, the observed buildings must be fully instrumented. At a minimum, this means the deployment of accelerometers to track the response of the free soil surface, the center of the structure foundation, and the center of the roof, and sensors to track vertical movement of the foundation corners due to rocking. More sensors to measure the torsional response and deformation of the floor would be necessary to examine the three-dimensional dynamic behavior of the building.

To observe differences between soils, buildings such as elementary schools, which are built to common specifications, could be chosen over varying soil conditions for instrumentation.

To understand the differences between structurally similar buildings with different numbers of floors, observations can be carried out in a single building, as earthquakes occur when different floor levels have been reached during construction. This data would also be useful for developing a better understanding of the differences between effective input motion and foundation input motion. In addition, continual observations of pile foundations would allow analysis to distinguish between the influence of inertia of the upper structure and the influence of soil deformation.

Simultaneous observations of buildings of the same height on the same site but of different structural types would provide data on the effect of different structures. Another method for obtaining a similar result would be to observe the responses to earthquakes before and after a building is retrofitted for earthquake resistance.

The effect of the presence of neighboring structures can be examined by instrumenting a building neighboring a site where another building is scheduled to be erected and observing it during earthquakes before and after the second building is built.

The effect of eccentricity of the upper floors can be examined by instrumenting a building scheduled for an addition and observing it before and after construction of the addition.

Fortunately, at Nagoya University, where the authors work, there are a large number of buildings, many still of original construction or under construction of additions, including seismic retrofit measures. Figure 4 shows a list of observations offered for access.

