CHANGES IN NATURAL FREQUENCY OF APARTMENT BUILDINGS BEFORE AND AFTER THE HYOGOKEN-NANBU EARTHQUAKE

S OHBA[1] And T FUKUDA[2]

SUMMARY

This paper discusses the changes in the natural frequency of five-story apartment buildings before and after the Hyogoken-Nanbu Earthquake. First, we carried out microtremor measurements at the top floor of apartment buildings in six housing developments before and after the Hyogoken-Nanbu Earthquake. Next, we attempted to form comparisons of the natural frequency of apartment buildings at various sites, before and after the Hyogoken-Nanbu Earthquake. As a result of our observations, it became clear that the changes in the natural frequency of buildings are caused by variances in the rigidity of the soil.

INTRODUCTION

It has been reported on the references 1),2) that the natural frequencies of buildings were decreased after the Hyogoken Nanbu Earthquake occurred though it didn't damage upper constructions of them. It can be considered that the damaged basement structure or the decreased rigidity of the ground deserved it. The strict relation between the natural frequency of rigid building and the ground conditions leads the variances of the rigidity of soil. This study extracts apartment houses, which has no damage in upper structure, and measures microtremors of them to make clear these instances as below. They are the comparison of natural frequencies and the changes between ground rigidities before and after the earthquake, and the shear stiffness of ground influenced by earthquake.

OUTLINES OF BUILDINGS AND GROUNDS

Outlines of buildings

This survey selects 6 collective housing areas as shown P I-P VI in Figure-1. The objects of this survey are apartments buildings which are 5-strioried and were measeured microtremors before Hyogoken-Nanbu Earthquake occurred, and the number of which is 139. The structure, the fundations and the ground types of these buildings are shown in Table-1..

[1] *Dept of Architecture, Faculty of Engineering, Osaka Institute of Technology, Japan Email:ohba@archi.oit.ac.jp*
[2] *Dept of Architecture, Faculty of Engineering, Osaka Institute of Technology, Japan FAX; 06(6957)2132*

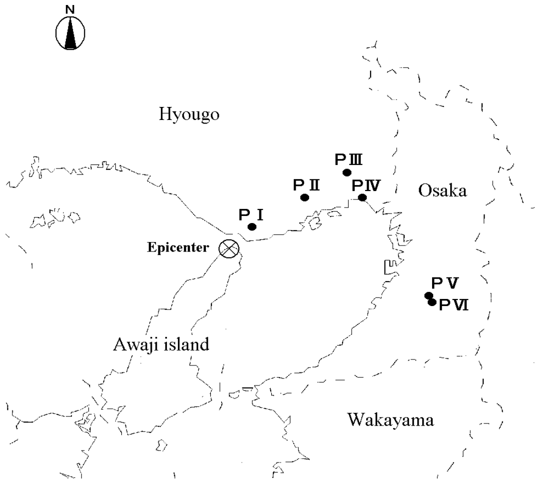

Figure 1: Points of observation

Table 1: An outline of buildings and grounds

Observation point	Structure form	Foundation form	Class of soil
PⅠ	PC,wall	-----	Diluvial ground
PⅡ	RC,wall,frame	Spread	Weathering granite
PⅢ	RC,frame	Pile or Spread	Diluvial ground
PⅣ	RC,wall,frame	Spread	Alluvial ground
PⅤ	RC,PC,wall	Pile	Diluvial ground
PⅥ	RC,PC,wall	Pile	Diluvial ground

Outlines of grounds

The selected grounds are classfied into weathering granite, diluvial(cut and filled), and alluvial ground as follows:

The ground of P II has the gravel layer of N-value 30 above 3m from the surface and the weathering granite layer of N-value more than 60 beyond 3m in depth. The grounds of P I, P III, P V and P VI are diluvium on the hill, and divided into cut and filled grounds. The certain parts of P I are cut ground and N-value of them is more than 50 around 5m in depth. The other parts of it are filled ground whose N-value is 15 in average and which has the gravel layer of N-value 50 around 20m in depth. The filled ground of P III is sandy soil of N-value 10 above 5m from the surface and N-value 50 around 10m in depth. N-value of the cut grounds of P Vand PVI is 50 around 3m, and those of the filled grounds are 15 around 8m from the surface and 50 around 10m in depth. The ground of P IV is the alluvial ground which was perfomed 25m soil inprovement and has the filled 10m soil.

