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PROPOSAL OF STRATEGIC SEISMIC OBSERVATION OF SOIL-STRUCTURE SYSTEM AND DATA PUBLICATION THROUGH WEB

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SUMMARY

The soil-structure interaction (SSI) is very important factor for the ordinary buildings. SSI governs their dynamic behavior and seismic performance. In Japan, recently, the seismic code considering SSI effect is newly introduced. However, the experimental or observational verification is not enough yet. Therefore, the reduction effect of seismic force due to SSI should be qualified through the seismic observation.

In order to increase the seismic observation data of ordinary buildings, the inexpensive and easily constructed seismic observation system should be proposed. In this paper, the low price seismometer is newly developed by converting the air-bag sensor. And the new seismic observation network system using in-house LAN, Internet, and mobile communication system is presented.

For the acquisition of high-quality data which can evaluate SSI effect, the systematic and strategic observation should be planned. The ideal datasets are the same buildings with different soil conditions, the different height buildings with same structure and soil conditions, and the different structural buildings with same height and soil conditions. Here, the several observation examples conducted by us are introduced. These are (a) the observation of elementary school buildings in Nagoya city, with same structure and height while different soil condition, (b) the observation of same height buildings with different structural type in Nagoya university campus, and (c) the observation of the building under construction where the effect of building height can be analyzed.

The exchange of useful data is also important matter. In order to promote the data circulation, the web system which opens data to public through Internet is the most suitable. Here the prototype system which includes explanation of the building plans, soil data, observation system as well as the download function of observed data is demonstrated.

INTRODUCTION

A better understanding of how buildings resist earthquakes and quake-induced loads is necessary to further performance-based design in the seismic preparation of buildings in the design stage. The

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extensive damage resulting from the Hyogo-ken Nambu Earthquake showed, however, highlighted how little we really know about this subject. The actual response behavior of the structures and the forces acting on the structures during the earthquake appear to have differed significantly from those predicted by current analytical methods. Since there are scant records from areas struck by earthquakes, however, there is no way to prove it.

Copious amounts of data have been recorded for skyscrapers and seismically isolated buildings during earthquakes, and methods for analyzing structure responses to these loads have been developed to match the observations. The structures of ordinary buildings are complicated, however, and analytical investigation is difficult. There has also been a dearth of data. Thus, our understanding of building behavior during earthquakes has proven to be entirely inadequate as the performance-based design philosophy has come to the fore.

In order to rectify this lack of information, (i) a far larger number of buildings must be equipped for observations during earthquakes, (ii) observations must be performed with the specific purpose of understanding building behavior, and (iii) a system for wide dissemination of the observation records must be assembled.

This report proposes an inexpensive seismic sensor developed to ease the financial burden of deploying instrumentation to make such observations, and outlines a simple method for establishing the observation network. The system is also expandable beyond use simply for seismic engineering, with possible uses for disaster measures, environmental monitoring and warning, crime prevention and education. The system also provides a list of items for earthquake observations, allowing the data to be analyzed to determine the most important factors contributing to the structure behavior during an earthquake. An example of the above network and some examples of analysis of observations are described. Finally, an example of an internet-based system for publishing observation records and data from structures and soil is presented.

NEED FOR STRATEGIC OBSERVATIONS OF SEISMIC STRUCTURE-SOIL RESPONSES

Many theoretical reports have pointed out the need for more intensive investigation of soil-structure interactions (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; 7) structure-soil-structure (SSSI) interactions due to neighboring structures; and 8) the effect of nonstructural members on the amplitude dependency of dynamic characteristics.

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 learn the differences between structurally similar buildings with different numbers of floors, observations can be carried out in a single building, when earthquakes occur as different floor levels are 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 the 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 1 shows a list of observations offered for access.

