SEISMIC OBSERVATION SYSTEM FOR A BUILDING AND SURROUNDING GROUND IN KOMABA RESEARCH CAMPUS OF THE UNIVERSITY OF TOKYO

G. D.Calle[1], M. Kohiyama[2] and F. Yamazaki[3]

ABSTRACT

Recently, the Institute of Industrial Science of the University of Tokyo has been moved from Roppongi Campus to Komaba Research Campus. In the relocation, seismic observation system was newly set up in the institute's building, on the ground surface, and in a borehole. The observation system has collected the records from six seismic events. On the basis of these records, site and building responses were analyzed. The results showed general characteristics of the seismic response in the urban center of Tokyo, particularly, the site amplification due to sediments over Tokyo Formation. A particular soil anisotropy was found around 4.2 Hz due to the soil-structure interaction. In the future, more observation records will be collected and it is expected that the data may provide the details of the site and building response characteristics.

Introduction

Seismic networks have been installed all around the world to study the spatial variation of earthquake ground motions and the potential level of damage due to amplification generated by local geologic and topographic conditions. For instance, in Japan, the largest network is Kyoshin Net (K-NET, Kinoshita, 1998), which has 1,000 observatories deployed all over the country with an average distance of about 25km station to station.

Recently, the Institute of Industrial Science (IIS) of the University of Tokyo has been moved from Roppongi Campus, located in the central part of Tokyo to Komaba Research Campus, located in the western part of Tokyo. During the relocation, a seismic observation system was set up in the institute's new building and its surrounding ground. This system consists of nine three-component accelerometers and four one-component accelerometers. Three three-component accelerometers were placed at different depths bellow ground level (–55m, -18m and –10m), while the others were set up on the ground surface, and on the basement and upper floors of the building. Also, the system can retrieve seismic records from seismometers at

[1] Graduate Student, Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro, Tokyo 153-8505, Japan.
[2] Research Associate, Institute of Industrial Science, The University of Tokyo, ditto
[3]Professor, School of Advanced Technologies, Asian Institute of Technology, P.O.Box.4, Klong Luang, Pathumthani 12120, Thailand

the Chiba Experiment Station (Katayama et al., 1990) of the University of Tokyo, located in 30 km east of Komaba site.

This paper introduces this new observation system and discusses on the soil and building responses based on the seismic records and microtremors.

Ground Characteristics

The Komaba Research Campus is located in the western part of Tokyo, 40 m above the sea level. In 1996, before construction of new Komaba research campus, boring surveys were conducted at six places. The deepest survey, at that time, was up to 20.7 m and six different layers of soil were identified as shown in Table 1. In October 2000, accelerometers were buried and another boring survey was conducted up to 55 m of depth. The soil profile obtained from these boreholes as well as the results of standard penetration test (SPT-N) and PS logging tests are shown in the Fig. 1.

Although the soil profile and SPT N-values of each one of the initial six boreholes are not shown here, they match fairly well the survey results shown in Fig. 1, suggesting that the soil layers are quite uniform and simple.

Table 1. Boring survey results

<table>
<tr><th>Height above sea level (m)</th><th>Depth GL–(m)</th><th>Type of Soil</th><th>SPT N-value (mean)</th><th>Geological time</th><th>Name of Stratum</th></tr>
<tr><td>40.7
39.5</td><td>0.0
–1.2</td><td>Fill</td><td>2～4 (3)</td><td>Holocene</td><td>Fill</td></tr>
<tr><td>36.0</td><td>–4.7</td><td>Volcanic cohesive soil</td><td>3～13 (6)</td><td rowspan="5">Pleistocene</td><td>young Kanto loam</td></tr>
<tr><td>28.0</td><td>–12.7</td><td>Volcanic cohesive soil</td><td>1～26 (6)</td><td>old Kanto loam</td></tr>
<tr><td>22.0</td><td>–18.7</td><td>Gravel</td><td>4～37 (17)</td><td>Tokyo Formation</td></tr>
<tr><td>20.0</td><td>–20.7</td><td>Gravel</td><td>≥ 60</td><td>Tokyo Gravel Bed</td></tr>
<tr><td></td><td></td><td>Fine sand</td><td>29～60 (≥ 60)</td><td>Kazusa Group</td></tr>
</table>

