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11. *Rocking and Elastic Vibrations of Actual Building. II. (Observation of Earthquake Motion).*

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1. Introduction

The property of earthquake-motion at a building varies according to the ground property on which the building stands. Therefore the value of earthquake force, which has to be taken into consideration in designing earthquake proof construction, depends on the ground property. In order to make the estimation of such a value more clearly, we made a simultaneous observation by installing seismographs both on the basements and the roof-floors of two buildings of the same structure standing on different ground properties, that is, one standing directly on the rock and the other on the crushed stone with concrete piles. These buildings are in Hitachi Mine site, Ibaraki prefecture.

The results of the vibration tests by means of a vibration generator at the buildings have already been given in the previous paper.[2]

2. Observations of earthquake motion

Four horizontal seismographs were installed on the roof-floors and on the ground-floors of two buildings. The component of beam direction (short length direction) of earthquakemotion was observed. The constants of seismographs used in the comparative observation are shown in Table 1.

The rough sketches of the buildings and positions of the seismographs installed are shown in Figs. 1 and 2.

Four recording drums of the seismographs were started automatically

1) K. KANAI and T. SUZUKI, "Relation between the Property of Building Vibration and the Nature of Ground", *Bull. Earthq. Res. Inst.*, **31** (1953), 305: Part II, *ditto*, **33** (1955), 109: Part III, *ditto*, **34** (1956), 61.

2) K. KANAI, T. TANAKA and T. SUZUKI, "Rocking and Elastic Vibrations of Actual Building. I", *ditto*, **36** (1958), 183

at the same time by means of a starter. The starter has a horizontal component pendulum with a period of 0.3 sec, which starts when

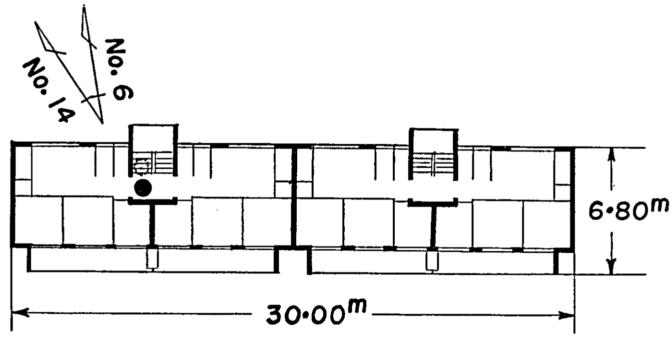

Fig. 1a. Sketch of the plane view.

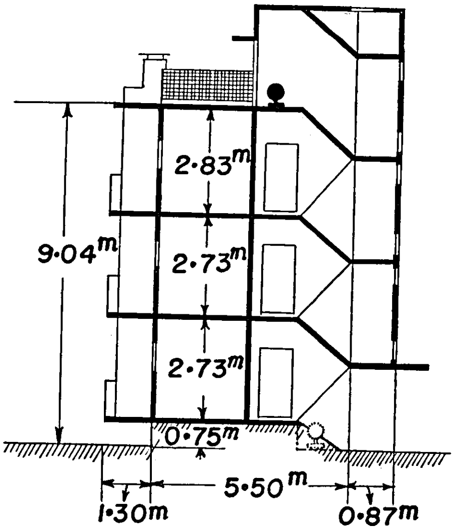

Fig. 1b. Sketch of the side view.

earthquakes were greater than 0.5 gals in acceleration, that is, twice the amplitude of usual micro-tremor, and stops automatically after a three-minute running record.[3] The driving speed of recording papers was 1.05 cm/sec. The period of observations of earthquake motion was about one year, from February, 1956 to March, 1957.

The number of earthquakes, recorded during the period was 110, among which 43 earthquakes were recorded satisfactorily. All the records of earthquakes treated here had been started before the main shocks began. The position of the origins of those earthquakes and the observation position are shown in Table 5.

Fig. 3, illustrates the epicenters of earthquakes treated here.