CHANGES IN NATURAL FREQUENCY BEFORE AND AFTER THE MAIN SHOCK BASED ON MICROTREMOR MEASUREMENTS

Results of measurement

The microtremor measurements were experimented with displacement of the long and short side on the top floor and the ground besides buildings to discriminate the natural frequencies of buildings. The natural frequencies, which analyzed by Fourier sperctrum on each point, are arranged orderly in accordance with a distance from the hypocenter as shown in Figure-2. Table-2 indicates that the averaged natural frequencies before and after earthquake, and the rates of the natural frequencies after the earthquake to that before ones. It is comfirmed in the table-2 that the natural frequencies of most of the buildings after the earthquake are decreased from 0.84 to 0.96 times lower than before earthquake, although they were hardly damaged. This result means that the natural frequencies were decreased by Hyogoken-Nanbu Eathquake, because the shocks of it agitated the ground and reduced the rigidity of it.

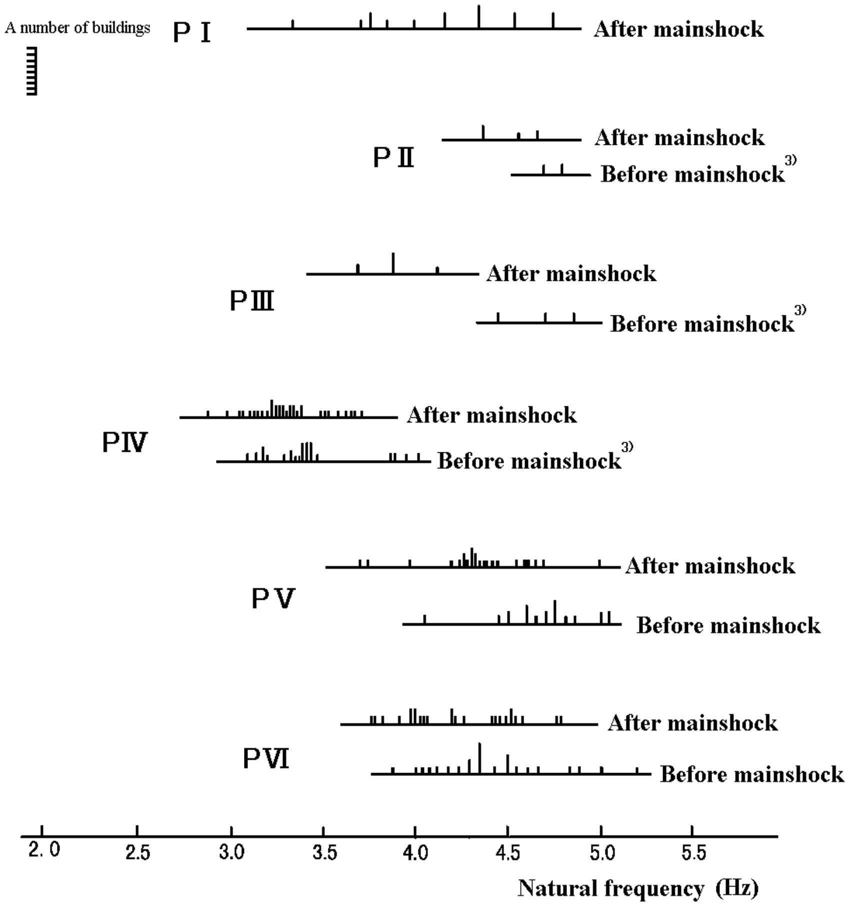

Figure 2: Distribution of natural frequency before and after the main shock

Table 2: The mean value of natural frequency and rate of decline

	The mean value of natural frequency (Before main shock)	The mean value of natural frequency (After main shock)	rate of decline after vs. before
P I	———	4.05	——
P II	4.75	4.56	0.96
P III	4.69	3.92	0.84
P IV	3.45	3.30	0.95
P V	4.71	4.33	0.92
PVI	4.41	4.23	0.96

INFLUENCES OF DISTANCE FROM THE EPICENTER ON NATURAL FREQUENCY

Figure-3 indicates the relation between the distances from the hypocenter and the rates of the natural frequencies before and after earthquake of P I-P VI. In Figure-3, P II(○) is building on bedrock and P IV(●) is on alluvial ground, and both of buildings are supported by spread foundations. The other buildings are supported by piling foudations. This Figure shows obviously that the natural frequencies of the buildings supported by piles are lower on alluvial ground, the closer the distance from the hypocenter is. On the contrary, The natural frequencies of P IIand P IV has no tendecy toward it. The reason is considered that the hard ground, for instant, weathering granite is hardly effected by the main shock and the rigidity of the performed soil improvement ground is decreased slightly.