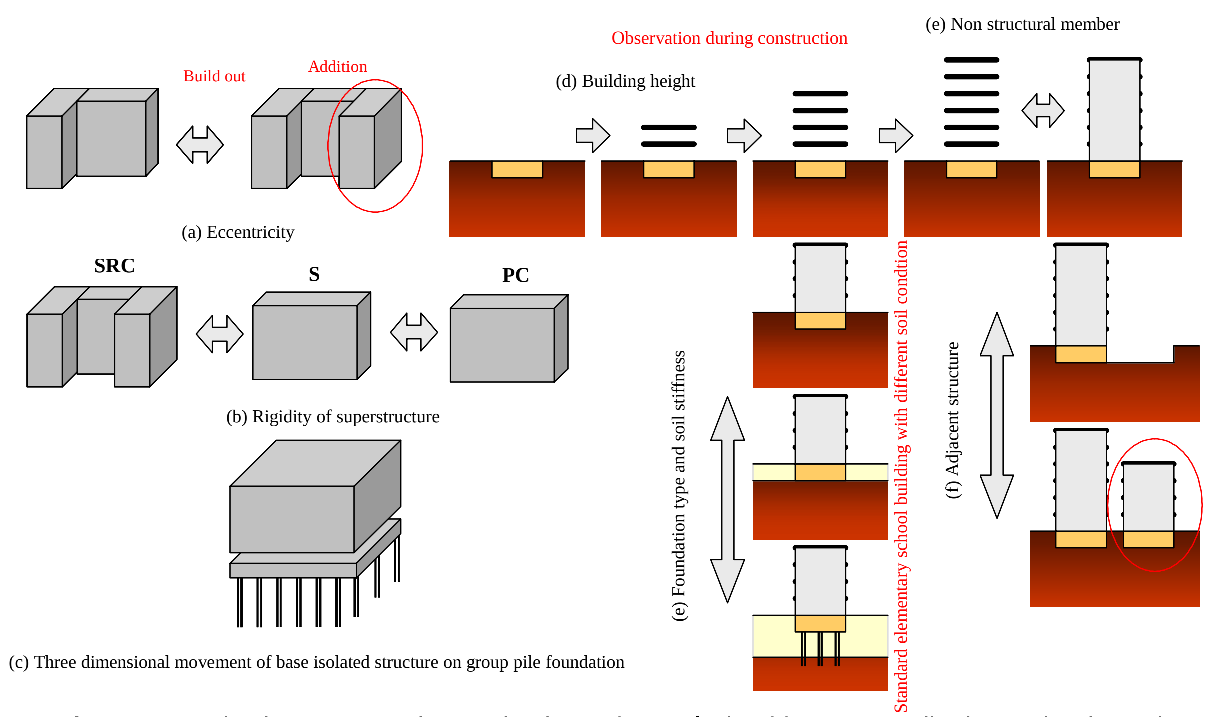


Figure 1 Seismic response observation items for analysis of factors contributing to the dynamic behavior of buildings

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 the 13 structures shown in Figure 2. These structures are on the Higashiyama and Tsurumai campuses of Nagoya university. Off campus, three individual house buildings, two buildings with base isolation, one temple, and two 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.