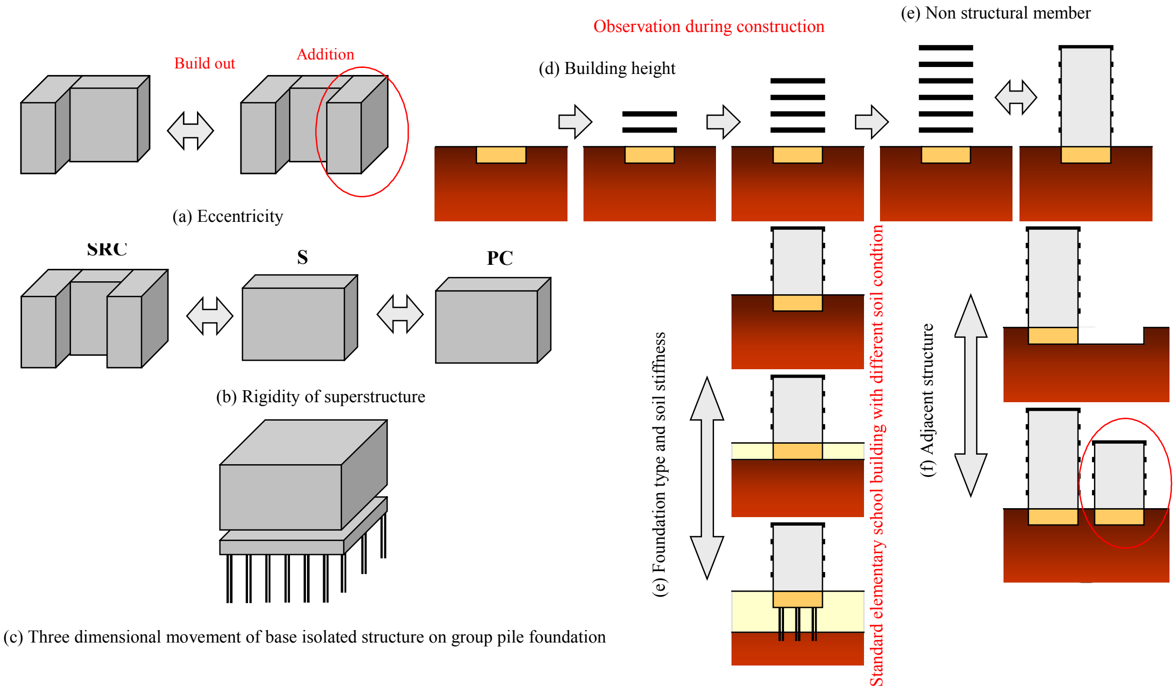


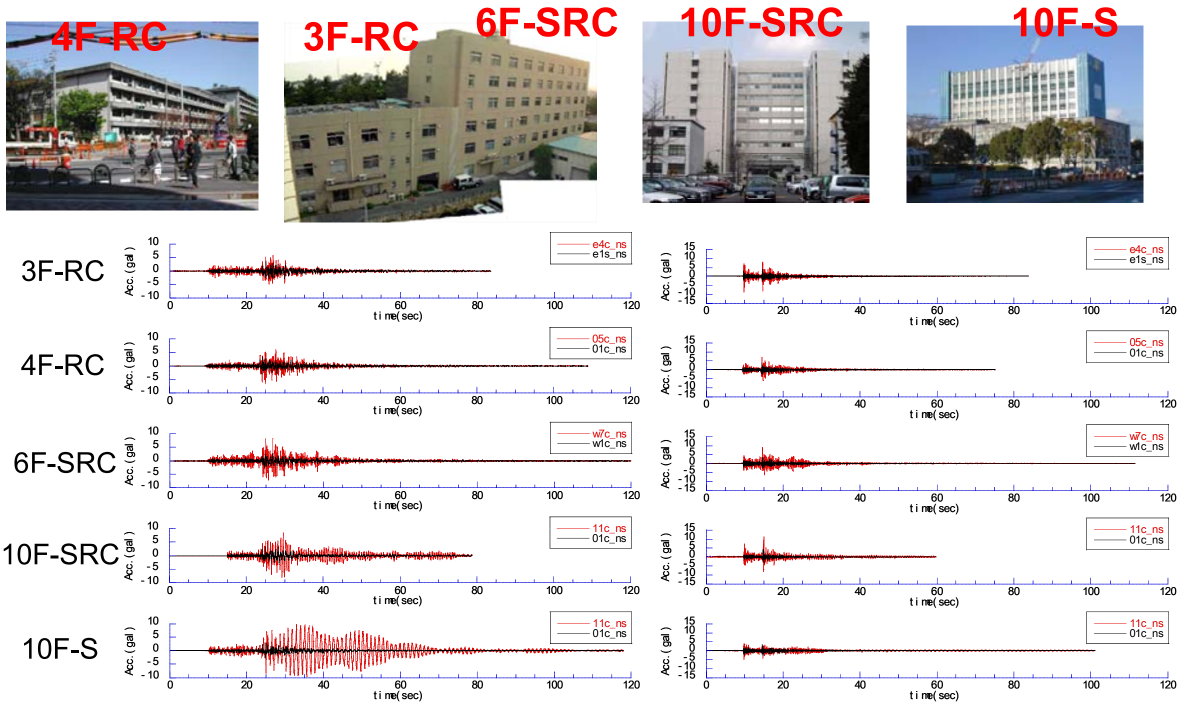
Figure 4 Earthquake observation items for analysis of factors contributing to the dynamic behavior of buildings

NUS-NET: NAGOYA UNIVERSITY SYSTEM FOR SEISMIC RESPONSE OBSERVATIONS OF STRUCTURES AND SOIL

Observations of seismic response are currently being carried out or are scheduled to begin soon at thirteen structures shown in Figure 5. These structures are on the Higashiyama and Tsurumai campuses of Nagoya university. Off campus, three residential buildings, two buildings with base isolation, one temple, and three governmental buildings are also under observation. The seismometers in the Nagoya University buildings are interfaced to the university LAN. As shown in Fig. 5, the records are in a form suitable for publishing and are made available on the Internet. The concept diagrams, structural drawings, soil data, observation point locations, sensor specifications, list of observed earthquakes, observed waveforms, microtremor records, and other data are always available via the Internet. It is also possible to download digitalized records of confirmed observation data. HTML programs are also available to ease the task of publishing seismic data on the web for other institutions.

