13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1243

DYNAMIC RESPONSE OF LOW AND MEDIUM-RISE BUILDING BASED ON DETAILED OBSERVATION CONSIDERING SOIL-STRUCTURE INTERACTION

Hiroaki KOJIMA[1], Nobuo FUKUWA[2] and Jun TOBITA[3]

SUMMARY

Effective input motion of low and medium-rise building is affected by soil condition, foundation, superstructure, input earthquake motion and the other various factors. It is experimentally investigated using large amount of seismic records and microtremor records on 9 buildings. First, in order to evaluate effective input motion in simply, the peak value of foundation and ground is compared using all seismic records. The seismic record is simultaneously observed. It is examined predominant frequency of input earthquake motion affect to effective input motion using relationship between peak value ratio of foundation/ground and equivalent predominant frequency. Equivalent predominant frequency is expressed PGA/PGV/2π or PGV/PGD/2π. In addition, relationship between peak value ratio and dimensionless frequency is investigated using all seismic records. Effective input motion decreases as frequency becomes high. Next, propriety of evaluation of effective input motion using peak value study is appraised using average Fourier spectrum ratio of all seismic records. The result is well correspondence. Last, in order to confirm usefulness of microtremor observation, the Fourier spectrum ratio of the foundation/ground compares the average of all seismic records with microtremor records. It shows good correspondence, thus the usefulness of microtremor observation shown. The influence of the superstructure which has not clearly appeared using the peak value study becomes clear.

INTRODUCTION

Researches on the input loss caused by soil-structure interaction (SSI) originate from Yamahara [1] and the mechanism of input loss has been theoretically clarified by Iguchi and Luco [2]. The followings are mentioned as experimental studies. Yasui et al. [3] investigated the influence of SSI on the reduction of building damage using strong seismic records of the Hyogo-ken Nanbu earthquake, Stewart [4] investigated input loss using strong seismic records obtained in a large amount of buildings. Other than these studies, there are few examples of the seismic observation which aimed at SSI of low and medium-rise buildings, and thus, experimental studies on dynamic response of low and medium-rise buildings are required. It examines below in order to grasp the qualitative tendency of effective input motion and the

[1] Graduate student, Nagoya Univ., Nagoya, Japan. Email: hiroaki@sharaku.nuac.nagoya-u.ac.jp
[2] Professor, Nagoya Univ., Nagoya, Japan. Email: fukuwa@sharaku.nuac.nagoya-u.ac.jp
[3] Associate Professor, Nagoya Univ., Nagoya, Japan. Email: tobita@sharaku.nuac.nagoya-u.ac.jp

usefulness of microtremor observation using large amount of seismic records and microtremor records which performed in 9 buildings of Nagoya University campus. Compare maximum acceleration and velocity of foundation with that of ground using seismic records in order to clarify the effect of input loss simply. It examines whether predominant frequency of input earthquake motion exerts influence on effective input motion with simple technique. Propriety of simple technique is verified. Usefulness of microtremor observation is verified by comparing the average of all seismic records with microtremor records.

DATABASE

Figs. 1 and 2 show plan and section of investigated low and medium-rise buildings in Nagoya University campus. Also locations of seismometer are shown in the respective figure. The hatching part of Building 2 means existence of underground floor. The part shown by dashed line means enlargement part of the building. The building area data is adopted after enlargement, because the influence of enlargement is little in this study. Building 4 and 5 are adjoined through expansion joints, and the detailed investigation