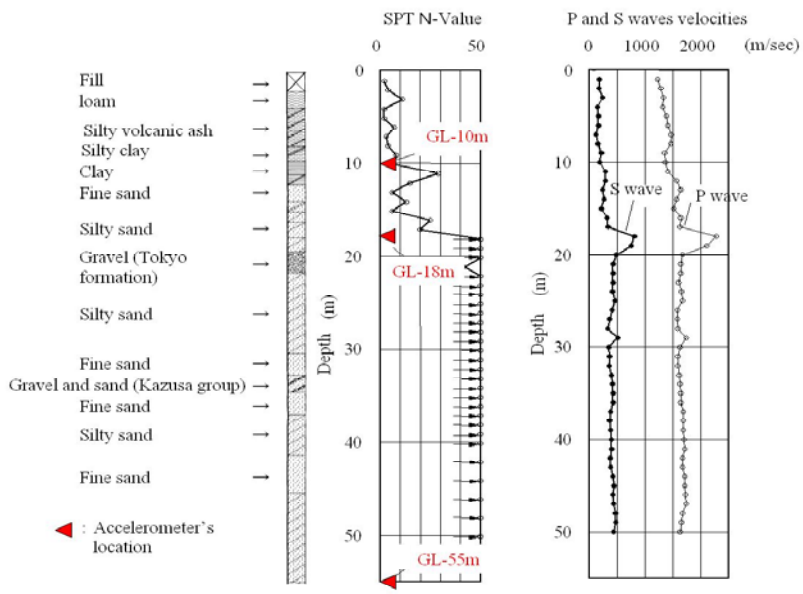


Figure 1. Soil profile, Standard Penetration Test (SPT) N-values and P and S wave velocities

Structural Characteristics of the Institute of Industrial Science Building

The Institute of Industrial Science Building is 218m long, 48m wide and it is oriented to the north-south direction. The first two stories (the base and first stories) are moment-resisting steel reinforced concrete frame structures (SRC). From the second story to the top the structure is a combination of concentrically braced and moment-resisting steel frames. The building is composed of two wings (east and west) orientated to the north-shout direction. The two wings are separated to each other, having a open space in between, but they share the same foundation. The two wings are linked by several simple-supported bridges. Each wing is composed of two structures separated by an expansion joint. For administrative purposes both wings are sub-divided into blocks B, C, D, E, and F. The expansion joint is located between blocks D and E (Fig. 2). The west wing is eight-story high, while the east wing is six-story high. The first story's height is 7.25m while the other inter-stories height is 4m. The building has a common glass roof designed in such a way that it does not interfere with the independent vibration of the two wings.

The building's foundation is a common reinforced concrete plate supported by high strength prestressed concrete piles. The piles are founded at a depth of 20m in the Tokyo Gravel Bed, on which most of the high rise buildings in Tokyo are founded.

Seismic observation system

The seismic observation system consists of nine three-component accelerometers and four one-component accelerometers, with acceleration and frequency ranges from 0 to 2000 cm/sec^2, and 0.1 to 30 Hz, respectively, and sampling frequency of 100 Hz.

