EARTHQUAKE MOTION OBSERVATION AND SSI CHARACTERISTICS OF AN 8-STORY BUILDING IN BRI

Toshihide KASHIMA
Building Research Institute, Ministry of Land, Infrastructure and Transport
Tachihara 1, Tsukuba, Ibaraki 305-0802, Japan
kashima@kenken.go.jp

ABSTRACT

Building Research Institute (BRI), Ministry of Land, Infrastructure and Transport, Japan, started the strong motion observation project in 1957. The observation network has been enriched and enlarged in the past forty years. BRI is now operating several networks with a number of strong motion instruments.

Urban Disaster Prevention Research Center building (annex) BRI was constructed in 1998 and instrumented with up-to-date observation system. Sensors are configured in order to grasp building behavior including the ground during earthquakes. Several valuable records have been obtained in last two years.

Firstly this paper introduces the observation system that is installed to the annex building of BRI. Fundamental dynamic characteristics of the ground and building are discussed secondly. Finally the soil-structure interaction behavior is studied using a simple swaying-rocking model.

Keywords: Strong motion observation, SRC building, Soil-structure interaction, Site effect

1. INTRODUCTION

Building Research Institute (BRI), Ministry of Land, Infrastructure and Transport, Japan, started the strong motion observation project in 1957. The observation network has been enriched and enlarged in the past forty years. BRI is now operating several networks with a number of strong motion instruments.

In 1998, BRI has installed the up-to-date strong motion observation system to a newly constructed 8-story steel reinforced concrete (SRC) building next to the main building in BRI. Totally 22 accelerometers were placed in the new building, in the main building and in the surrounding ground. We hope the recording system of this kind will be very directly useful for evaluating the soil-structure interaction (SSI) phenomena. In this paper, we are introducing a new system that is installed to buildings and underground at BRI, and some observation results.

2. OUTLINE OF STRONG MOTION OBSERVATION AT BRI ANNEX

2.1. Geological conditions

BRI is located with approximately 60 kilometers to the northeast from Tokyo. The site is situated 30 meter above sea level on the diluvial heights between the Sakuragawa River flowing into the Kasumigaura Lake and the Kokaigawa River, a branch flow in the greater the Tonegawa River water system.

The geological investigation shows that clay and fine sand are main contents up to 90 meters depth underground, inserting sandy gravel. Table 1 indicates surface soil structure at BRI. We confirmed a sandy gravel layer at 88 meters in depth. Its shear wave velocity, however, is not obtained. Transfer functions for shear waves between ground surface and depths of 42 meters, 68 meters and 88 meters are shown in Figure 1. We assume here that the shear wave velocity of the layer 88 meters deep is about 500 m/s. The figure shows common predominant periods of 2 to 4 Hz and 9 Hz. Moreover, the transfer function of 88-meter layers has the peak at 1 Hz. This might be the peak relevant to the fundamental frequency of the surface soil layers. In addition, the layer between 88 meters deep and approximately 250 meters deep is called upper Kazusa formation group, and the underlying layer is called lower Kazusa formation group, the Tertiary layers.

Table 1. Structure of surface soil layers

No.	*H* (m)	*D* (m)	V_P (m/s)	V_S (m/s)	*r* (t/m^3)	Soil Type
1	2.0	2.0	170	110	1.30	Loam
2	6.0	8.0	1430	200	1.30	Sandy Clay & Clayey Sand
3	6.0	14.0		160	1.50	Sandy Clay & Clay
4	8.0	22.0	1630	260	1.80	Fire Sand & Clayey Fine Sand
5	6.0	28.0	1500	200	1.75	Sandy Clay & Clay
6	14.0	42.0	1570	270		
7	6.0	48.0	1880	460	1.90	Gravel
8	8.0	56.0	1780	340	1.75	Sandy Clay & Clay
9	12.0	68.0	1690	290		
10	12.0	80.0	1790	380	1.95	Gravel & Fine Sand
11	8.0	88.0	1600	280	1.75	Sandy Clay & Clay
12				*500*	*2.00*	Gravel

H: Thickness, *D*: Depth, V_P: P-wave Velocity, V_S: S-wave Velocity, *r*: Density