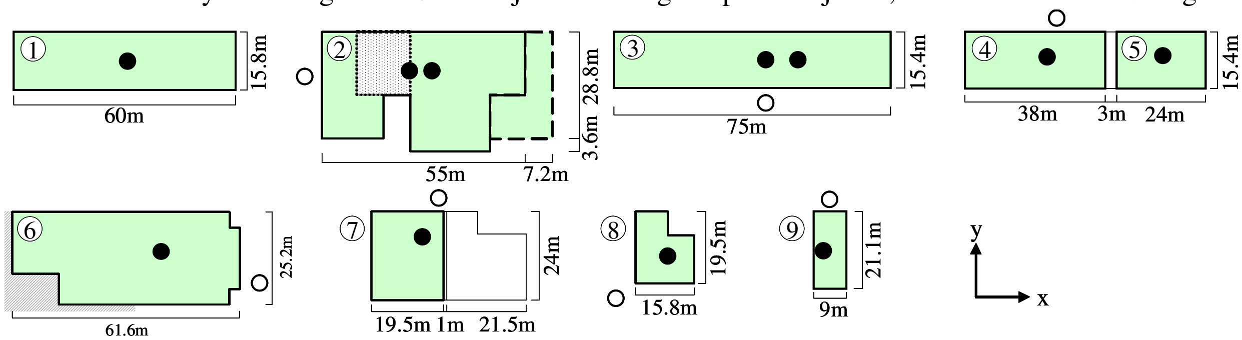

Fig. 1 Plan of investigated buildings and sensors location

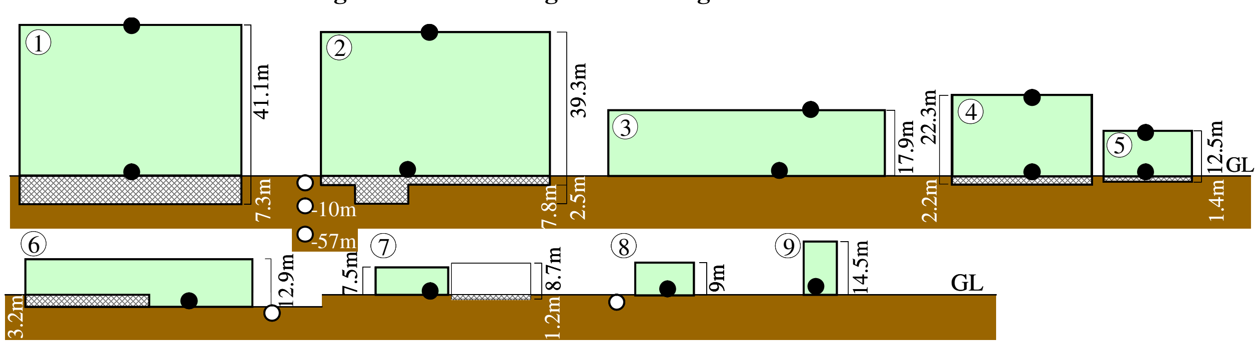

Fig. 2 Section of investigated buildings and sensors location

Table 1 Outline of investigated buildings

No.	STR	Stories	Height (m)	Foundation Type	Length(m)	Embed.(m)	Area (m^2)	Avg. Vs(m/s) N-value	PS	Seismic records	Microtremor records
1	S	10	41.1	Pile	41.7	7.3	987	243	250	28	o
2	SRC	10	39.3	Pile(PHC)	45-48	2.5 (7.8)	1841	254	220	47	o
3	RC	4	17.9	Pile(RC)	6	0	1155	244	-	49	o
4	SRC	6	22.3	Pile(PC)	10, 12	2.2	604	302	-	57	o
5	RC	3	12.5	Spread	-	1.4	374	335	-	29	o
6	RC	3	12.9	Pile(RC)	4, 5	0 (3.2)	1649	(315)	-	77	o
7	M*	1	7.5	Spread	-	0	466	291	330	77	x
8	RC	2	9.0	Pile(PC)	10, 12	0	263	275	228	67	o
9	RC	1	14.5	Pile(RC)	9	0	189	291	269	70	o

of structure-soil-structure interaction was done [5]. The hatching part of Building 6 means high ground level, because of inclined ground. Seismic observation of Building 1-5 is done simultaneously at roof, foundation and ground. The others are done at foundation and ground only. In regard to Building 1, the ground surface observation point has not installed yet. In place of that record, another ground observation point which leaves approximately 100m from Building 1 is used.

Table 1 shows outline of those buildings. Number of Fig. 1, Fig. 2 corresponds with Table 1. The structural type of Building 7 is recorded M, because this building is mixed structure that has reinforced concrete (R.C.) column and steel beam. The embedment depth is defined the depth to bottom of base-slab level from ground surface in this paper. The embedment depth in parenthesis means deeper port of the building. The shear-wave velocities (V_s) in Table 1 are estimated from N-value and PS logging that represents an average value over 10m depth from the bottom of base-slab. The V_s in parenthesis means having adopted the data of about 50m away point because there was no boring data in the building vicinity.

Fig. 3 shows relationship of area and average V_s on each building. When there is the data of PS logging, the result is adopted. In comparison with other buildings, building 2 has large area and slow average V_s. In contrast, building 4,5,7,9 have small area and fast average V_s. Fig. 4 shows relationship of embedment depth and length of on each building in x, y direction. The length of x direction is almost same for all buildings, only y direction length is different. Thus, Fig.4 is almost similar to the plan aspect ratio. It can understand that longer building has large aspect ratio.

Magnitude (JMA magnitude, Mj) and the number of occurrence of earthquake which record is obtained in Nagoya area is shown in Fig. 5. Small and medium scale earthquake (Mj < 5) is the majority. As for investigation using these data, buildings and ground are almost elastic. As for examination after the next section, among the data which show in Fig. 5, abundant records which were recorded at each building is used. The number of observed seismic data is shown in Table 1.

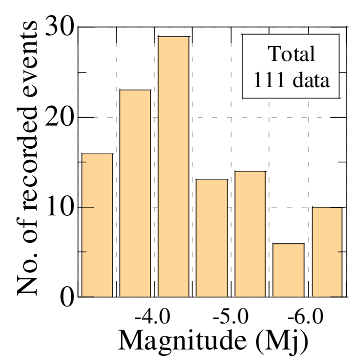

Fig. 5 Relationship of number of recorded events and magnitude (Mj)

EXAMINATION OF EFFECTIVE INPUT MOTION USING PEAK VALUE

Relationship between peak value of foundation and ground

Fig. 6 compares peak base acceleration (PBA) with peak ground acceleration (PGA) for all seismic records. In the same way, Fig. 7 compares peak base velocity (PBV) with peak ground velocity