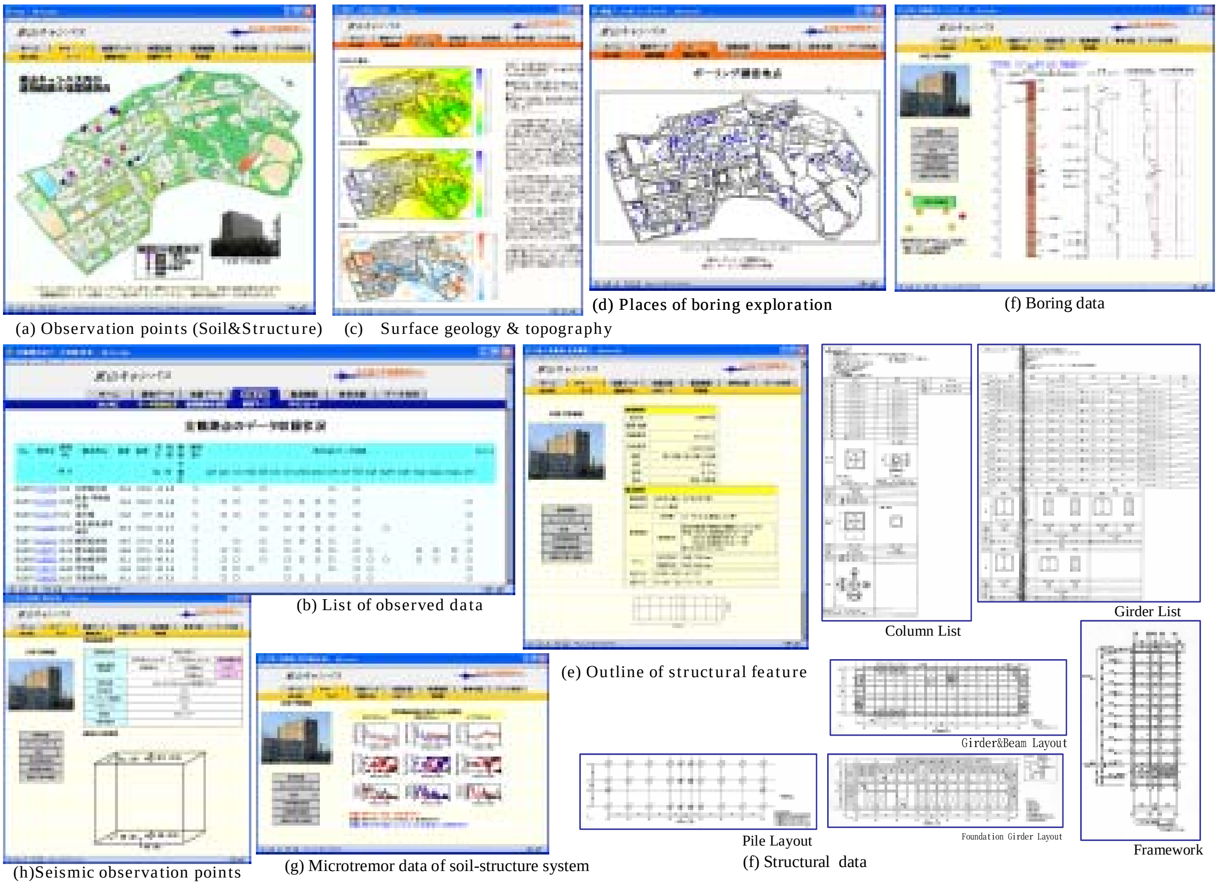
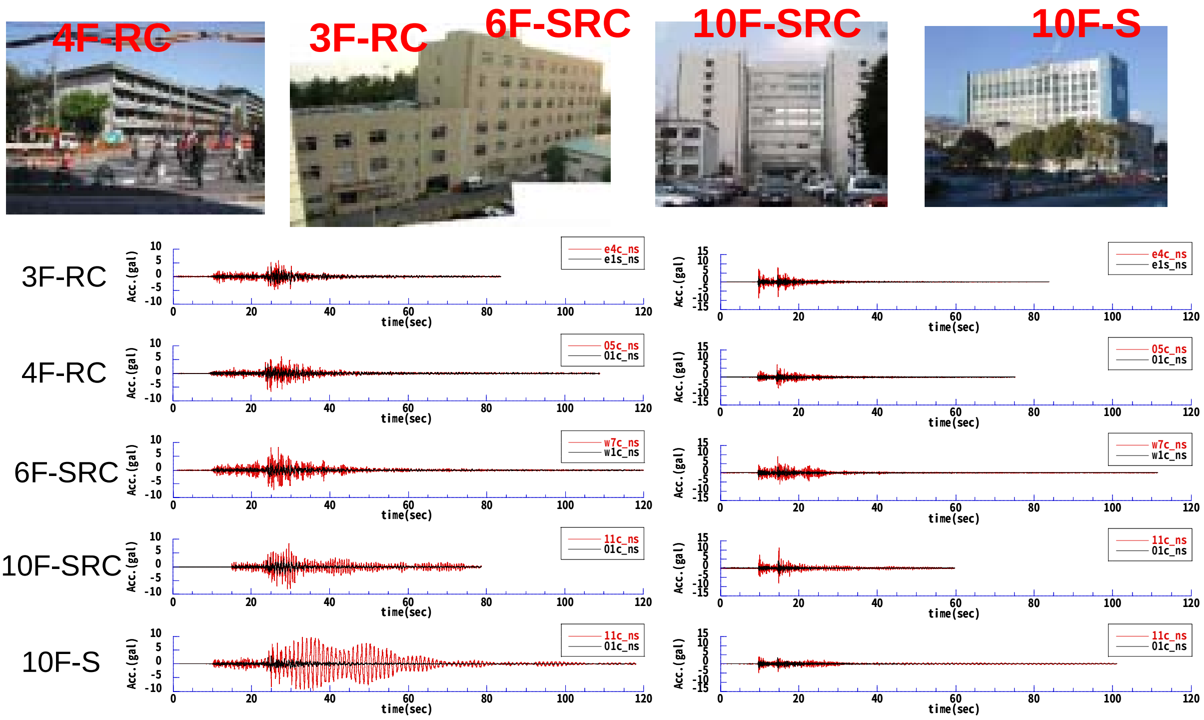