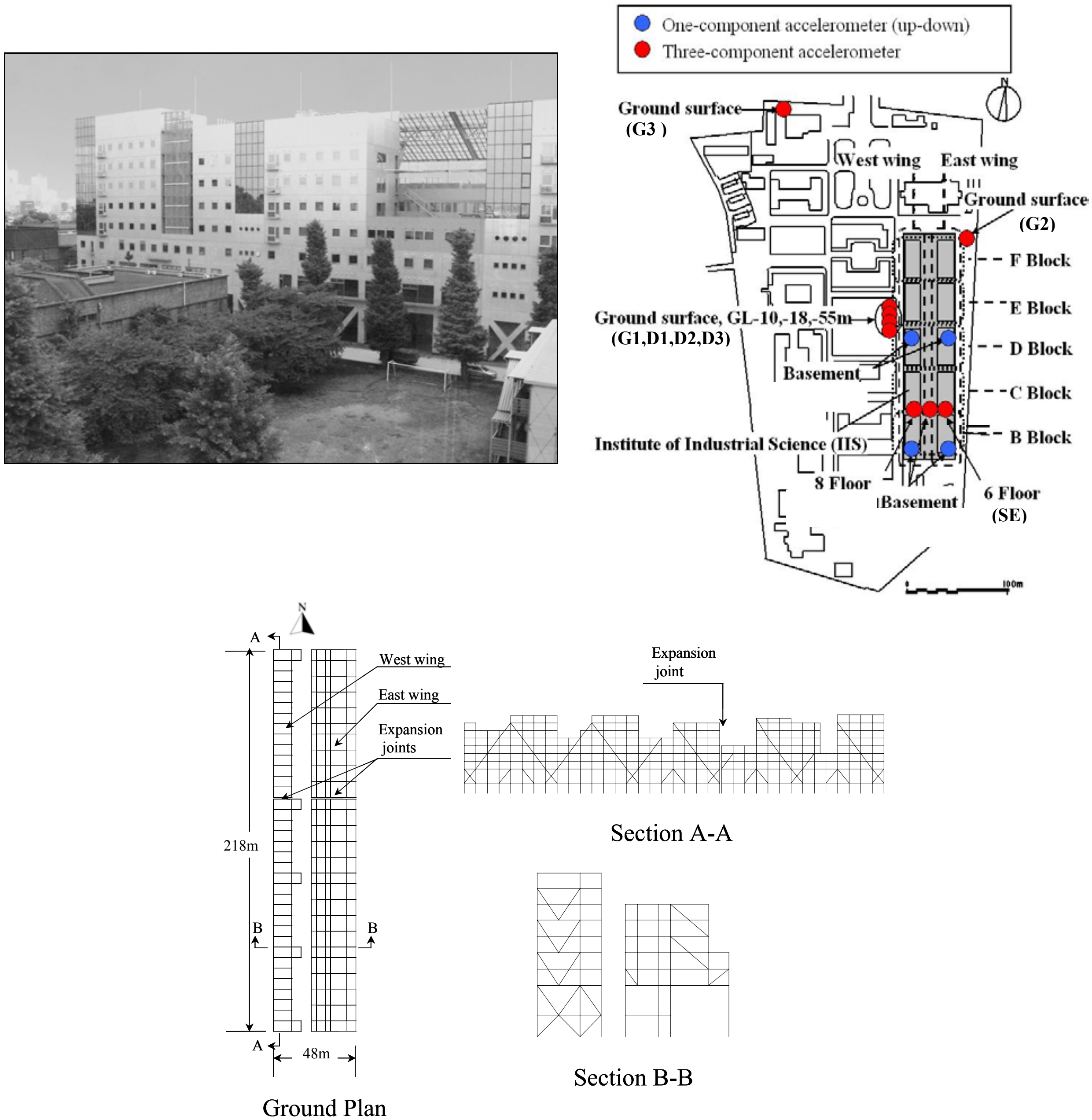


Figure 2. The Institute of Industrial Science Building and location of accelerometers

Figure 2 shows the locations of accelerometers. There are three three-component accelerometers placed on the ground surface and another three three-component accelerometers buried at different depth levels (–55m, -18m and –10m). The accelerometer located at –18m below the ground surface is in the Tokyo Formation stratum, which is a stiff gravel layer. The deepest instrument is placed in the Kazusa Group stratum.