DIFFERENCE OF STRUCTURAL RESPONSE WITH BUILDING HEIGHT AND STRUCTURE AND WITH SEISMIC GROUND MOTION

Let us examine some analyses of the observation data. Figure 6 shows seismic records



(a) Distant Earthquake:2001 Shizuokaken-chubu(M4.8) (b) Subjacent Earthquake:2001 Aichiken-seibu(M4.1)

Figure 6 Records of observations of five buildings during an earthquake (left, distant focus; right, nearby focus) for 5 typical buildings, including foundation data with roof data for comparison. The left side shows time histories during an earthquake with a distant epicenter. The right side shows corresponding results during an earthquake directly beneath the campus. The differences in the response characteristics with the number of floors, with structural types, and with duration of seismic ground motion can be read in the figure.

CHANGE OF SEISMIC RESPONSE OF TALL BUILDING DURING CONSTRUCTION

Figure 7 presents earthquake response records for an 18-story steel-frame building under construction. This shows a tendency for resonance and a reduction of radiation damping in taller buildings.

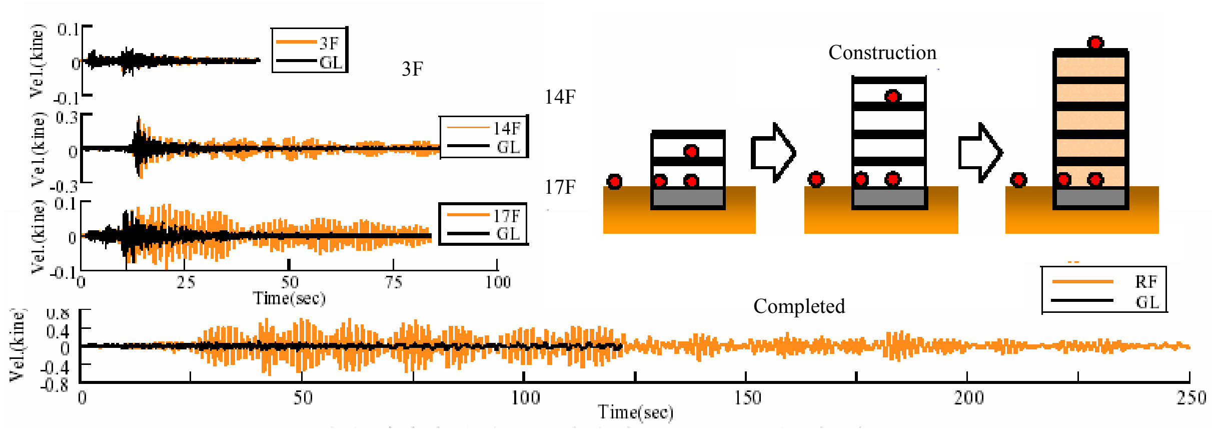
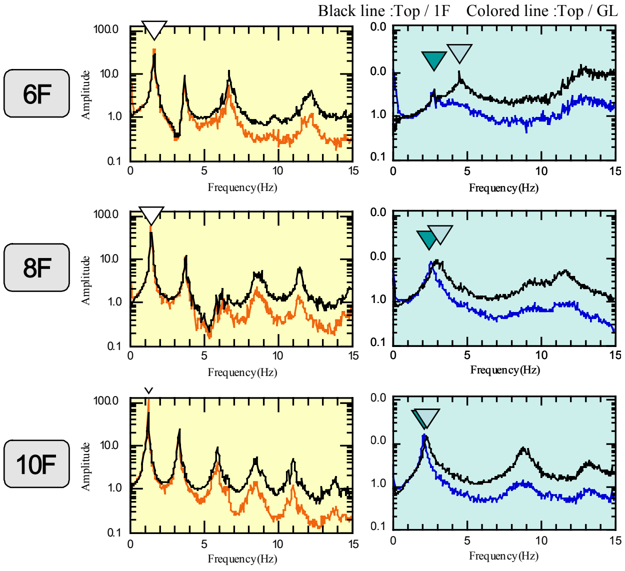