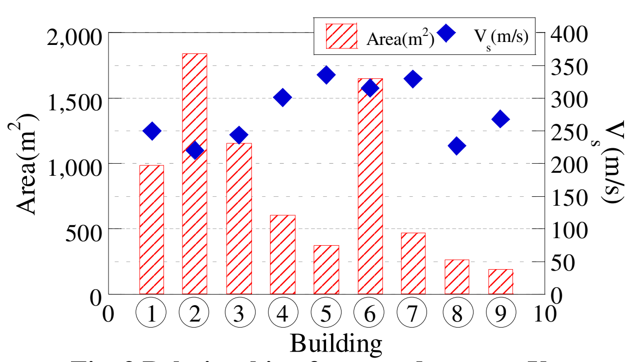

Fig. 3 Relationship of area and average V_s on each building

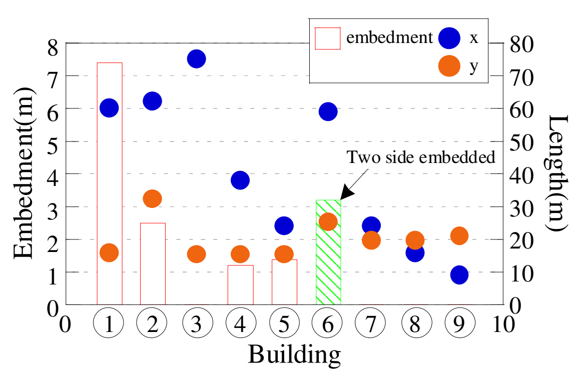

Fig. 4 Relationship of Embedment and side length on each building

(PGV). In order to examine the effect of embedment, peak value at GL-10m are compared with GL-1m which are observed beside Building 2, it is shown in the 10th fig. of Fig. 6. These signs are PG10A, PG10V. The mark of each seismic record is below a line, it means foundation motion is less than ground motion.

Foundation motion of Building 1, 2, 3, 6 is less than ground motion. These buildings have large area as shows in Fig. 3. The correlation of Building 1 is low, because the ground observation point is approximately 100m from the building. Comparing x direction with y direction, there are no clear difference except for Building 6. Remarkable difference in Building 6 may caused by ground condition around the building. Compare acceleration with velocity, foundation motion of acceleration is smaller than that of velocity. Variation of acceleration is larger than that of velocity.

Relationship between peak value ratio and magnitude

Fig. 8 shows relationship between peak acceleration ratio (PBA/PGA) and magnitude. Fig. 9 shows relationship between peak velocity ratio (PBV/PGV) and magnitude. Both PBA/PGA and PBV/PGV have trend which become so small that magnitude become large. This trend is clear in the building with large area, and low average V_s. In addition, peak value ratio becomes low in case of large magnitude.

Relationship between peak value ratio and frequency

It is examined predominant frequency of input earthquake motion affect to effective input motion. Predominant frequency of earthquake motion is appraised at equivalent predominant frequency.

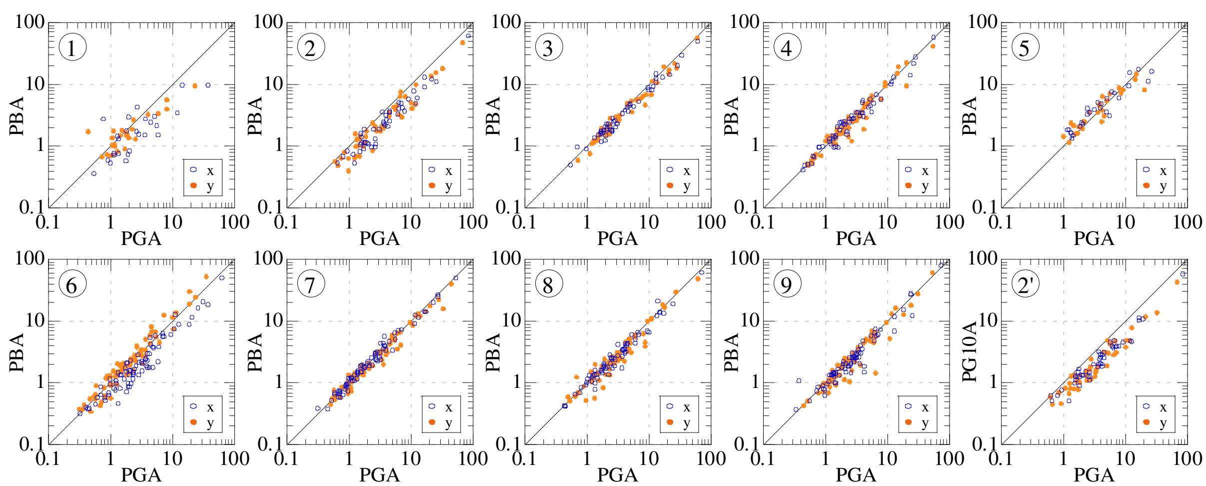

Fig. 6 Correlation between peak base acceleration (PBA) and peak ground acceleration (PGA)