Figure 3 shows a schematic diagram of the observation system. The signals captured by the accelerometers are sent to an observation panel, where they are amplified and stored in a digital format which can be accessed through a Local Area Network (LAN). The system is also

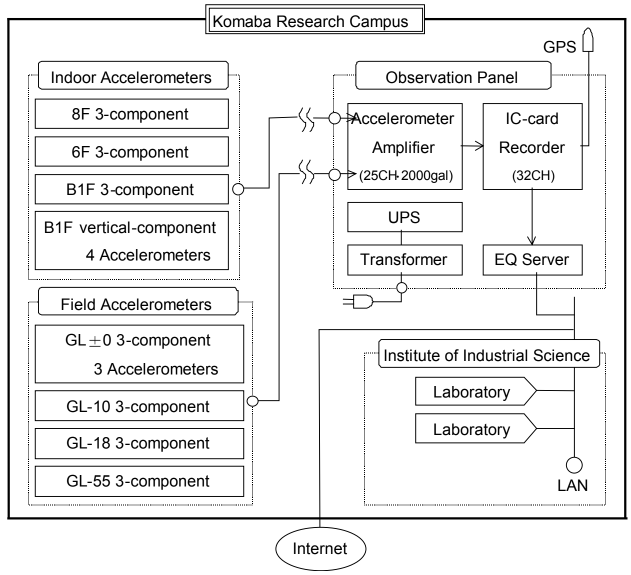


Figure 3. General scheme of the observation system

capable of retrieving records from a seismometer array set up in 1982 in the Chiba Experiment Station (Katayama and Sato, 1982). Based on this observation system and the Chiba seismometer array, it is possible to study the wave propagation characteristics in Tokyo. The information on the array in the Chiba Experimental Station is not discussed herein. Further details are available in Katayama et al. (1990), Lu et al. (1992) and Yamazaki and Turker (1992).

On the basement of the building four one-component (up-down) accelerometers and one three-component accelerometer were placed. Also, two three-component accelerometers were placed between blocks B and C on the eighth and sixth floor of the west and east wing respectively. This observation system will provide valuable information on the dynamic response characteristics of the soil and structure under seismic excitation.

Earthquake response of soil and structure

The observation system started its operation in April 2001 and it has already recorded six earthquake events with Peak Ground Accelerations (PGA) ranging from 7.8 cm/s^2 to 54 cm/s^2. Microtremors were also measured at locations of surface accelerometers G1, G2, G3, and on different floors of the building. Based on the seismic records and microtremors the dynamic response characteristics of the soil and structure were studied.

Soil amplification evaluated from earthquake records

The amplification of peak acceleration was evaluated from the six recorded events at depths of 0m (ground level), -10m,-18m, and -55m in the three boreholes separated 3m from each other (Fig. 2). All records from all events were normalized by those at 55m of depth. The ratio of the three components, North-South (NS), East-West (EW) and Up-Down (UD), for each event are shown in Fig. 4.