3. Results of observations

The representative seismograms observed simultaneously at those

3) T. TANAKA and K. KANAI, "A New Starter for Observations of Earthquakes", *Monthly Meeting of the Earthq. Res. Inst.*, (Dec. 1955).

Table 1. Constants of seismographs.

No. of seismograph	Natural period (sec)	Damping ratio	Magnification	Position	Direction
1	1.0	13	200	No. 6 roof	beam
2	〃	〃	210	No. 6 ground	〃
3	〃	〃	190	No. 14 roof	〃
4	〃	〃	180	No. 14 ground	〃

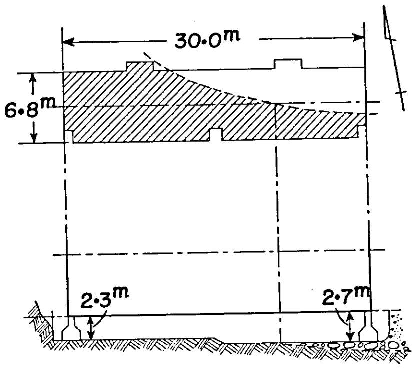

Fig. 2a. Foundation parts of No. 6 house.

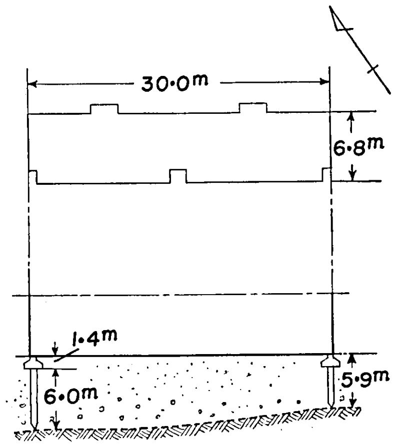

Fig. 2b. Foundation parts of No. 14 house.

positions are illustrated in Fig. 4.

As the constants of every seismograph were almost equal, we are able to know easily the difference of earthquake motions at those positions by merely looking at Fig. 4. That is to say, from Fig. 4, the amplitudes on the ground-floor of No. 6 house standing on the rock are smaller than those of No. 14 house standing on the crushed stone. On the other hand, the amplitude ratios of the roof-floor to the ground-floor of No. 6 house are larger than those of No. 14 house. The precise discussions will appear in the successive paragraphs.

(i) Period characteristics of earthquake-motion

Table 6 gives the values of the maximum amplitude of buildings observed at the roof-floor, the amplitudes and the periods at the ground-floor in the time when the amplitude of roof-floor became maximum and the amplitude ratios of the roof-floor to the ground-floor mentioned above,

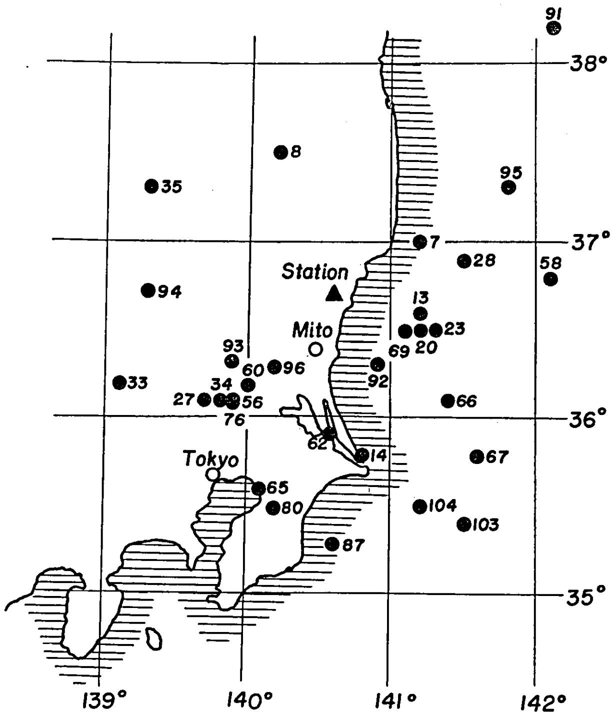

Fig. 3. Epicenters of earthquakes.

for each earthquake. Figs. 5 and 6 represent the relation between the period and the amplitude ratio mentioned above for No. 6 house and No. 14 house respectively. In these figures the vertical stripes indicate the natural period of the buildings. It will be seen from Fig. 5 that the period of the earthquake-motion at the ground on which No. 6 house stands is 0.1 sec when the ratio of amplitude of the roof-floor to that of the ground-floor becomes maximum. The maximum value of the ratio is about 9.5. On the other hand, from Fig. 6 it is found that this ratio for No. 14 house becomes maximum at the period of 0.2 sec and the value is 4.5.