Figure 7 Record of 18-story steel building under construction during earthquake

CHANGE OF STRUCTURAL AMPLIFICATION AND INPUT LOSS EFFECT DUE TO MICROTREMOR DURING THE CONSTRUCTION

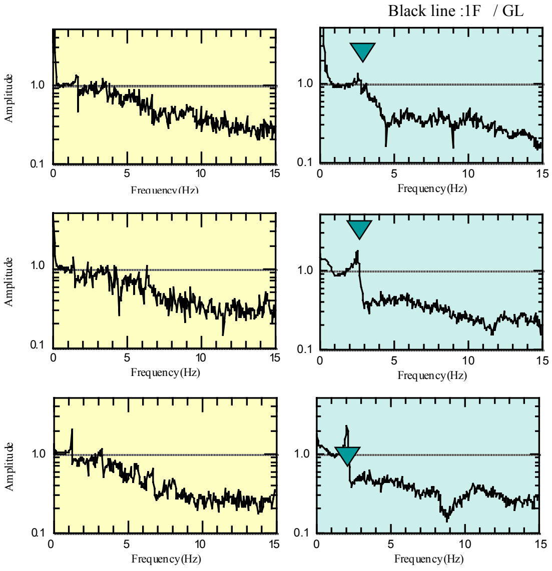
Figures 8 and 9 show the results of observations of microtremors for a 10-story steel-frame building and a 10-story steel-reinforced concrete (SRC) building. The results for semi-completion at 6 and 8 stories are shown in addition to the results for completion of 10 stories.

Figure 8 provides comparisons of Fourier spectral ratios of microtremor records between the soil and the building roof and between the foundation and building roof. There is a greater SSI effect in the stiffer SRC structure, particularly in shorter buildings. In contrast, there is almost no SSI effect in plain steel frame building, particularly for taller buildings. Figure 9 presents a comparison of the Fourier spectra of soil motion and foundation motion,



(a) Steel building (b) SRC building

Figure 8 Fourier spectral ratio of microtremors between 10-story SRC structure and 10-story steel structure under construction (building vs. soil; building vs. foundation)



(a) Steel building (b) SRC building

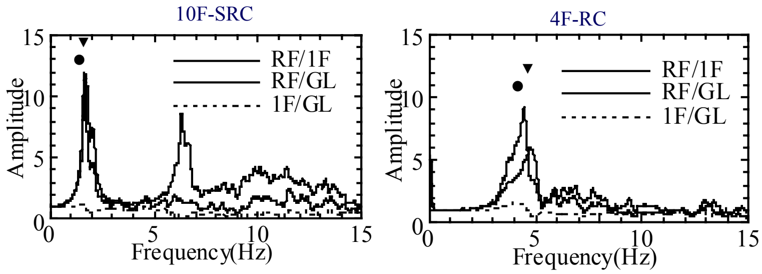
Figure 9 Fourier spectral ratio of microtremors between 10-story SRC structure and 10-story steel structure under construction (foundation vs. soil)

indicating an input loss effect, and that the effective input motion does not depend on the number of floors or structure type.