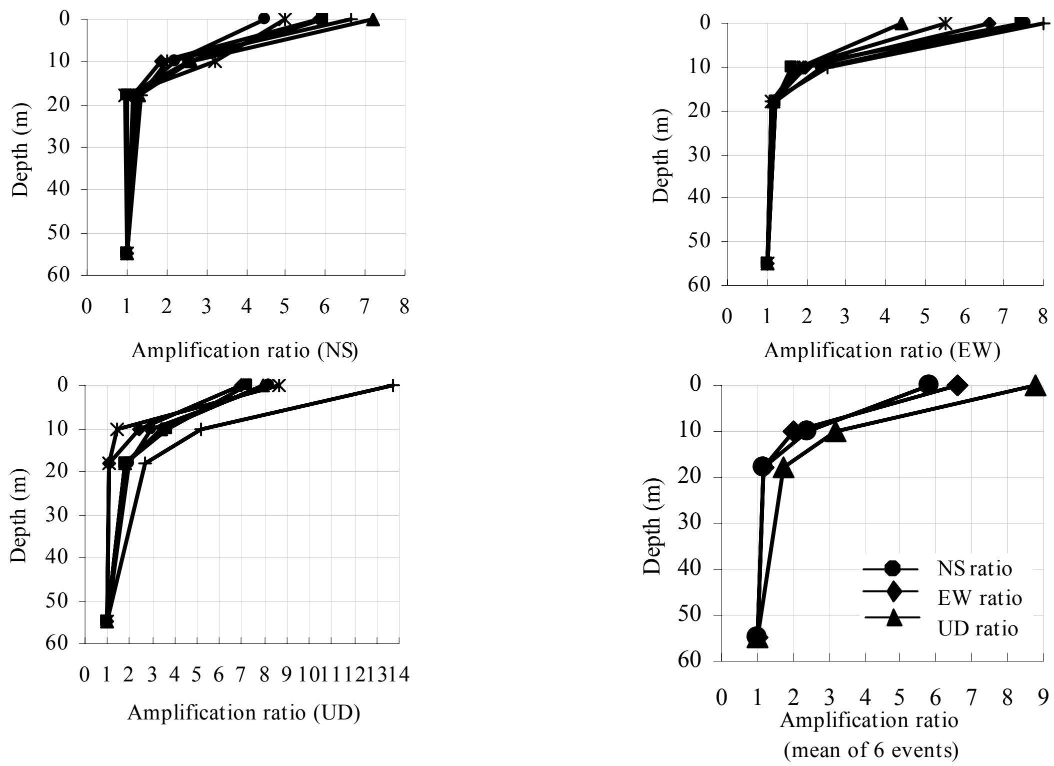


Figure 4. Amplification ratios of peak acceleration

The amplification is significant in the first 18m below the ground surface. From the soil profile and SPT N-values shown in Fig. 1, it is seen that the stiffness of the soil above the Tokyo Formation stratum is much softer than the stiffness of this layer. The north-south component of the events shows larger scatter between -18m and -55m than the east-west components, while in the first 18m both components are scattered in a rather similar manner. However, the average of the amplification ratios of the horizontal components for the 6 events were almost equal for all the depths (Fig. 4). On the other hand, the vertical components were scattered substantially for all the depths. It is noticed that the amplification ratios of the vertical component are bigger than those of the horizontal one for all the depths.

Soil amplification characteristics were investigated in terms of transfer function defined as the ratio of Fourier spectra of the records at 55m of depth and those on ground surface. The Fourier spectra were smoothed by means of a Parzen window with bandwidth 0.4 Hz. Figure 5(a) shows the transfer functions for 6 events in the two components (NS and EW) computed based on the records from accelerometer G3 (ground surface far from the building) and D3 (buried at –55m). It can be seen that the transfer functions of both horizontal components are quite similar up to 7 Hz. Figure 5(b) shows the transfer functions for 6 events in the two components (NS and EW) computed based on the records from accelerometer G1 (ground surface) and D3 (buried at –55m), located at the east side of block E. In this case, it can be seen that the transfer functions are different around 4.2 Hz in the two horizontal components. Moreover, a similar tendency was also observed in the transfer functions computed from accelerometers G2 (located close to the north-east corner of block F) and D3, which are not shown here. It should be noted that the accelerometers G1 and G2 are placed at 11m and 15m, respectively from the building, while accelerometer G3 is far away from it. The anisotropy exhibited around 4.2 Hz seems to be due to the soil-structure interaction. However, the real causes of this phenomenon have not been proved yet and computer simulation of the soil-structure system should be carried out for further investigation.