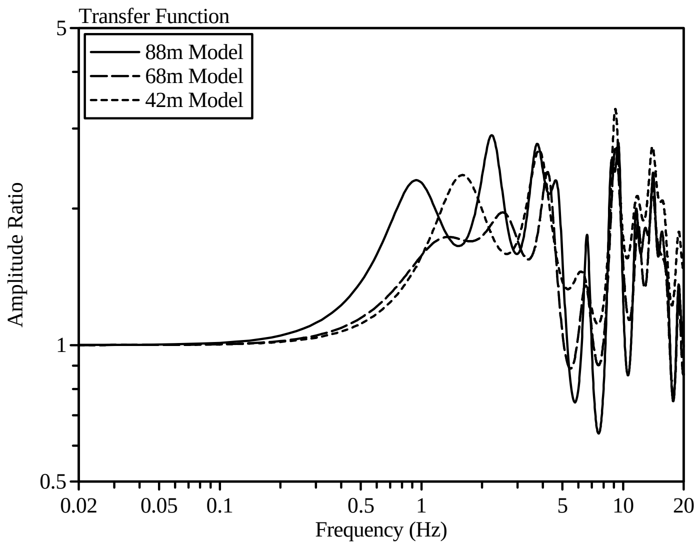


Figure 1. Transfer function of surface soil layers

2.2. Building characteristics

The building for accelerometer installation is a newly constructed Urban Disaster Prevention Research Center building (annex) that was completed in March 1998. The annex building has eight stories with single basement floor. Total building area is approximately 5,000 m^2 and supported by mat foundation on the clayey layer of 8.2 meters underground. The annex is connected to the main building with passages, but is structurally separated.

2.3. Recording system

The sensors are installed with 11 locations (33 channels) in the new building, 7 locations (21 channels) in the surrounding ground, and 4 locations (12 channels) in the main (older) building. The sensor configuration is shown in Figures 2 and 3. The farthest sensor on the ground is 100 meters away from the annex building, and the deepest sensor is set up 89 meters in depth. Three sensors are set up at the basement floor and the eighth floor in order to investigate torsional vibration.

All sensors are connected to the recording equipment at the observation room in the annex. The specifications of the recording system are shown in Table 2. The system has 66-channel 24-bit A-D converters, a digital processing unit and 40 MB flash memory storage. PC cards are used as storage device and are directly processed by PC. Broad dynamic range and certain operation are ensured by the most up-to-date facilities.