Figure 2 Web system for publishing structure-soil seismic response observation data

Difference of structural response with building height and structure and with seismic ground motion

Let us examine some analyses of the observation data. Figure 3 shows seismic records 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 between reinforced concrete (RC) structures with earthquake-resistant walls and plain steel-frame structure, and with duration of seismic ground motion can be read in the figure.



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

Figure 3 Records of observations of five buildings during an earthquake (left, distant focus; right, nearby focus)

Change of seismic response of tall building during construction

Figure 4 presents an earthquake response records for a 18-story steel-frame building under construction. This shows a tendency for resonance and a reduction of radiation damping in taller buildings. 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) structure.

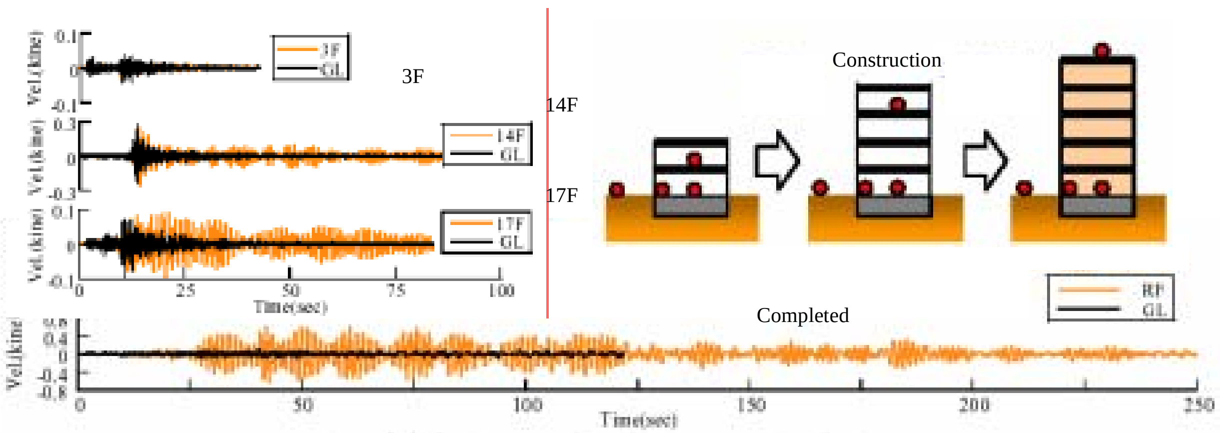


Figure 4 Record of 18-story steel building under construction during earthquake

Change of structural amplification and input loss effect due to microtremor during the construction

The results for semi-completion at 6 and 8 stories are shown in addition to the results for completion of 10 stories. Figure 5 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 construction, especially for taller buildings.

Figure 6 presents a comparison of the Fourier spectra of soil motion and foundation motion, indicating an input loss effect, and that the effective input motion does not depend on the number of floors or structure type.