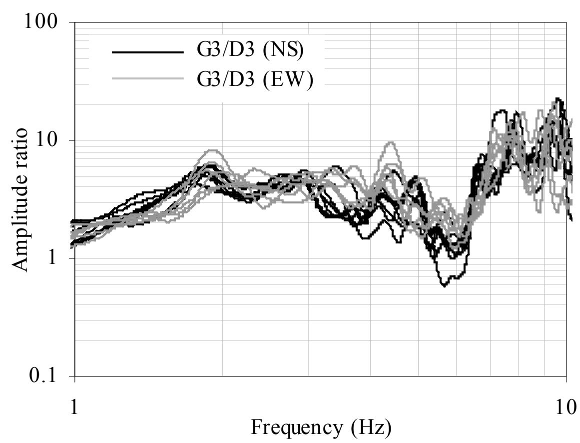
Microtremor observation

Microtremors were measured at the ground surface at the places where the accelerometers are located. The instrument used for the microtremor measurement is a SPC-35N (Tokyo Sokushin Co.). The velocity records are high-pass filtered, amplified and converted to digital format using a 16 bit AD converter for storage in a personal computer. A sampling frequency of 100 Hz was used. The measurements were carried out during both day and night time on different dates. The total time length (day and night) of microtremor measurements at each place was of 13 minutes.

Fourier spectra were calculated for the microtremor records using the same procedure as for seismic records. The H/V spectral ratio method (Nakamura, 1989) was used to evaluate site response characteristics, where H and V are the smoothed Fourier spectra of the resultant of the two horizontal components and the vertical one, respectively. This method has also been used for strong motion records (Maruyama et al., 2000) and its stability was explained by Yamazaki and Ansary (1997) based on the attenuation relations of the velocity response spectra for the horizontal and vertical components of seismic motion.

Figure 6 shows the horizontal and vertical Fourier spectra of microtremors measured next to the location of the accelerometer G3 and their ratio.

Each microtremor record was analyzed for several time windows of 20.48 seconds lengths, and thus, the stability of microtremors with time was checked. In the figure, each thin line represents one of these windows and the thick one the average of them.



(a)

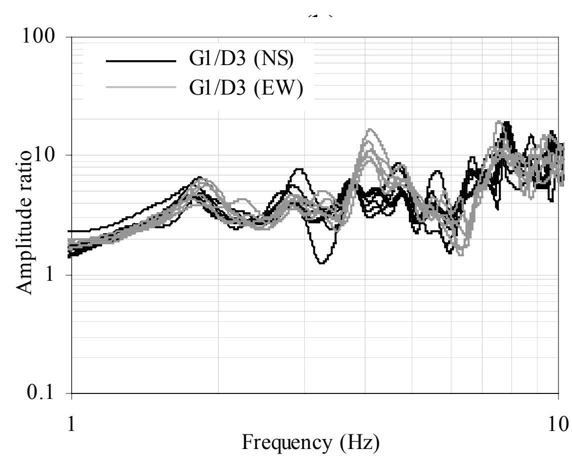


Figure 5. Transfer functions of the seismic records in the NS and EW components. (a) between G3 and D3 and (b) between G1 and D3.

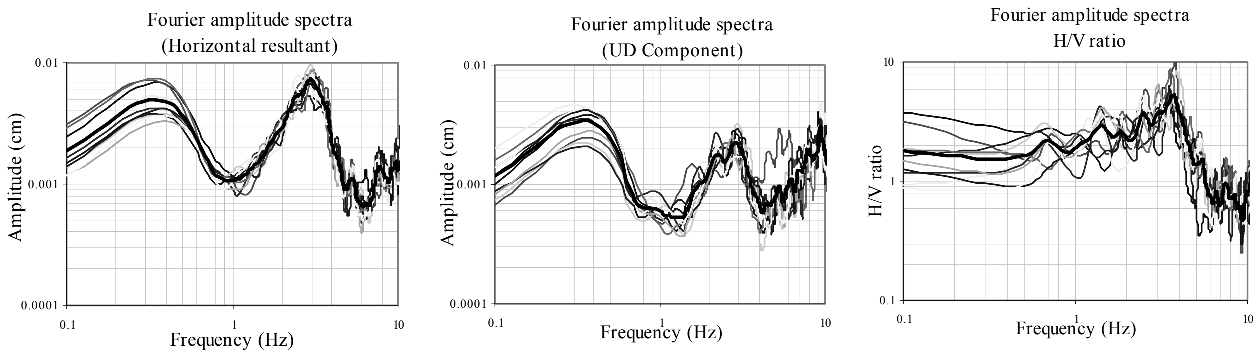


Figure 6. Fourier spectra of 10 time windows of microtremors and their average at the location of accelerometer G3.