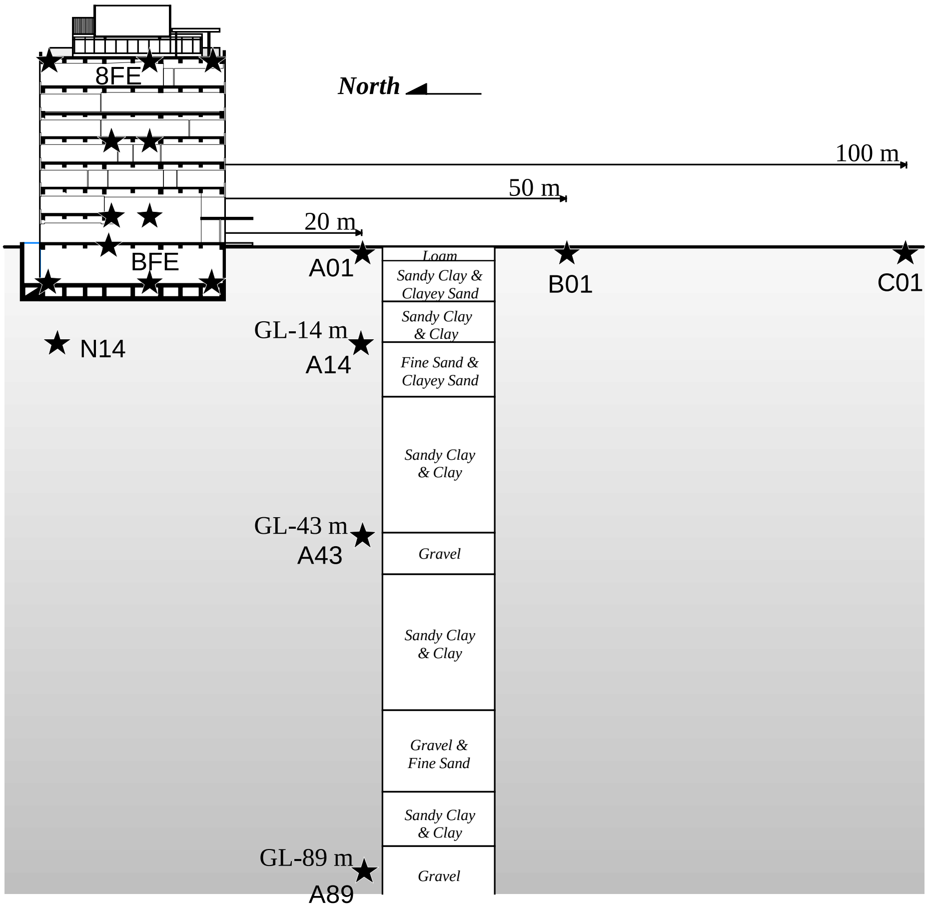


Figure 2. Vertical sensor configuration

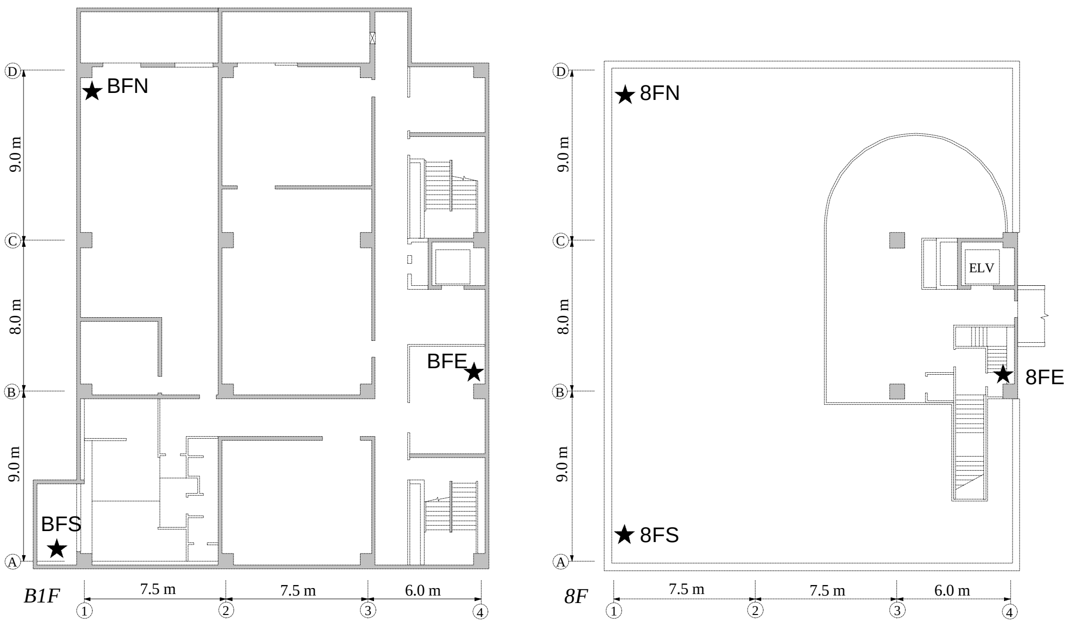


Figure 3. Sensor configuration at basement floor and 8th floor

Table 2. Specifications of recording system

Model	AJE-8200, Akashi Corp.
Sensor	V403BT (negative feedback servo), Akashi Corp.
Number of Channels	66
Frequency Range	DC ~ 30 Hz
Acceleration Range	± 2 G
A/D Converter	24-bit, (Delta-Sigma)
Dynamic Range	114 dB
Recording Medium	ATA Flash Memory Card
Triggering Logic	Disjunction (OR) of Specified Three Components
Functions	Peaks, JMA Seismic Intensity, Spectral Intensity (SI)

3. OBSERVED RECORDS AND DISCUSSION

3.1. Observed records

In the past two years, we obtained several records with moderate acceleration levels. Observed earthquakes and peak accelerations on the ground (GL, shown as A01 in Fig.2), at the basement floor (BF, shown as BFE in Fig.3) and at the eighth floor (8F, shown as 8FE in Fig.3) are listed in Table 3.
Horizontal acceleration records on the ground (A01), 89 meters below the ground (A89), at the basement floor (BFE), and at the eighth floor (8FE) for the eathquke#21 are plotted in Figure 4. Dynamic characteristics of ground motions and building response are discussed through the analysis using these records in the following paragraphs.