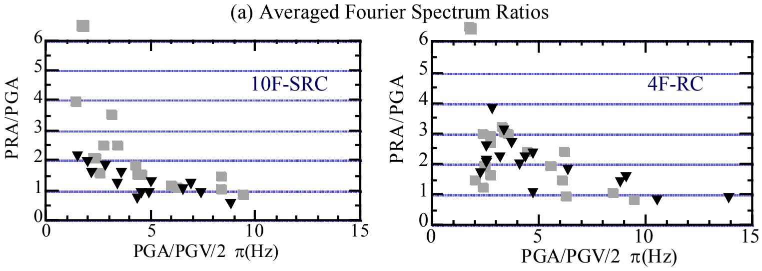
DIFFERENCE OF SEISMIC STRUCTURAL RESPONSE AMPLIFICATION AND INPUT LOSS WITH BUILDING HEIGHT AND FREQUENCY CONTENT OF SEISMIC INPUT MOTION

Figure 10 compares a 4-story building with a 10-story building. The upper graph provides comparisons of Fourier spectral ratios between the soil and the building roof, between the foundation and building roof, and between the soil and the foundation. The maximum acceleration response ratio of the building is also plotted against soil response to show the amplification of the building response. The horizontal axis is the predominant frequency of the soil response. The lower graph shows similar results for amplification of response of a building foundation vs. soil response. The responses vary with varying predominant frequency of the input seismic ground motion. The results indicate that a lower number of floors results in lower amplification, a higher predominant frequency, higher input loss effects.

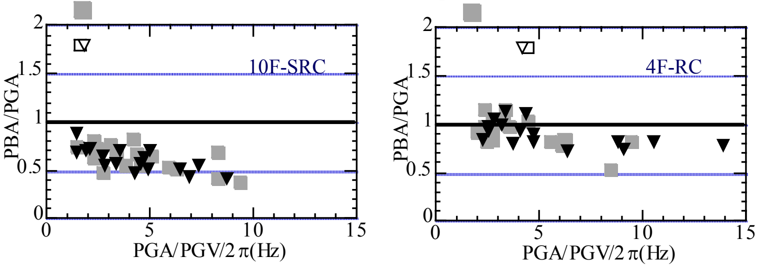
EFFECT OF NEIGHBORING BUILDING : STRUCTURE-SOIL-STRUCTURE INTERACTION



(a) Averaged Fourier Spectrum Ratios



(b) Maximum acceleration amplification in building



(c) Maximum acceleration reduction due to input loss effect

Figure 10 Fourier Spectrum ratios, maximum acceleration response amplification in building, and maximum acceleration reduction in foundation for a 10-story SRC building and a 4-story RC building

Figure 11 shows the response modes observed in neighboring 6-story and 3-story buildings when the 6-story building displayed the maximum response in a time series. The smaller 3-story building vibrated in a bending mode, as if bowing, due to the influence of the larger neighboring 6-story building.

EFFECT OF ECCENTRICITY

Figure 12 shows the response of a 10-story RC building with eccentricity compared to the torsional response of the building after construction of an addition that eliminated the eccentricity. There is a notable difference in the responses due to the eccentricity. This figure shows the response mode at the vibratory frequency where the torsional response was predominant.

EXPANSION OF NUMBER OF OBSERVED BUILDINGS THROUGH THE DEVELOPMENT OF INEXPENSIVE SEISMOMETERS

One of the reasons for the sluggish increase in the number of instrumented buildings is

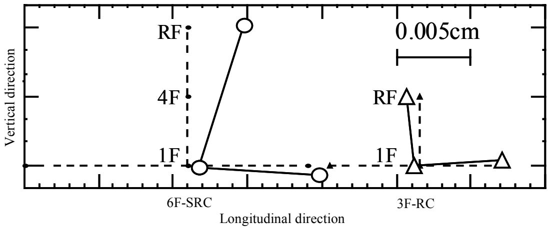


Figure 11 Response modes of neighboring 3-story RC and 6-story SRC structures when the 6-story building displayed the maximum response in a time series