Based on the H/V ratio, the predominant frequency of the ground at the location of accelerometer G3 is found to be around 3.7 Hz (Fig. 6). The H/V Fourier spectral ratio for all the seismic records at the three accelerometers deployed on surface (G1, G2, and G3) were also calculated. Figure 7 shows the average of H/V ratio of the seismic motions and microtremors recorded at G1, G2 and G3 for the two horizontal directions. In the figure, the general trend of H/V ratios of strong motion records and microtremors are similar. However, the amplitude ratio of microtremor is smaller than that of seismic records. It was noted that the fundamental frequency of the ground according to the H/V ratio for the seismic records is less than that of microtremor for the both horizontal directions at G2 and G3 locations. The fundamental frequencies of the ground at G1 location obtained from seismic records and microtremors are close to each other. By comparing H/V ratios of microtremors in the north-south direction with those in the east-west direction at G1, G2, and G3 locations, it can be seen that microtremors did not reflect the soil's anisotropy detected in the seismic records.

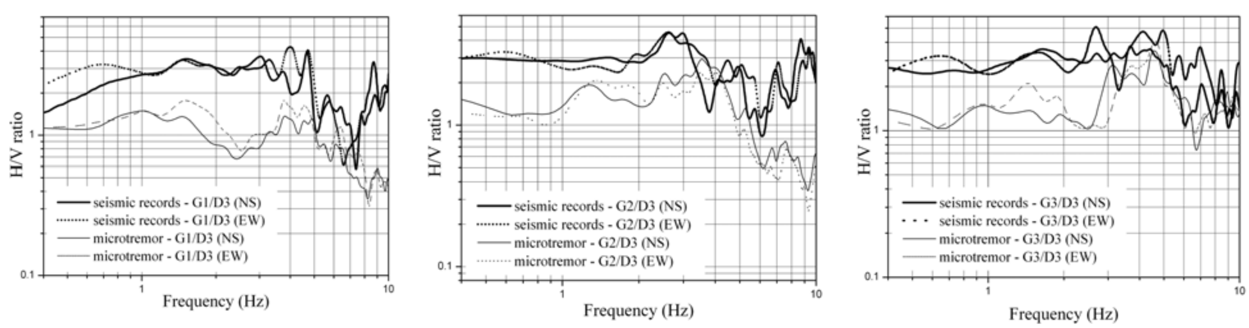


Figure 7. H/V Fourier spectral ratios of seismic ground motions and microtremors at G1, G2, and G3 accelerometer's location.

Building's response

Based on the records of the accelerometers set up at sixth floor and eighth floor of the east and west wing respectively, and those deployed at the basement, the fundamental frequency of the building was evaluated. Using the same procedure as for soil response analysis, the Fourier

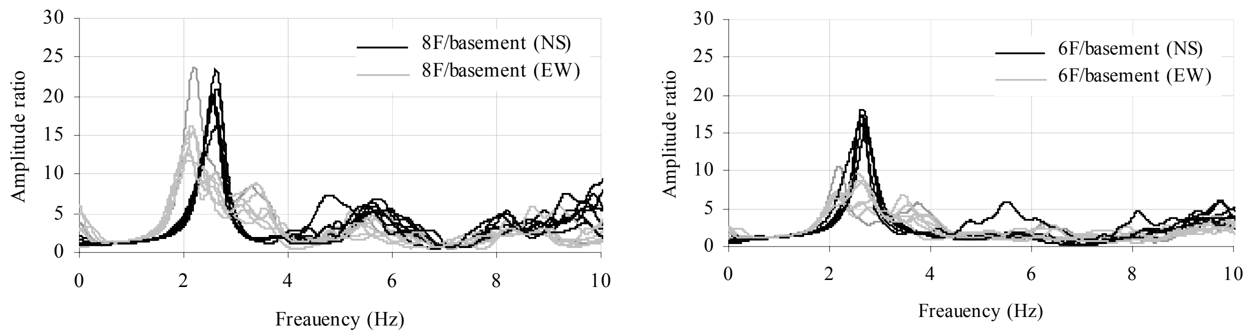


Figure 9. Fourier spectral ratios between the 8th floor (west wing) or 6th floor (east wing) and basement for the 6 seismic events.