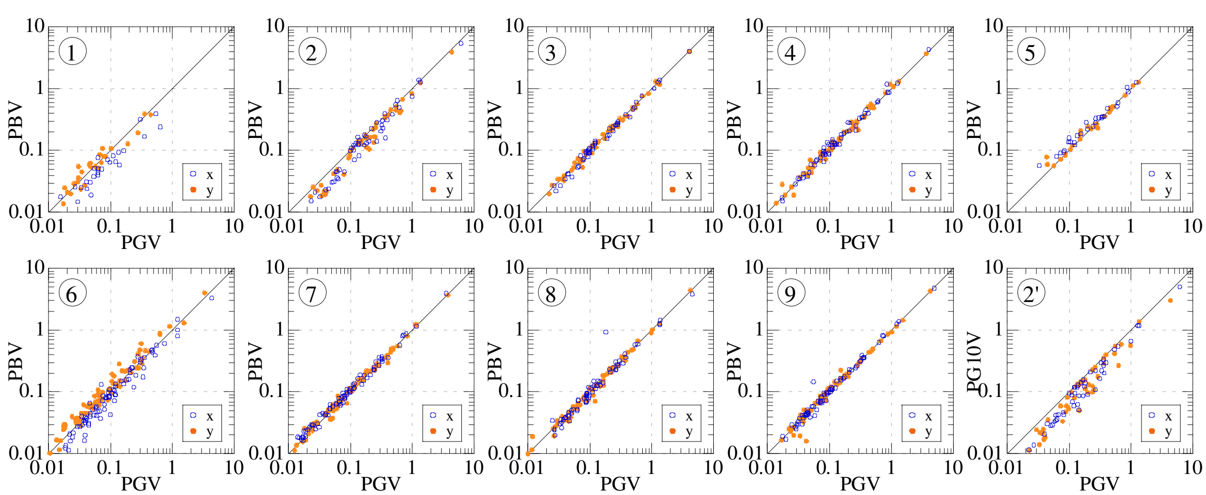

Fig. 7 Correlation between peak base velocity (PBV) and peak ground velocity (PGV)

Equivalent predominant frequency is introduced PGA/PGV/2π or PGV/PGD/2π. Peak value of acceleration, velocity, and displacement should be given in 2 seconds time interval. Because in case the time of maximum acceleration (or velocity) and the time of maximum velocity (or displacement) are widely different, equivalent predominant frequency may not be required appropriately. Though, these cases are rare.

Fig. 10 shows relationship between peak acceleration ratio (PBA/PGA) and equivalent predominant frequency of input earthquake motion (PGA/PGV/2π). Fig 11 shows relationship between peak velocity ratio (PBV/PGV) and equivalent predominant frequency of input earthquake motion (PGV/PGD/2π). Effective input motion decreases as the equivalent predominant frequency becomes high frequency in both acceleration case and velocity case. This tendency is significant at the building with large area. On the contrary, foundation motion and ground is almost equal in the building with small area. Amplification is observed in Building 4 and 5 at 3 to 6 Hz, respectively. This may caused by the influence of adjoining building mutually [5].

In order to remove the influence of area and foundation conditions, Figs. 11 and 12 are redrawn by use of dimensionless frequency (a_0). Each figure contains all seismic records except the adjoining Buildings 4, 5 and Building 6 of y direction which record has much variation. Fig 14, 15 shows relationship between peak acceleration ratio (PBA/PGA), peak velocity ratio (PBV/PGV) and dimensionless frequency of the adjoining Building 4, 5 only. Dimensionless frequency is calculated from half length of foundation, average V_s, and equivalent predominant frequency. Equivalent predominant frequency is adopted PGA/PGV/2π in case of acceleration, and adopted PGV/PGD/2π in case of velocity. Effective input motion has decreased as dimensionless frequency becomes high. Compare PBA/PGA with PBV/PGV, there is an effect of similar input loss. When two adjoining buildings are compared with the others, effective input motion of adjoining buildings amplifies with low frequency.

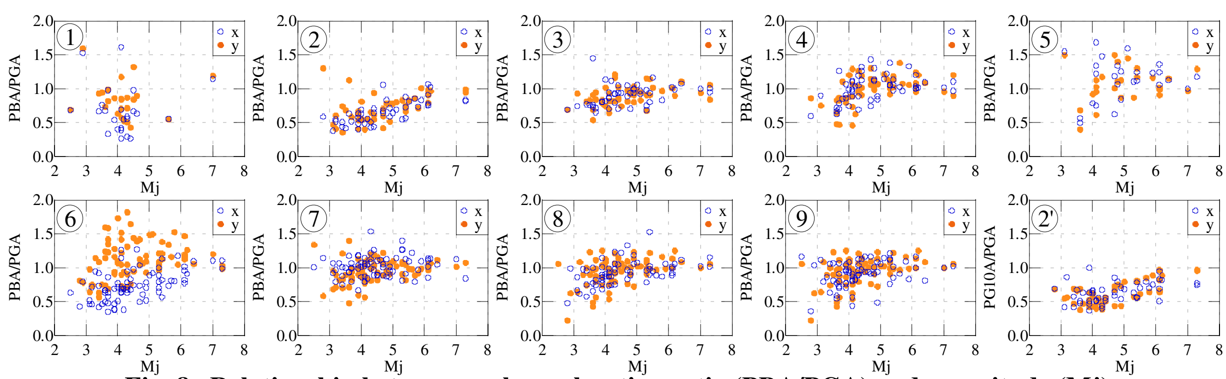

Fig. 8 Relationship between peak acceleration ratio (PBA/PGA) and magnitude (Mj)