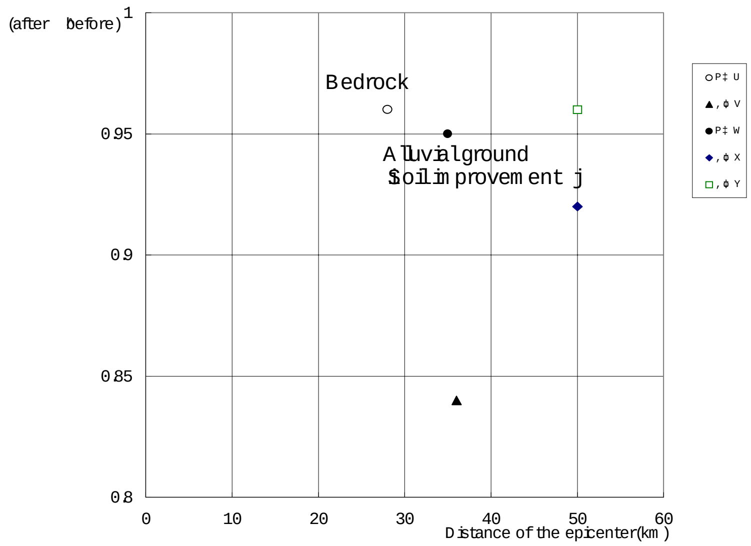

Figure 3: Influence of distance of epicenter on natural frequency before and after the main shock

CHANGES OF NATURAL FREQUENCIES OF BUILDINGS DEPENDED ON GROUND CONDITION

Differences in natural frequency of buildings on cut and filled grounds

Figure-4 indicates the natural frequencies of buildings(PⅤ and PⅥ), which has the same distance from hypocenter, on cut and filled grounds. Table-3 indicates the changes in natural frequency of buildings on the cut and filled grounds, and shows that the natural frequency on cut ground is 0.95 times and that on filled ground is 0.92 times lower after the earthquake than before ones. This result means that the filled ground is affected by main shock more than the cut ground, because of the compared rates between the declined natural frequencies of buildings on fill and on cut ground.

Table 3: Changes of natural frequency of buildings on cut and filled grounds before and after the main shock

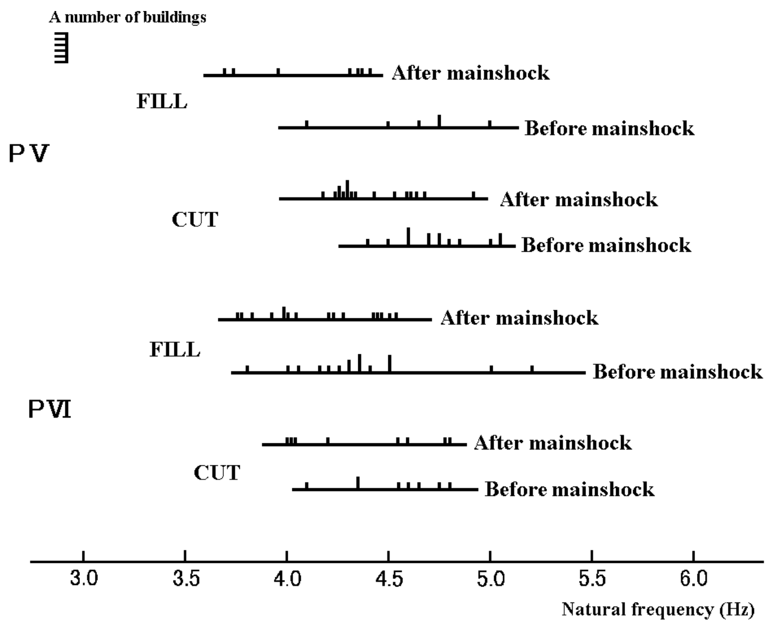

Figure 4: Distribution of natural frequency of buildings on cut and fill grounds before and after the main shock

Differences in the natural frequency of buildings on liquefaction and non-liquefaction area