spectra for all the six events were computed for the three components. Figure 9 shows the Fourier spectral ratio between the eighth floor and basement for the west wing and the Fourier spectral ratio between the sixth floor and basement for the east wing. The fundamental frequency of the west wing (8 story) is obtained as about 2.6 Hz (period=0.39 sec) and 2.1 Hz (period=0.48 sec) in the NS and EW directions respectively, and 2.7 Hz (period=0.37 sec) and 2.6 Hz (period=0.39 sec) for the east wing (6 story) in the NS and EW directions respectively.

Microtremors were also measured in the building, and the Fourier spectral ratios based on them showed good agreement with those obtained from the seismic records. The fundamental frequencies of the east wing of the building in the two perpendicular horizontal directions are relatively close to each other, showing that there is not much difference between the stiffness in the two directions regardless of the big differences in length (considering up to the expansion joint its length is: L=132 m to the NS and 46.7 m to the EW).

Conclusions

The seismic observation system in Komaba Research Campus was introduced. The amplification of the peak ground acceleration took place mostly within the first 18m of depth, above the Tokyo Formation layer. Fourier analysis and H/V ratio method were used to analyze the records from six earthquakes and microtremors. The H/V ratio of microtremors was less than those of seismic motion records. The anisotropy, observed in the seismic records, was not clearly observed in the Fourier spectral ratios of microtremors.

The new building of the Institute of Industrial Science showed rather similar stiffness in the two horizontal directions regardless of the big difference in their lengths. This is due to the bracing system provided in the EW direction. An unusual anisotropy was seen in the transfer functions of the ground motions recorded at two accelerometers (G1 and G2) at around 4.2 Hz. Because of the similarity among the records from different events around this particular frequency, source and path effects were excluded as possible causes, and the most probably cause seem to be the soil-structure interaction. However, to explain this anisotropy in more clear manner two and/or three dimensional soil-structure interaction analysis may be carried out.

References

Katayama, T., and N. Sato (1982). Ground strain measurement by a very densely located seismometer array, *Proc. of 6th Japan Earthquake Engineering Symposium,* 241-248.

Katayama, T., F. Yamazaki, S. Nagata, L. Lu, T. Turker (1990). A strong motion database for the Chiba seismometer array and its engineering analysis, Earthquake *Engineering and Structural Dynamics*, 19, 1089-1106.

Kinoshita S.(1998). Kyoshin Net (K-NET), *Seismological Research Letters* 69 (4): 309-332.

Lu, L, F. Yamazaki, and T. Katayama (1992). Soil amplification based on seismometer array and microtremor observations in Chiba, Japan, *Earthquake Engineering and Structural Dynamics* 21, 95-108.

Maruyama, Y., F. Yamazaki, and T. Hamada (2000). Microtremor measurements for the estimation of seismic motion along expressways, *Proc. 6th International Conference on Seismic Zonation,*1361-1366.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Quarterly Report of RTRI*,.30 (1), 25-33.

Yamazaki, F., and T. Turker (1992). Spatial variation study on earthquake ground motion observed by the Chiba array, *Proc. of the Tenth World Conference on Earthquake Engineering*, 2, 651-656

Yamazaki, F., and M.A. Ansary (1997). Horizontal-to-vertical spectrum ratio of earthquake ground motion for site characterization, *Earthquake Engineering and Structural Dynamics*, 26,671-689.