Table 3. List of observed records

No.	*Date*	*Time*	*Latitude*	*Longitude*	*h (km)*	*M*	*D (km)*	*Peak Acc. (cm/s²)*		
								GL	*BF*	*8F*
1	1998/06/08	08:02	036°06.5'N	139°54.3'E	73	4.6	3	8	3	8
2	1998/06/24	23:52	036°07.3'N	140°06.4'E	67	5.1	58	19	14	53
3	1998/08/29	08:46	035°36.2'N	140°02.7'E	58	4.9	60	10	6	16
4	1998/11/08	21:40	035°36.6'N	140°03.2'E	58	5.1	62	6	3	10
5	1999/03/26	08:31	036°27.3'N	140°37.0'E	54	4.0	19	46	26	61
6	1999/04/25	21:27	036°27.6'N	140°37.8'E	58	4.4	58	37	25	67
7	1999/06/27	19:50	036°06.1'N	139°48.8'E	55	4.6	7	17	12	18
8	1999/07/15	07:56	035°55.4'N	140°27.8'E	48	6.0	77	6	4	16
9	1999/07/23	06:53	036°04.2'N	141°10.3'E	49	6.0	101	2	1	6
10	1999/08/09	06:39	035°50.0'N	139°57.6'E	37	5.3	107	5	4	10
11	1999/12/10	10:55	036°03.0'N	140°06.2'E	73	4.6	3	2	1	3
12	1999/12/16	22:28	036°37.5'N	139°26.1'E	67	5.1	58	3	2	4
13	1999/12/16	22:47	036°37.9'N	139°26.4'E	58	4.9	60	9	6	12
14	1999/12/27	00:05	036°08.8'N	139°52.0'E	58	5.1	62	19	10	32
15	2000/01/12	11:09	036°27.0'N	140°35.4'E	54	4.0	19	12	7	13
16	2000/04/10	06:30	036°11.2'N	140°04.1'E	58	4.4	58	64	32	96
17	2000/04/15	05:26	036°13.1'N	139°59.5'E	55	4.6	7	17	8	15
18	2000/05/08	18:45	036°22.8'N	140°58.3'E	48	6.0	77	6	4	8
19	2000/05/16	19:40	036°26.5'N	140°42.7'E	49	6.0	101	9	5	16
20	2000/06/03	17:54	035°40.6'N	140°43.1'E	37	5.3	107	16	11	47
21	2000/07/21	03:39	036°31.3'N	141°05.8'E	73	4.6	3	38	26	84
22	2000/08/15	03:54	036°12.2'N	140°02.4'E	67	5.1	58	10	5	8
23	2000/08/21	21:27	036°04.4'N	139°57.4'E	58	4.9	60	11	7	16
24	2000/12/05	01:47	035°50.5'N	141°09.6'E	58	5.1	62	9	8	31