Figs. 5 and 6 tell us that the magnification of amplitude in building at the time of earthquakes is maximum when the period of the earthquake motion at the ground nearly corresponds to the natural period of the building. It seems that the principal cause that the amplitude ratio of roof-floor to ground-floor varies even when the period of the ground vibration is the same is correlated to the succession number of the earthquake-motion of the same period.[4]

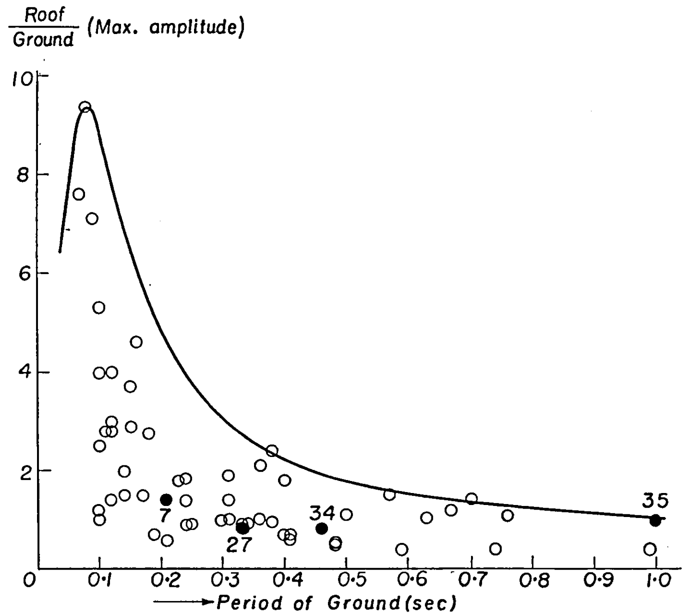

Fig. 5. Relation between the ratios of maximum amplitude of roof-floor to ground-floor of No. 6 house and the periods of ground vibration, for each earthquake.

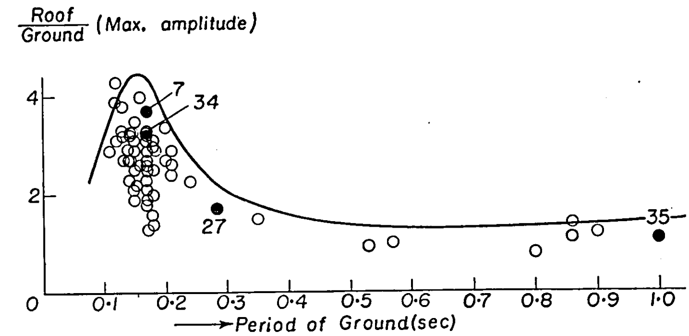

Fig. 6. Relation between the ratios of maximum amplitude of roof-floor to ground-floor of No. 14 house and the periods of ground vibration, for each earthquake.

4) K. KANAI, K. OSADA and S. YOSHIZAWA, "Observational Study of Earthquake Motion in the Depth of the Ground. IV", *Bull. Earthq. Res. Inst.*, **31** (1953), 233, Fig. 12.

Figs. 7 and 8 show the amplitude ratios of the roof-floor to the ground-floor concerning each wave of No. 35 earthquake at No. 6 house and No. 14 house, respectively. It will be seen that the envelope of Fig. 5 is considerably similar to that of Fig. 7 and that of Fig. 6 to that of Fig. 8.