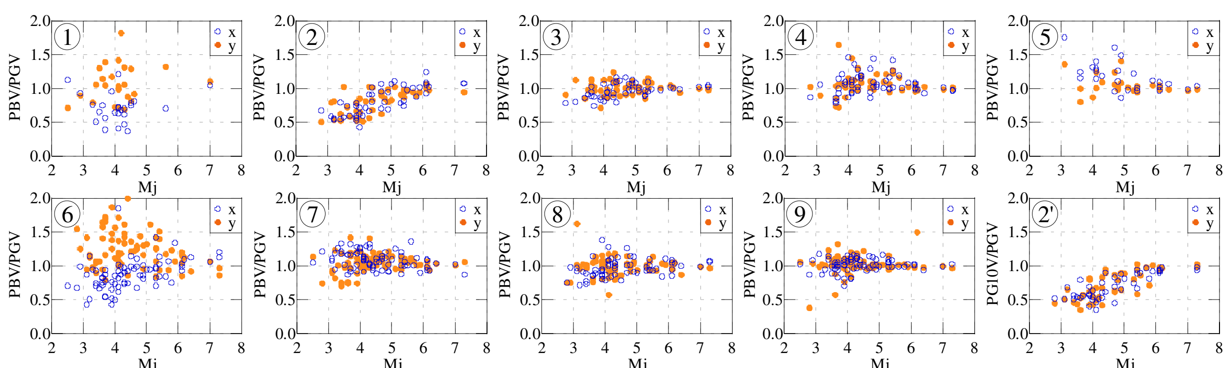

Fig. 9 Relationship between peak velocity ratio (PBV/PGV) and magnitude (Mj)

EXAMINATION OF EFFECTIVE INPUT MOTION USING FOURIER SPECTRUM RATIO

Comparison of effective input motion using peak value and Fourier spectrum ratio

Propriety relation between peak acceleration ratio, peak velocity ratio and equivalent predominant frequency of input earthquake motion is examined and verified in the previous section. Relationship peak acceleration ratio, peak velocity ratio and equivalent predominant frequency of x, y direction and average Fourier spectrum ratio are shown together in Figs. 16 and 17. Average Fourier spectrum is used all seismic records which is observed foundation and ground simultaneously. Marks which are calculated with peak