The liquefaction appeared after the earthquake on the certain parts of P IV. Figure-5 indicates the differences in the natural frequencies of buildings on liquefied and non-liquefied areas. The natural frequency of buildings on liquefied ground are from 2.87Hz to 3.55Hz. On the other hand, those of building on non-liquefied ground are from 2.97Hz to 3.70Hz. These results mean that the natural frequency of buildings on liquefied area is lower than that on non-liquefied area. In addition, Table-4 indicates the averages of the natural frequencies of buildings on liquefied and non-liquefied area before and after earthquake. In the table-4, the natural frequency of the buildings after the earthquake on non-liquefied is 0.95 times lower than that before ones and that on liquefied area is 0.92 times lower. These result shows the decline of the natural frequencies on liquefied area is much bigger than that on non-liquefied. It means that liquefaction decreases the rigidity of the ground.

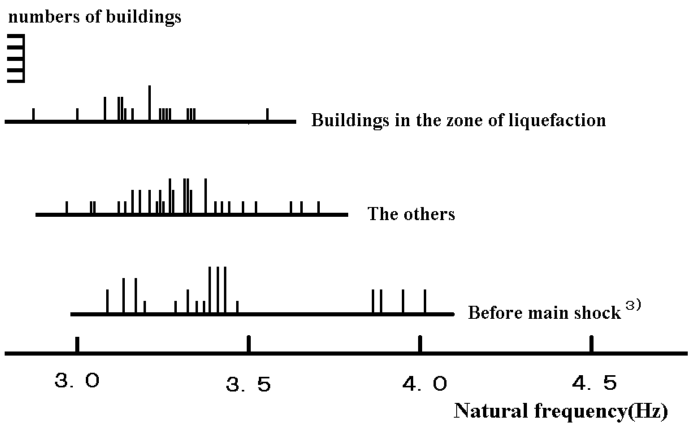

Figure 5: Distributions of natural frequency whether there are zone of liquefaction

Table 4: Changes of natural frequency whether there are zone of liquefaction

		Natural frequency(Hz)	rate of decline (after/before)
Before main shock		3.45	———
After main shock	the others	3.30	0.95
	zone of liquefaction	3.19	0.92

THE MATHEMATICAL ANALYSIS

This chapter confirms it mathematicaly that the decline of the ground rigidity affects the natural frequency of building.The dynamic characteristic of the ground can express the equation of the transmitting velocity of S wave as Vs= $\sqrt{\frac{G}{\rho}}$. This equation indicates that the rigidity is related to the velocity of S wave. Therefore, The relation between the change of S wave velocity and the natural frequency should be anlayzed.

Modeled buildings

The building of P IV, which has spread foundation, is modeled rigidly and illustrated in Figure-6. This building is 5 storied and the mesurements of it are 8.7 meters in width and 13.7 meters in height.

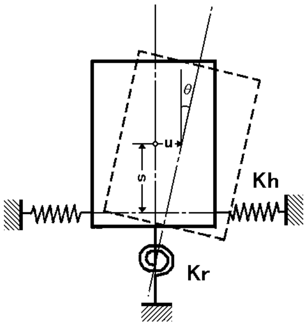

Figure 6: Analytical model

The relation between Shear wave velocity and natural frequency

According to referense 4), the horizontal spring constant (Kh) and the rocking spring constant (Kr) can be evaluated by S wave velocity. In this chapter, we analyze the model of building by the means of eigenvalue analysis. Eq.(1) indicates the horizontal spring constant, and Eq.(2) indicates the rocking spring constant. These equations suppose that Poisson’s ratio is 0.45 and the weight per unit volume of ground is 1.8t/m^3.

$$Kh = \frac{8b\rho V_S^2}{2-\nu} \cdot A_x \tag{1}$$

$$Kr = \frac{8b^2\rho V_S^2}{3(1-\nu)} \cdot A_\Phi \tag{2}$$

$$A_x = \frac{2}{\pi}\left\{\log\tan\left(\frac{\pi}{4}+\frac{1}{2}\tan^{-1}\frac{c}{b}\right)+\frac{c}{b}\log\tan\left(\frac{\pi}{4}+\frac{1}{2}\tan^{-1}\frac{b}{c}\right)\right\}$$

$$A_\phi = \frac{\pi}{4}\left[\log\tan\left(\frac{\pi}{4}+\frac{1}{2}\tan^{-1}\frac{c}{b}\right)+\left(\frac{c}{b}\right)^3\left\{\frac{1}{2}\frac{b}{c}\sqrt{\left(1+\frac{b}{c}\right)^2}-\frac{1}{2}\log\tan\left(\frac{\pi}{4}+\frac{1}{2}\tan^{-1}\frac{c}{b}\right)\right\}\right]$$