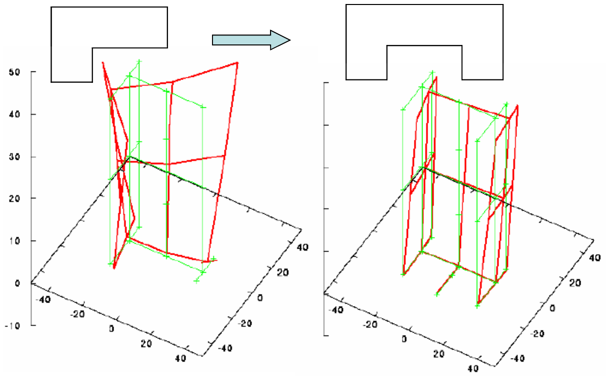


Figure 12 Difference between torsional response modes (2.5Hz) before and after addition to 10-story SRC structure

the cost of seismometers. A regular seismometer costs up to $10,000. As mentioned earlier, observations of buildings require instrumentation at several points, in the soil, foundation and within the building itself. When installation and transmission system costs are considered along with instrumentation, preparation of a single building can easily run to $50,000. That is why instrumented buildings in Japan tend to be limited to the super high rise buildings or base-isolated buildings. Observations of ordinary buildings are extremely rare.

In an attempt to improve this situation, the authors have cooperated with an automobile manufacturer to develop a seismometer that costs less than $1,000. The basis of the instrument is a mass-produced accelerometer used to activate the air bags of an automobile in the event of a crash (Fig. 13). This semiconductor sensor detects acceleration, and features a resolution of 1 Gal with 16-bit AD conversion and compatibility with connection to computers or the Internet. It can record up to 160 s of 10-wave records and outputs the maximum acceleration, spectrum intensity and seismic intensity. An example of the acceleration Fourier spectrum output by such a sensor is shown in Fig. 13, along with the record from a standard servo-type acceleration seismometer. The figure indicates that the new sensor has sufficient accuracy in the frequency portion of the spectrum that is important for buildings. This sensor is very promising for observations of earthquake responses. Once inexpensive seismometers become widely available, it will no longer be impossible to instrument all buildings, and will prove to be an essential tool for pursuing performance-based design.

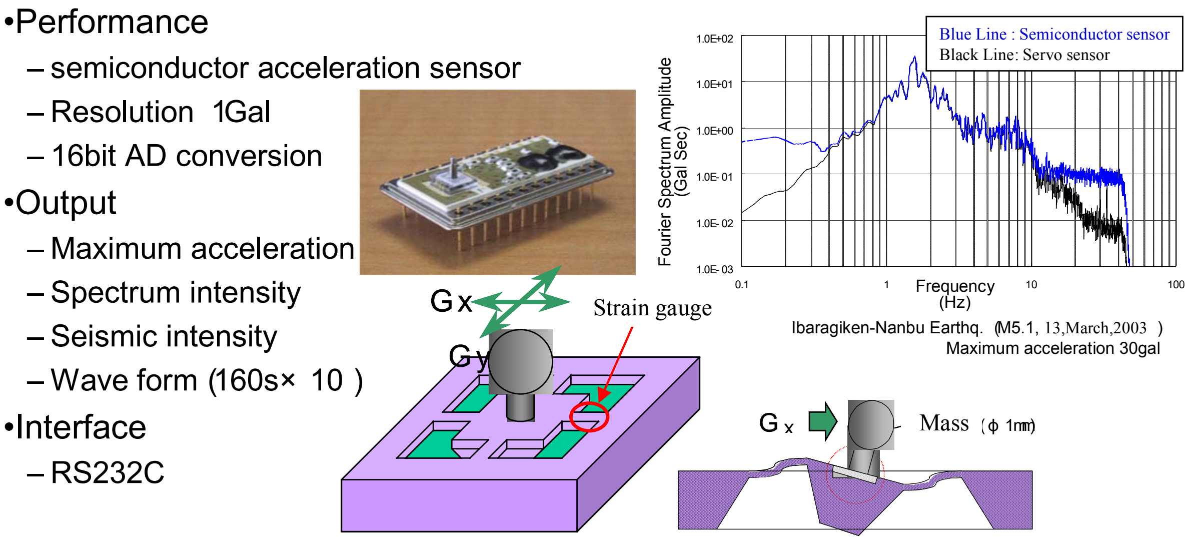


Figure 13 Overview of inexpensive seismometer, Comparison of recorded Fourier spectra from standard servo-type seismometer and new inexpensive seismometer