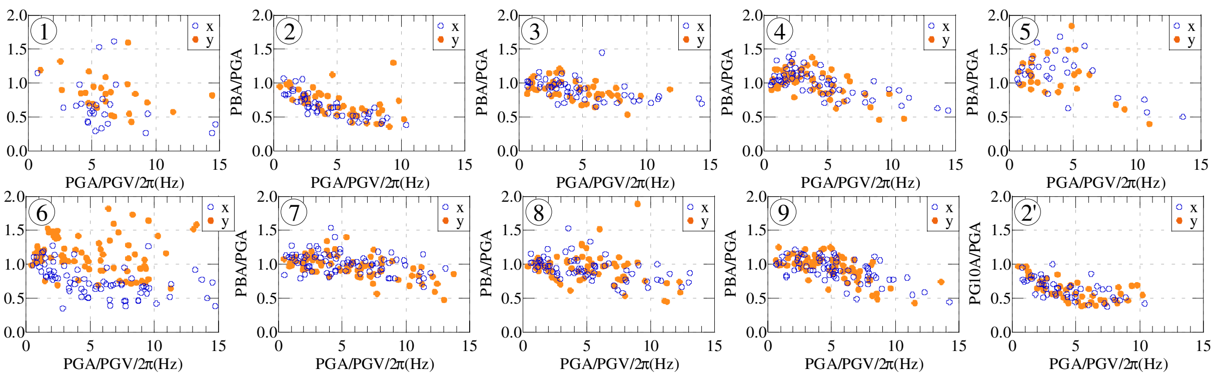

Fig. 10 Relationship between peak acceleration ratio (PBA/PGA) and PGA/PGV/2π

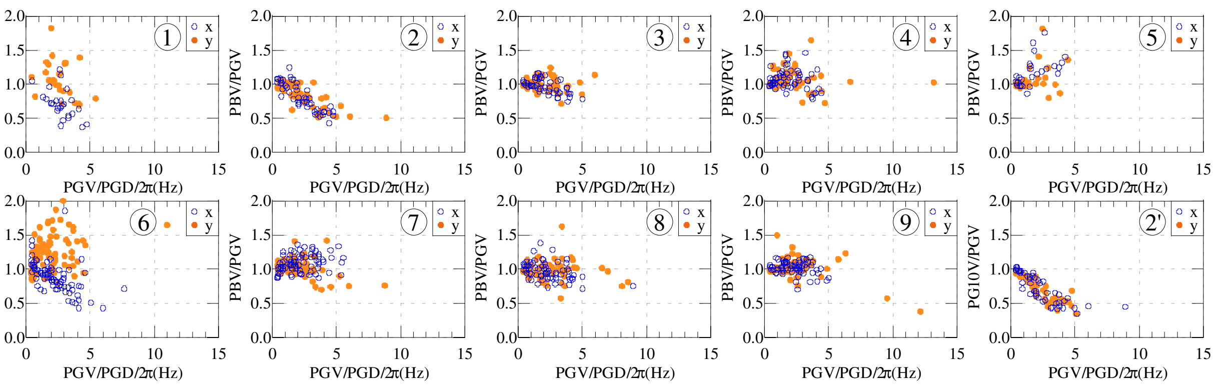

Fig. 11 Relationship between peak velocity ratio (PBV/PGV) and PGV/PGD/2π

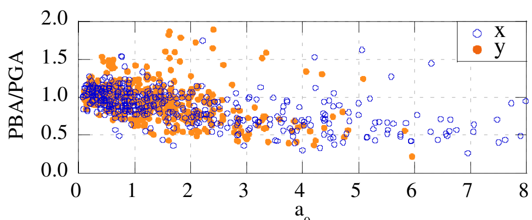

Fig. 12 Relationship between peak acceleration ratio (PBA/PGA) and dimensionless frequency (a_0)

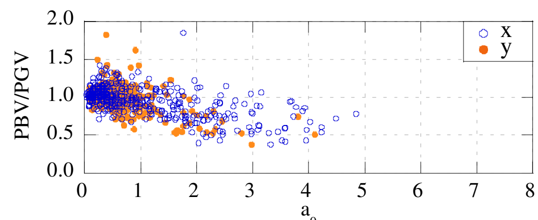

Fig. 13 Relationship between peak velocity ratio (PBV/PGV) and dimensionless frequency (a_0)

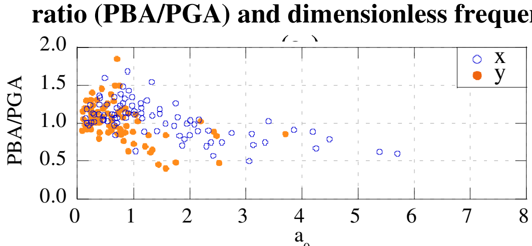

Fig. 14 Relationship between peak acceleration ratio (PBA/PGA) and dimensionless frequency (a_0) for adjacent buildings only

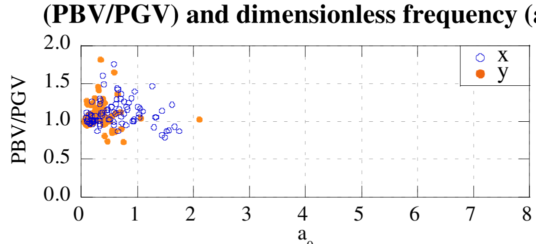

Fig. 15 Relationship between peak velocity ratio (PBV/PGV) and dimensionless frequency (a_0) for adjacent buildings only

value and line of average Fourier spectrum correspond very well in both directions. In addition, the frequency range which have change in the line and the range where variation of points is large correspond well. Therefore, the evaluation of effective input motion using peak value is useful.

Comparison of microtremor records and seismic records

In order to specify the usefulness of microtremor observation, microtremor records is examined by comparing with seismic records. Average Fourier spectrum ratio of all seismic records and standard deviation are shown together in Fig. 18, 19 with Fourier spectrum ratio of microtremor in x, y direction respectively. Triangular marks in the figure mean flexible-base frequency of the structure (i.e., the frequency incorporating structural flexibility as well as foundation flexibility in translation and rocking). As for Buildings 6-9, triangular marks do not plotted because flexible-base frequencies are not clear.

It corresponds well in frequency properties from microtremor record and seismic record. Effective input motion decreases in higher frequency range. This tendency is remarkable at large building. For adjacent buildings 4 and 5, the dispersion of seismic record is large near flexible-base frequency of the mutual buildings. The influence is large at smaller Building 5 than Building 4. Such properties are well correspond in microtremor record and seismic record.

The influence of the superstructure has appeared in buildings whose flexible-base frequency is clear, which is not apparent in section 3. The influence is large at R.C. and SRC buildings with heavy superstructures. Comparing Building 1 with Building 2, these are the same 10-floor building. However, the influence of superstructure is very small at Building 1, because superstructure of Building 1 is light which structural type is steel.