A_x A_φ shape factor ν Poisson’s ratio

P :density of ground (t sec^2/m^4)   half width of building(m)

The results of Eq.(1)(2) can give an answer by the use of equation(3).

$$\begin{bmatrix} m & 0 \\ 0 & I_G \end{bmatrix}\begin{Bmatrix} \ddot{u} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} Kh & -KhS \\ -KhS & Kr + KhS^2 \end{bmatrix}\begin{Bmatrix} u \\ \theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \tag{3}$$

m :mass of building*t sec^2/cm

$I_{G:}$ moment of inertia around center of gravity (t cm)

u: displacement of center of gravity (m)

θ: rotation angle around center of gravity (rad)

S: distance from the center of gravity to the line of action of resultant force of subgrade reaction (m)

Thus, we can obtain the relation between with S wave velocity (Vs) and natural frequency (f) and the equation as shown in Eq.(4).

$$f = Vs\sqrt{\frac{4b^3\rho A_x}{(2-\nu)m}\left\{\left(1+\frac{mb^2A_\phi(2-\nu)}{3I_G(1-\nu)A_x}+\frac{mS^2}{I_G}\right)\mp\sqrt{\left(1+\frac{mb^2A_\phi(2-\nu)}{3I_G(1-\nu)A_x}+\frac{mS^2}{I_G}\right)-\frac{4mb^2A_\phi(2-\nu)}{3I_G(1-\nu)A_x}}\right\}} \quad (4)$$

Eq. (4) can express a straight line as shown in Figure-7 and confirm that the natural frequencies are decreased in proportion to the decline of S wave velocity.

Using the averages of natural frequency obtained by microtremor measurements, Eq.(4) gives the S wave velocities of each ground as shown in Figure-7. Table-5 indicates these natural frequencies and S wave velosities. It shows that the S wave velocity is 172.5(m/sec) before main shock, that on non-liquefied area is 165(m/sec) and that on liquefied area is 159.5(m/sec). Each S wave velocity was decreased 0.96 times and 0.92 times.

These evaluated velocities mean that the declines of the ground rigidities before and after earthquake are 0.92 times on non-liquefied area and 0.85 times on liquefied area.

Thus, the mathematical analysis can prove the decline of the ground rigidity on liquefied area is bigger than that on non-liquefied area.

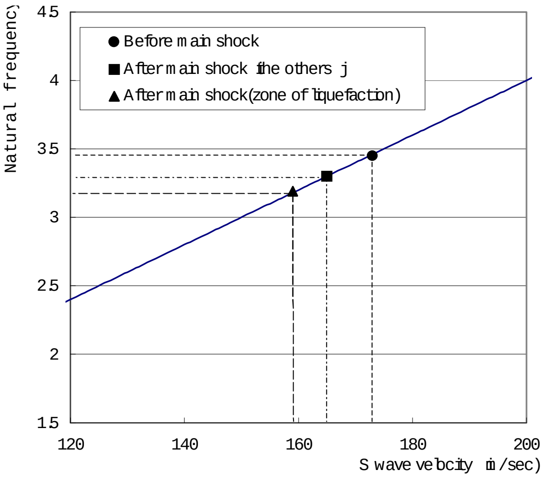

Figure 7: The relation between S wave velocity and natural frequency

Table 5: Changes of S wave velocity before and after the main shock

		Natural frequency(Hz)*	S wave velocity m/sec **
Before main shock		3.45	172.5
After main shock	Not zone of liquefaction	3.30	165.0
	zone of liquefaction	3.19	159.5

* observed value,** analytical value

CONCLUSIONS

As a result of this study, these following conclusions are obtained:

1) The natural frequency is decreased after earthquake, though it didn't damage buildings

2) The decline rate of natural frequencies is higher, the closer the distance from hypocenter is. And that of building supported by piles and soft ground is higher. On the other hand, that of building supported by the bedrock or improved ground and spread foundation is lower.

3) The natural frequency on liquefied ground is decreased much more than that of buildings on non-liquefied, after the earthquake attacks.

Therefore, It can be said that the decline of natural frequencies of buildings, whose upper structure and piles have no damaged, is related that the shocks of earthquake agitated the ground and reduced the rigidity of it.

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