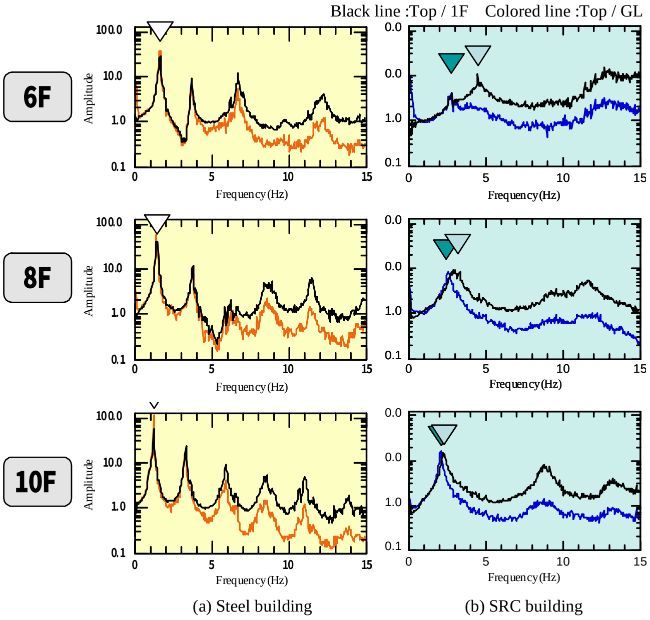


Figure 5 Fourier spectral ratio of microtremors between 10-story SRC structure and 10-story steel structure under construction (building vs. soil; building vs. foundation)

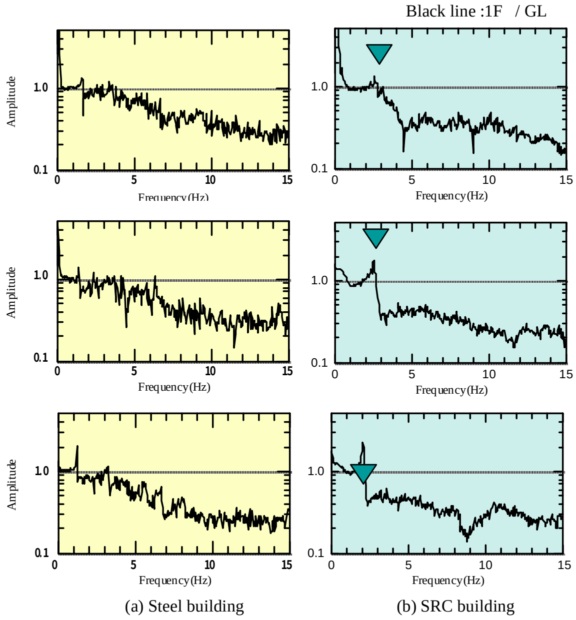


Figure 6 Fourier spectral ratio of microtremors between 10-story SRC structure and 10-story steel structure under construction (foundation vs. soil)

Difference of seismic structural response amplification and input loss with building height and frequency content of seismic input motion

Figure 7 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 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. It indicates that a lower number of floors results in a lower amplification, higher predominant frequency, higher input loss effect, and variation in response with varying predominant frequency of the input seismic ground motion.

Effect of neighboring building : structure-soil-structure interaction

Figure 8 shows the response modes observed in a neighboring 6-story building and 3-story building when the 6-story building displayed the maximum response in a time series. The smaller building vibrated in a bending mode, as if bowing, due to the influence of the larger neighboring building.

Effect of eccentricity

Figure 9 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.