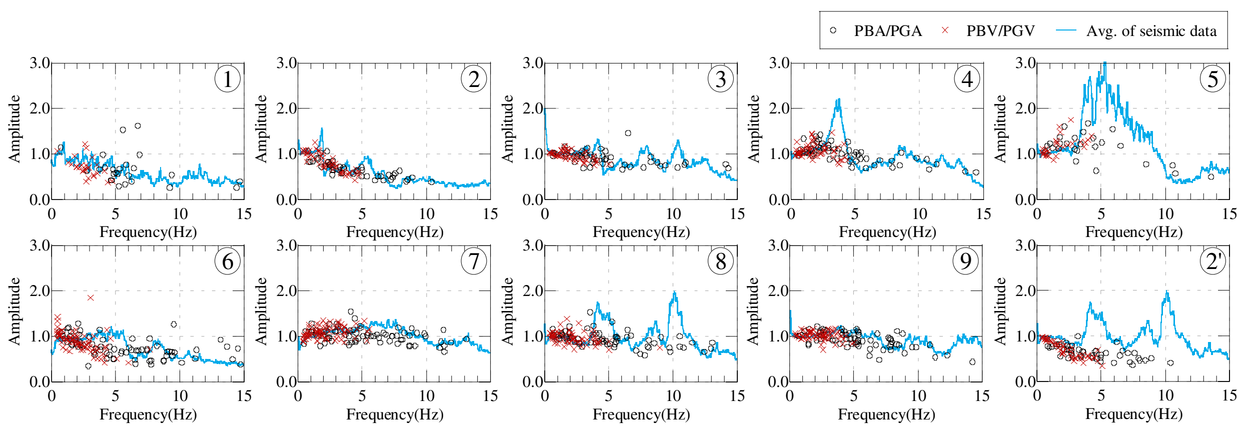

Fig. 16 Fourier spectraum ratio (foundation/ground) x direction

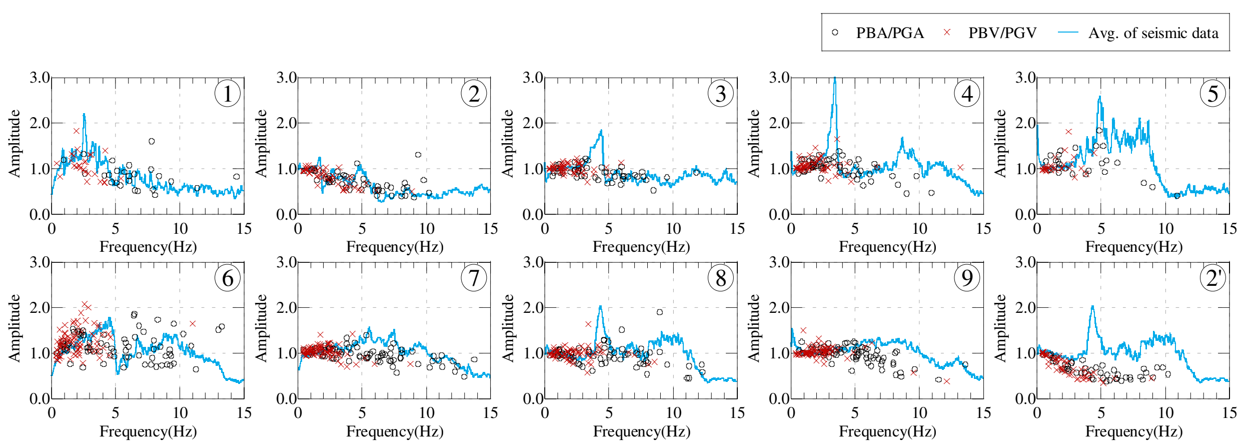

Fig. 17 Fourier spectrum ratio (foundation /ground) y direction

CONCLUDING REMARKS

Effective input motion was investigated experimentally using large amount of small-to-medium level seismic records and microtremor record of nine buildings which exist in Nagoya University campus. The main concluding remarks are as follows:

In order to verify the input loss effect quite simply, maximum acceleration and velocity at foundation and ground is compared respectively using seismic records. Peak value of the foundation becomes small in comparison with ground as a result. This is remarkable at the large building. Input loss effect becomes little in the earthquake which magnitude become large. This tendency was observed in all buildings and it appeared strongly in the large building.

The influence of predominant frequency of input earthquake motion on the effective input motion is examined using peak value. Predominant frequency of input earthquake motion is estimated by equivalent dominant frequency expressed as $PGA/PGV/2\pi$ or $PGV/PGD/2\pi$. Effective input motion is decreased both acceleration and velocity when equivalent dominant frequency becomes high. Its tendency is prominent in the large building.

The influence of dimensionless frequency gives to effective input motion is examined. Effective input motion decreases when dimensionless frequency becomes high. This is similar with in case of acceleration and velocity. In case of the adjacent building, effective input motion amplifies in low frequency because adjacent buildings exert influence mutually.