h: Focal Depth, *M*: JMA Magnitude, *D*: Epicentral Distance

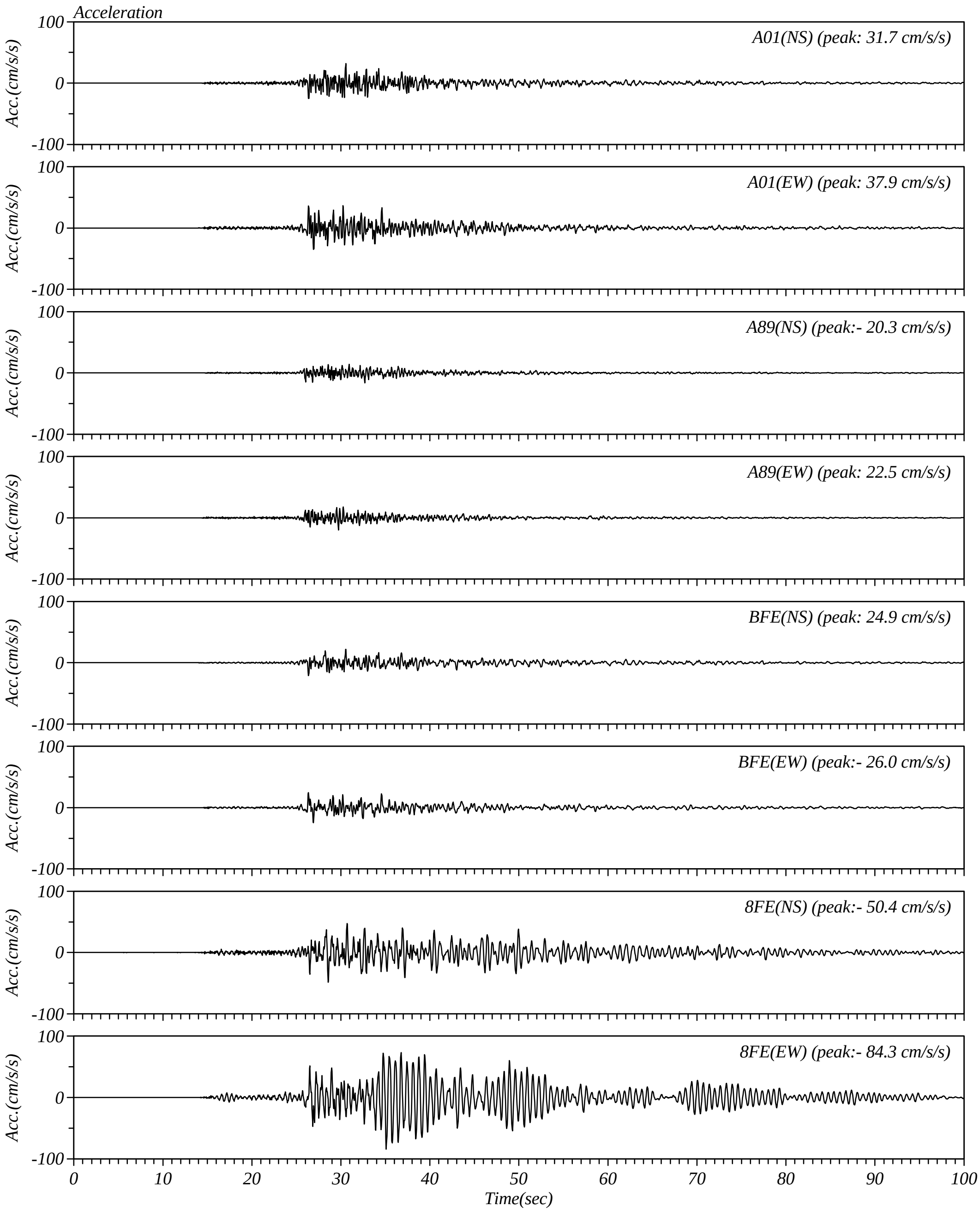


Figure 4. Acceleration records of the earthquake #21 on July 21, 2000

3.2. Amplification of surface soil layers

Figure 5 shows Fourier amplitude spectral ratios of earthquake motions on the ground (A01) to ones at 89 meters below the ground (A89). Theoretical ratio calculated from the soil structure shown in Table 1 is also indicated by the dotted line in the figure. Both spectral ratios, N-S component and E-W components, have common peaks at 0.8 to 1.0 Hz, 2.2 Hz and 3 to 4 Hz. Observed results show good agreement with the theoretical ratio upon the location of peaks. However, there are differences in heights of peaks. We assumed damping ratio of 5% for each soil layer in the theoretical calculation. Reevaluation of physical constants, especially damping property, of soils using observed data is necessary for further discussion.

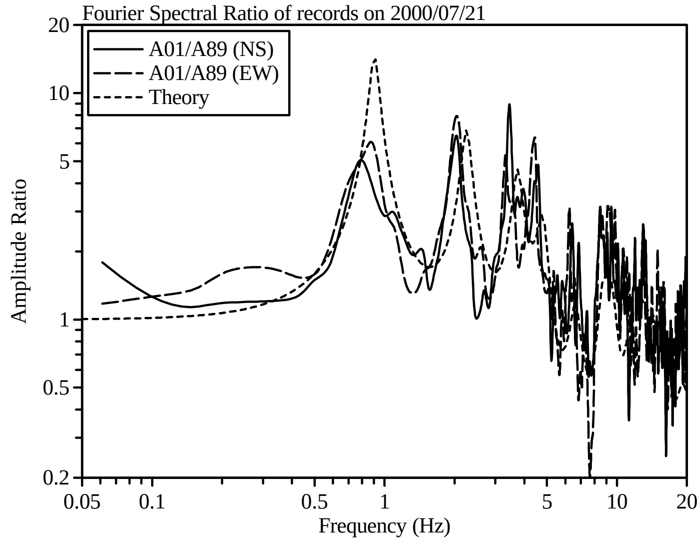


Figure 5. Fourier spectral ratios of records on the ground (A01) to ones at 89 meters below the ground (A89) for the earthquake #21

3.3. Dynamic characteristics of annex building

We try to discuss general characteristics of the annex building including the soil-structure interaction effect hereinafter. The left-hand graph in Figure 6 shows ratios of peak accelerations at BF (basement floor, BFE in Fig.2 and Fig.3) and 8F (eighth floor, 8FE in Fig.2 and Fig.3) to GL (ground level, A01 in Fig.2) in the horizontal directions. Peak accelerations at BF are 40 to 70 % smaller than at GL. The mean values of the ratios are 0.61 and 0.59 in the N-S and E-W directions respectively. In contrast, peak acceleration ratios of 8F to GL widely vary. Average peak velocity ratios are 1.46 and 1.66 in the N-S and E-W directions respectively. The right-hand graph of Figure 6 compares peak velocities at BF and RF with peak velocities at GL. Similar tendencies can be observed with the case of peak accelerations. Non-linearity of amplification does not clearly appear in ratios in Figure 6.