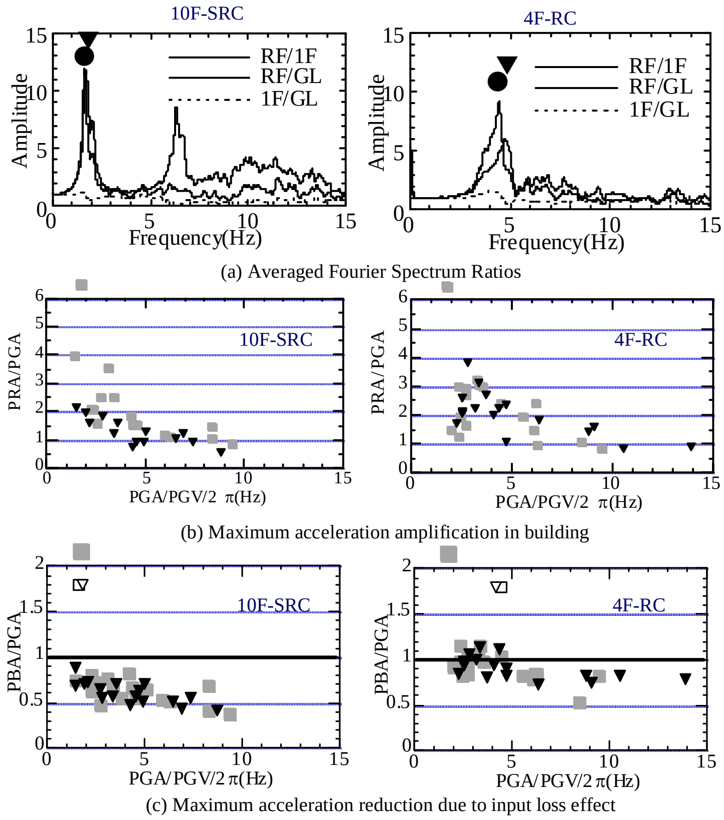


Figure 7 Fourier Spectrum ratios, maximum acceleration response amplification in building, and maximum acceleration reduction in foundation for a 4-story RC building and a 10-story SRC building

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 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 the 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. 10). 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

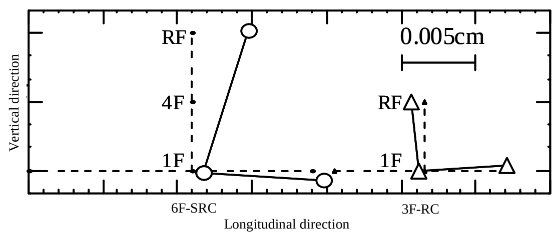


Figure 8 Response modes of neighboring 3-story RC and 6-story SRC structures

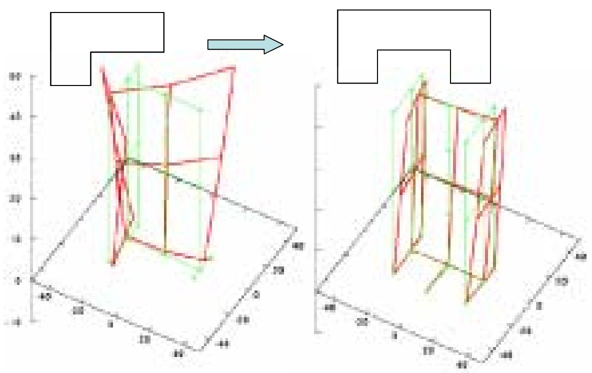


Figure9 Difference between torsional response modes (2.5Hz) before and after addition to 10-story SRC structure