Propriety of evaluation of effective input motion using peak value is appraised using average Fourier spectrum ratio of all seismic records. As a result, peak value study and average Fourier spectrum ratio

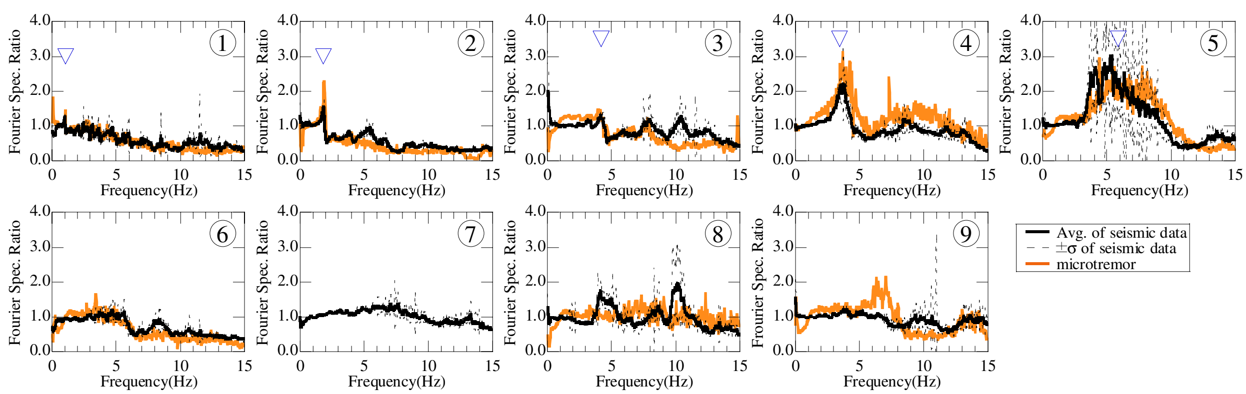

Fig. 18 Fourier spectrum ratio (foundation /ground) x direction

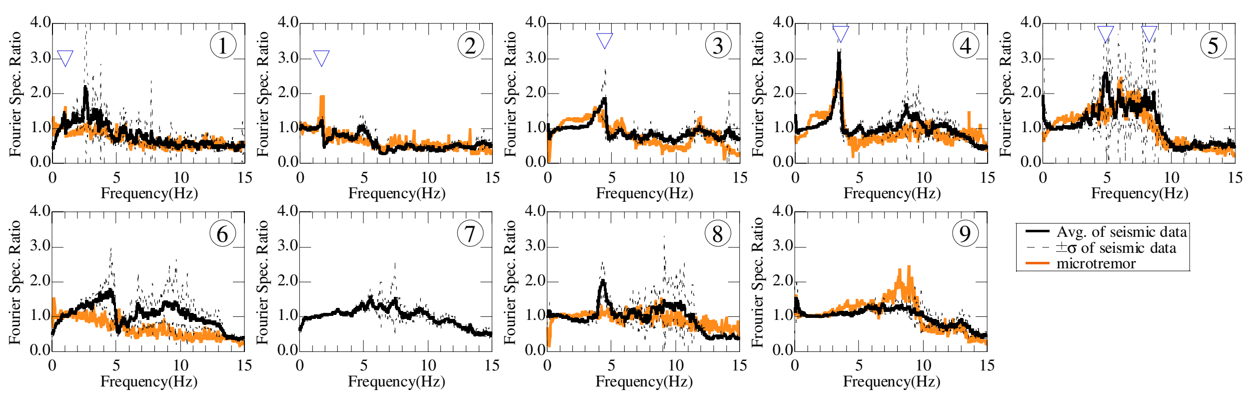

Fig. 19 Fourier spectrum ratio (foundation /ground) y direction

corresponded well. Thus, peak value study for effective input motion is useful.

In order to specify the usefulness of microtremor observation, microtremor records compare with seismic records using Fourier spectrum ratio of foundation/ground. As a result, there are corresponded well. Therefore, microtremor observation is useful to study effective input motion. In addition, the influence of superstructure is observed in Fourier spectrum ratio, which has not clearly appeared in peak value study. This influence is prominent in large area and heavy weight building which structural type is R.C. and SRC.

REFERENCES

1. Yamahara, H. (1970). "Ground motions during earthquakes and the input loss of earthquake power to an excitation of buildings." Soils and Foundations, 10(2), 145-161.
2. Iguchi, M. and Luco, J. E. (1981). "Dynamic Response of Flexible Rectangular Foundations on an Elastic-Space.", Earthq. Engrg Struct. Dyn., Vol. 9, 239-249.
3. Yasui, Y., Iguchi, M., Akagi, H., Hayashi, Y. and Nakamura, M. (1998). "Examination on Effective Input Motion to Structures in Heavily Damaged Zone in the 1995 Hyogo-ken Nanbu Earthquake." J. Struct. Constr. Eng., AIJ, No.512, 111-118 (in Japanese).
4. Stewart, J. P. (2000). "Variations between Foundations-Level and Free-Field Earthquake Ground Motions." Earthquake Spectra, Vol. 16(2), 511-532.
5. Kim, S. and Stewart, J. P. (2003). "Kinematic Soil-Structure Interaction from Strong Motion Recordings." J. Geotech. Eng., ASCE, 129(4), 323-335
6. Matsuyama, C., Fukuwa, N and Tobita, J (2001). "Dynamic Characteristics of adjacent Low and Medium-rise Buildings based on Earthquake Observation, Forced Vibration Experiment and Microtremor Observation." J. Struct. Constr. Eng., AIJ, No.545, 87-94 (in Japanese).