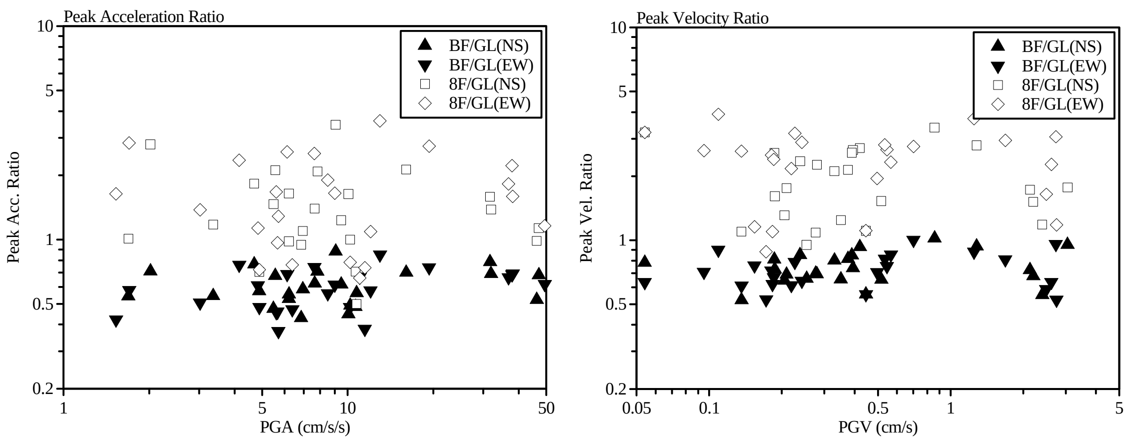


Figure 6. Peak acceleration ratio at BF and 8F to A01

Fourier spectral ratios of the records at BF to at GL for all earthquakes in Table 3 are plotted in Figure 7with average lines. Average spectral ratios are shown in Figure 9 again. Differences are observed in the higher frequency range more than 1.7 Hz. Figure 8 shows Fourier spectral ratios of the records at 8F to GL. The spectral ratio in the N-S component has clear peaks of 1.7 Hz and 2.3 Hz. Natural frequency of the annex building in the N-S direction can be estimated at 1.7 Hz. The spectral ratio in the E-W direction also has a peak of 1.7 Hz, but doesn’t have a peak of 2.3 Hz. First natural frequency in the E-W direction is very close to the N-S direction. The vibration system discussed here includes effect of the soil-structure interaction. Incidentally, damping ratios of the first vibration modes in N-S direction and E-W direction are estimated at 5% and 7%, respectively.