Using company and home LANs will allow networking of seismic sensors, which can be linked to local servers over the Internet, ISDN lines, PHS and other means.

EXPANDED USES OF METEOROLOGICAL SENSORS AND LIVE CAMERAS

Seismometers need not be the only sensors connected to the lines. The uses of the network could be expanded by connecting meteorological sensors, live cameras and other instruments via the local computer, allowing access to other information over the Internet. In ordinary conditions, it could be used as an environmental monitoring system, to keep track of vibrations due to construction or traffic. In the event of a major quake, it would send and receive signals about strong ground motion and damage. Combination with Web-GIS would allow use as a disaster warning system, and the attachment of meteorological sensors would allow it to be used for science education in elementary and middle schools. This would also allow assembly of a highly dense environmental monitoring system. Live cameras would be useful for crime prevention under ordinary conditions, and could also be connected to home computers when triggered by seismometers to record images automatically during seismic events. In addition, the seismometer network could be connected to warning light towers or other signals, forming an early warning system. The wide range of possible uses of such a network may itself help to encourage a great increase in the installation of seismic sensors.

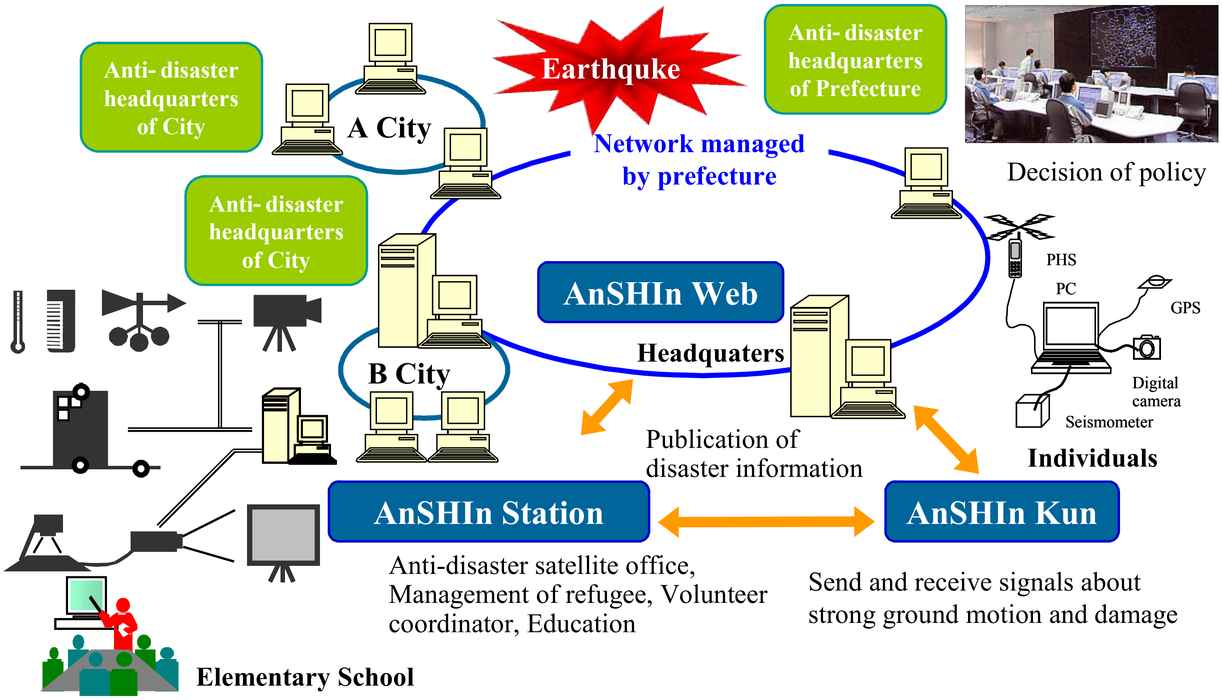


Figure 14 Overview and components of AnSHIn System

Figure 14 shows the system assembled by the authors. This system was conceived as a combination of the Nagoya region local authority disaster warning network Web-GIS (AnSHIn Web), the network established by elementary schools and other members (AnSHIn Station), and the network established by municipalities and disaster relief bodies of other authorities (AnSHIn-Kun; Anti-Seismic Hazard Information Keeping Unit). The latter network combines GPS, PHS, mobile PCs, digital cameras and inexpensive seismometers. To these components, AnSHIn Station adds meteorological sensors, live cameras, warning light towers, LC projectors and others, and is scheduled to be connected to the Internet in the near future.

CONCLUSIONS

This paper described an example of a system developed and assembled by the authors with the objective of increasing the quality and number of seismic observations in buildings and soil to create more complete records of seismic responses.