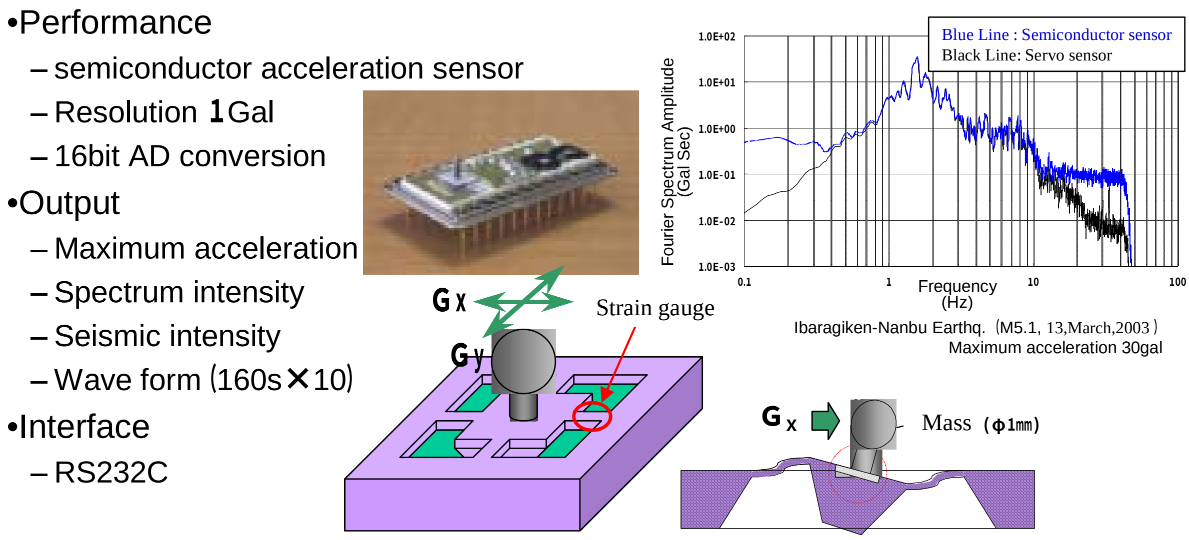


Figure 10 Overview of inexpensive seismometer, Comparison of recorded Fourier spectra from standard servo-type seismometer and new inexpensive seismometer

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. 10, 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.

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. Combining it with Web-GIS would allow use as a disaster warning system. Attaching meteorological sensors would allow it to be used for science education in elementary and middle schools. This would also allow assembly of a highly precise 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 11 shows the system assembled by the authors. We conceive this system as a combination of Nagoya region local authorities' 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. It is scheduled to be connected to the Internet.

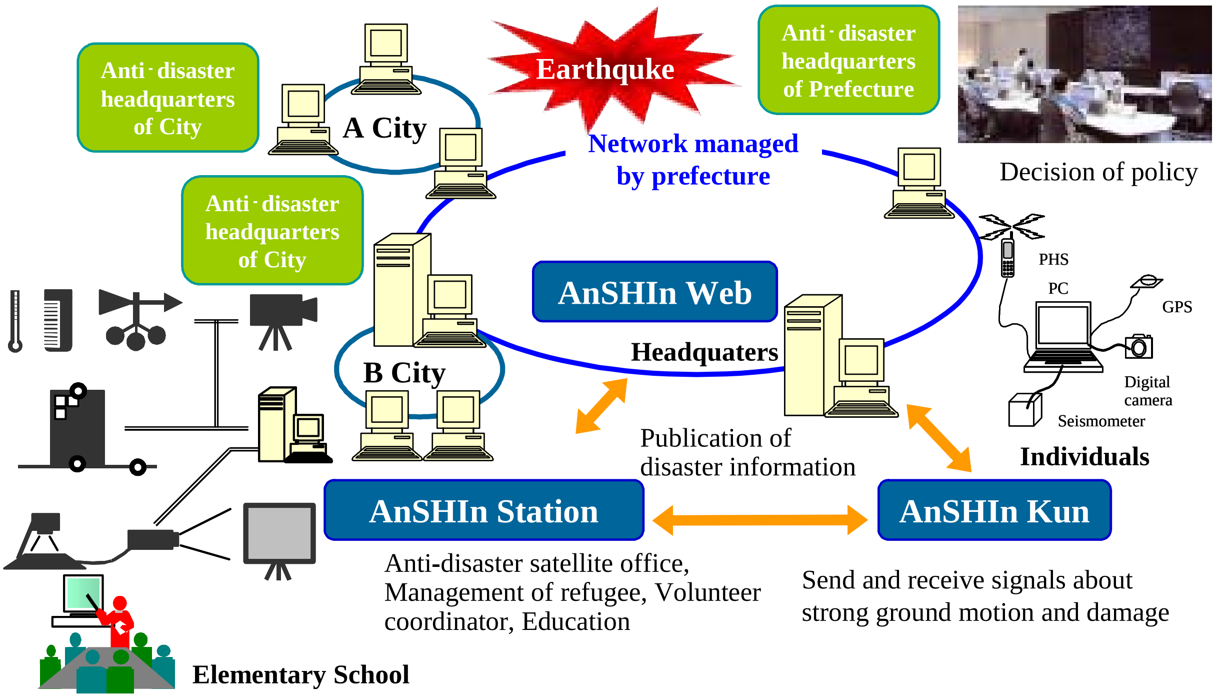


Figure 11 Overview and components of AnSHIn System

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) 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, structural type, soil conditions, the effect of eccentricity in the structure and the effect of close neighboring structures.

2) 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.

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