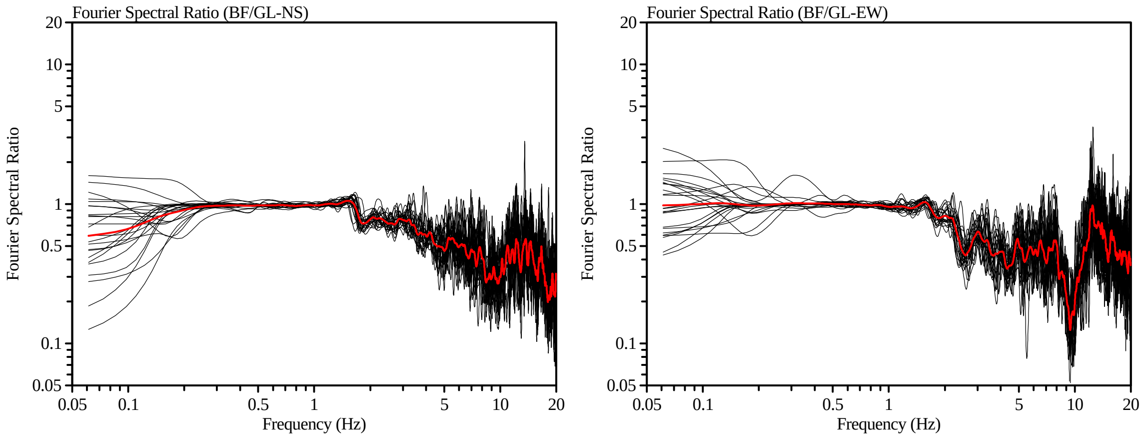


Figure 7. Fourier spectral ratios of records at BF to A01

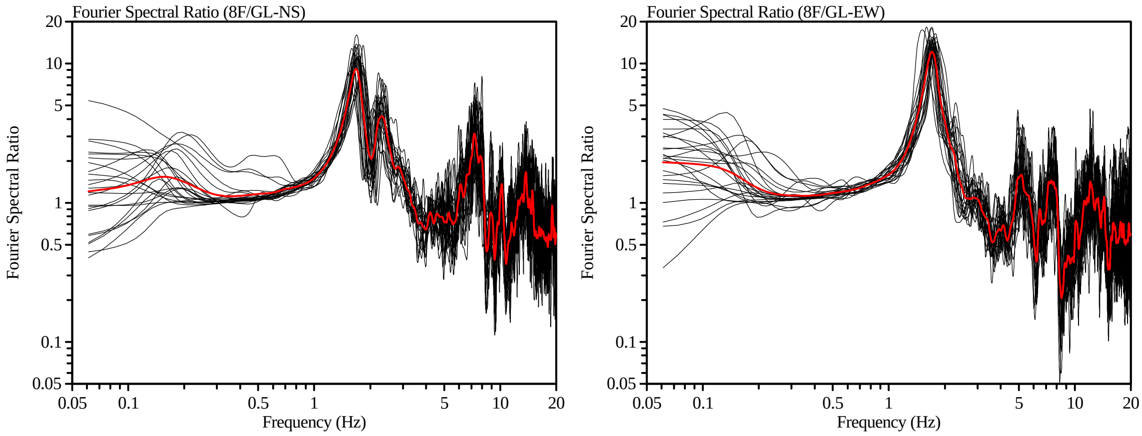


Figure 8. Fourier spectral ratios of records at 8F to A01

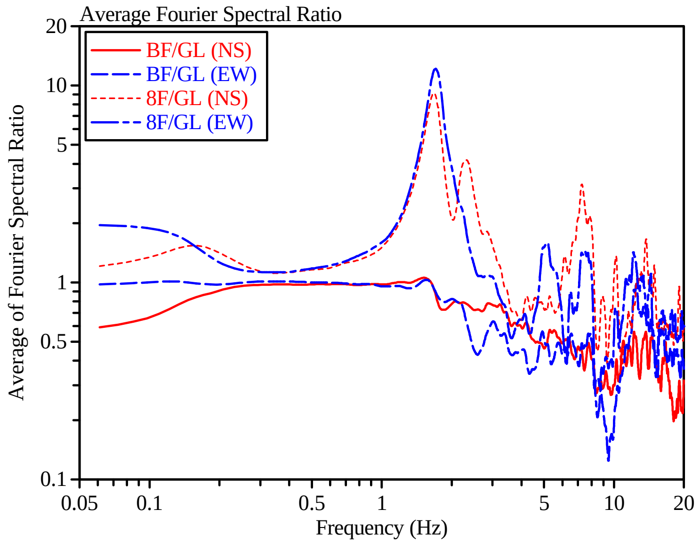


Figure 9. Average Fourier Spectral Ratio of records at BF and 8F to GL

Fourier spectra of records at 8FE, 8FN and 8FS (cf. Fig. 3), and Fourier spectral ratios 8FN/8FE and 8FS/8FE in the N-S direction are shown in Figure 10 in order to clarify the behavior of the top floor. Although movement of western side of the eighth floor (8FN and 8FS) is lager than the eastern side, the phases of both movements are same at a frequency of 1.7 Hz. At frequencies 2 to 2.3 Hz, spectral ratios quickly reduce and remarkable phase differences develop. The peak at 2.3 Hz on the spectral ratio 8F/GL in the N-S direction is caused by the vibration mode with torsional component.

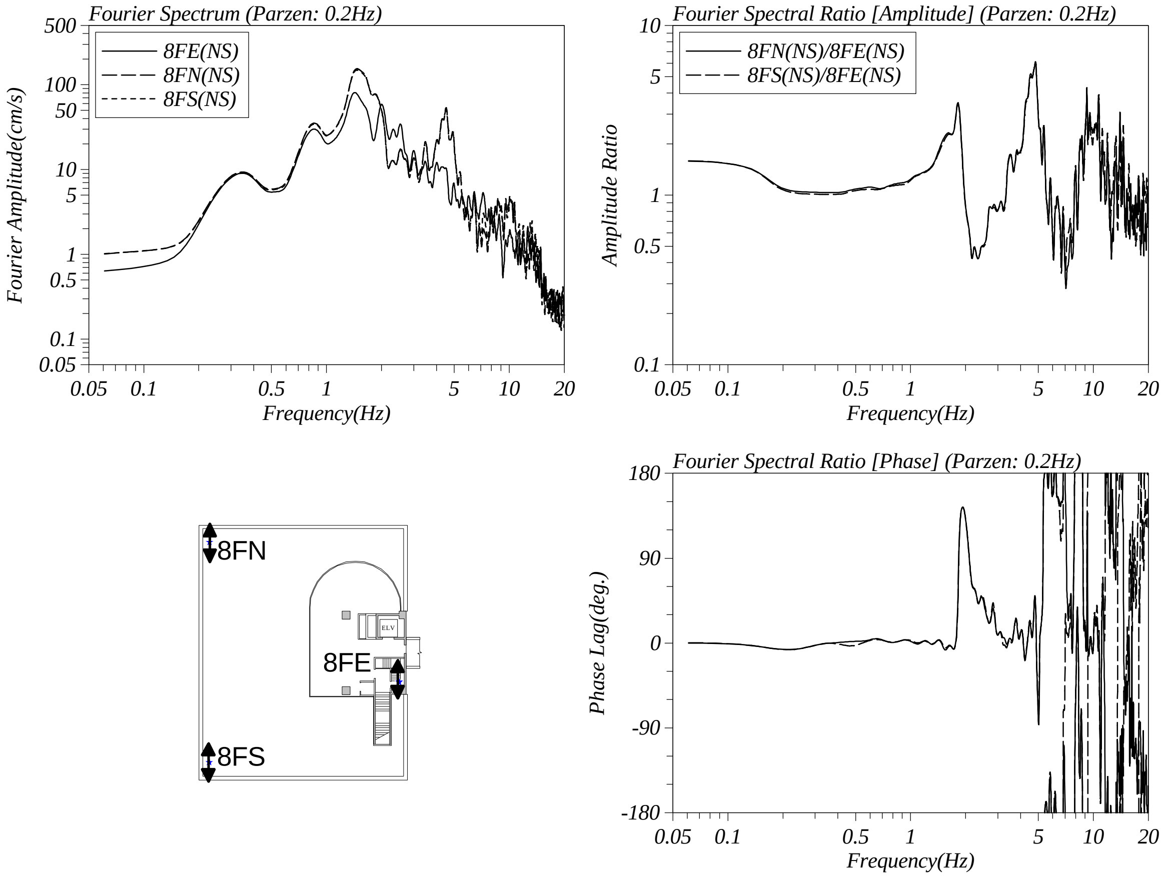
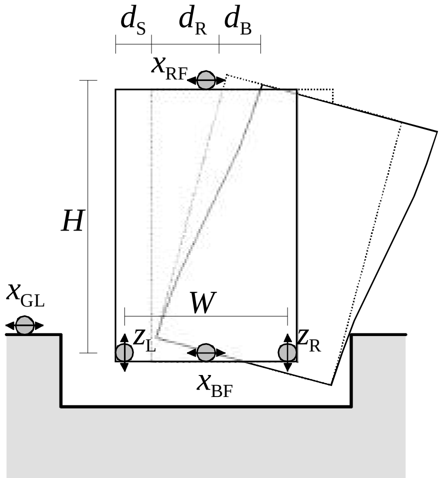