1) A super-net of seismic observation networks deployed by multiple institutions has been constructed in the third-largest metropolitan region in Japan in order to collect and publish a unified, on-line set of observations of strong ground motion data. This extensive collection of data over a wide area allows analysis of region-wide seismic motion characteristics.

2) An earthquake response observation system capable of analyzing separate influential factors in the behavior of buildings has been conceived and a version has been established on the Nagoya University campus. A web site has also been constructed to publish observation records, soil data and structural data in order to encourage the use of seismic data. Observations have been used to show the influences of various factors in building vibrations, including structure height, structure type, soil conditions, the effect of eccentricity in the structure and the effect of close neighboring structures.

3) An inexpensive seismometer based on an air bag sensor was developed with the goal of increasing the number of seismic observation points. A new system integrating meteorological sensors, live cameras and other components was proposed in order to encourage broader use of earthquake observations in society. This will allow exploitation of the system for multiple uses beyond earthquake observation, such as general disaster warnings, environmental observation, crime-fighting, and education.

REFERENCES

Resolution of 2nd UJNR-SSI workshop held at Tsukuba, 2001.3

M.Nakano, N.Fukwua and J.Tobita : Regional Variation of Ground Motion in Nobi Plain, Japan, Based on Seismic Records, Microtremor and Geological Data, An International Conference on Geotechnical & Geological Engineering, GeoEng2000, GEE645, 6p., 2000.11

N. Fukuwa , M. A. Ghannad , J. Tobita and R. Nishizaka : Analytical AND Experimental Studies on the Effect of Soil-Structure Interaction on Damping, Natural Frequency and Effective Input Motion of Buildings, 1st US-Japan Soil Structure Interaction Workshop, Menlo Park, CA, pp.14-1~14-15, 1998.9

N. Fukuwa and J. Tobita : SSI Effect on Dynamic Characteristics of Low & Medium Rise Buildings Based on Simplified Analysis and Observation, 2nd US-Japan Soil Structure Interaction Workshop, Tsukuba, 10p., 2001.3.

J. Tobita and N. Fukuwa: Anshin-System :Intercommunication System for Earthquake Hazard and Disaster Information, The 2002 Japan-Taiwan Joint Seminar on Earthquake Mechanisms and Hazards, Nagoya, pp.66-67, 2002.1

N. Fukuwa, J.Tobita, H. Takai, and E. Ishida : Effective Application of Geographic Information Ssystem in the Field of Earthquake Engineering and Disaster Prevention, 12th World Conference on Earthquake Engineering, Paper No.2229, 8p, 2000.1

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