Figure 10 Fourier spectra and spectral ratios of 8FN and 8FS to 8FE for the earthquake #21

A simple swaying-rocking model shown in Figure 11 is adopted to discuss basic properties of soil-structure interaction phenomena. Displacement at the top floor includes the swaying component d_S and rocking component d_R in addition to building deformation d_B. These displacements can be computed from records at five points as shown in Figure 11.



$$d_S = x_{BF} - x_{GL}$$

$$d_R = (z_L - z_R)H / W$$

$$d_B = x_{RF} - x_{BF} - d_R$$

Figure 11. Swaying and rocking model

Figure 12 shows ratios of swaying, rocking and building displacements in the horizontal directions for the earthquake #21. Average values of swaying ratios in N-S and E-W directions are 3 % and 2 %, respectively. Rocking ratios are 11 % and 8 % in average, respectively.

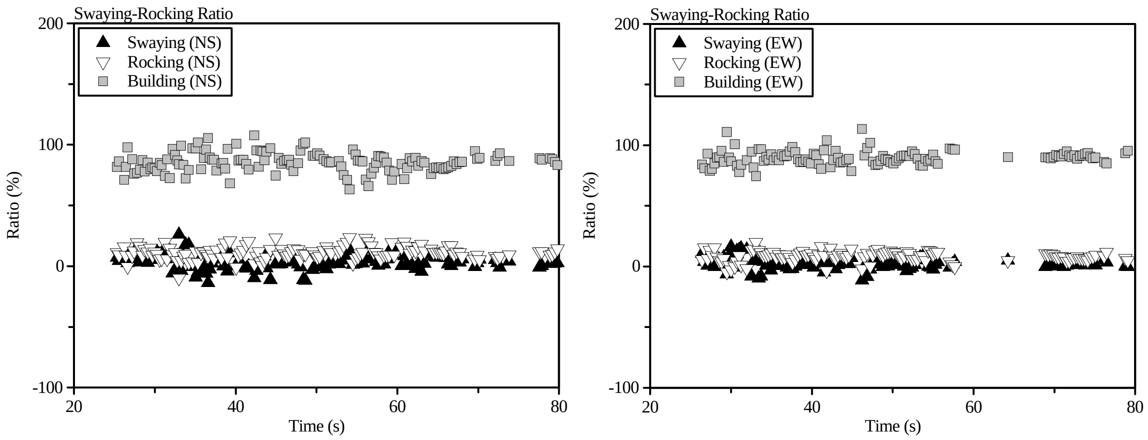


Figure 12. Swaying and rocking ratios in the displacement at 8F

4. CONCLUSIONS

BRI has started new earthquake motion observation with the dense instrumentation. Amplification effect of surface geology was examined with good agreement between observed and the theoretical result. Dynamic characteristics of the annex building are also discussed through analyses of earthquake motion records. First natural frequencies of annex building in the N-S direction and the E-W direction can be clearly distinguished from the spectral analysis. Results here will be fundamental information for following studies.
Assuming the simple swaying-rocking model, 2 % to 3 % of the displacement at the building top is caused by the swaying. 8 % and 11 % of the displacement is originated from the rocking. We intend to proceed with studies on the soil-structure interaction behavior using a number of observation records of the annex building.

5. REFERENCES

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