(ii) Spectral analysis

The displacement spectra of the earthquake-motions of Nos. 7, 27, 34 and 35 at the roof-floor as well as the ground-floor in No. 6 house and No. 14 house obtained by means of the response computer[5] are shown in Figs. 22~29. The velocity and acceleration spectra have been calculated from the displacement spectra on the assumption of simple harmonic motion. These velocity and acceleration spectra are presented in Figs. 30~37 and 38~45, respectively.

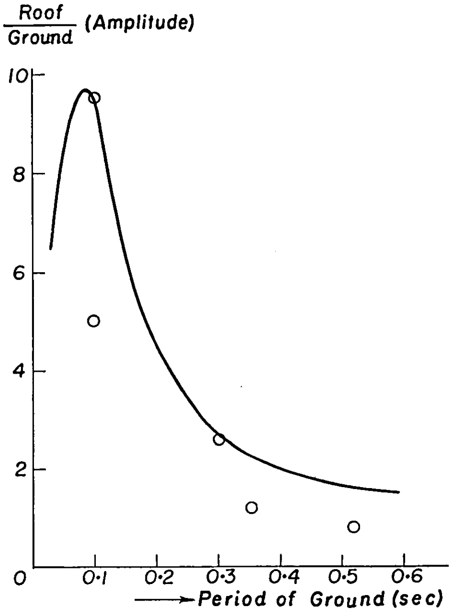

Fig. 7. Amplitude ratios of roof-floor to ground-floor for each wave of No. 35 earthquake at No. 6 house.

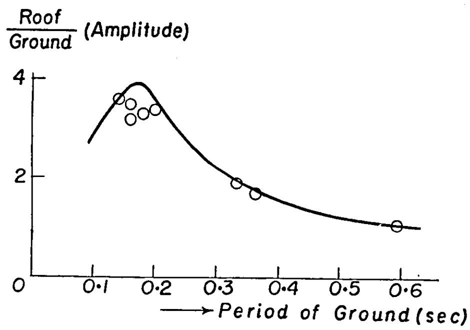

Fig. 8. Amplitude ratios of roof-floor to ground-floor for each wave of No. 35 earthquake at No. 14 house.

It will be seen from Figs. 26~28 that the amplitude at the roof-floor in the No. 14 house corresponding to the period of 0.2 sec, that is, the natural period of the house, grew considerably large. Figs. 25 and 29 show that, in the special case of No. 35 earthquake, the roof amplitude corresponding to 0.2 sec natural period of No. 14 house, appears rather modest because the amplitudes corresponding to 0.5 sec as well as 1.0 sec are extremely large.

In the case of No. 6 house, the absolute amplitude at the roof

5) R. TAKAHASI, "A Response Computer Preliminary Report", Proc. 3rd Japan National Congr. *Applied Mech.*, (1953), 373.

hardly grew large, in spite of the fact that the roof amplitude corresponding to 0.1 sec of the natural period of the house was magnified considerably. This is because the absolute amplitude of the period mentioned above at the ground on which the house stands was very small.

Figs. 22∼25 tell us it is not only in the earthquake motion on fresh rock that the vibration of short period predominates.

The values of the periods corresponding to the maximum amplitudes at the roof in the spectral analysis as well as in the original records

Table 2. The periods (in sec.) corresponding to the vibrations when the amplitudes of the roof-floor became largest.

No. of earthquake	No. 6 house		No. 14 house	
	(*A*)	(*B*)	(*A'*)	(*B'*)
7	0.1, 0.21	0.12, 0.21	0.18	0.17
27	0.35	0.33	0.19, 0.39	0.28
34	0.14, 0.55	0.46	0.18	0.16
35	0.52, 1.0	1.0	0.55, 1.1	1.0

(*A*) and (*A'*) represent the periods corresponding to the maximum amplitudes at the roof-floor in the results of the spectral analysis. (See Figs. 22∼29.)

(*B*) and (*B'*) represent the periods corresponding to the maximum amplitudes at the roof-floor in the original records.

are shown in Table 2. It will be seen from Table 2 that the periods, when the roof amplitude in the original records is maximum coincide mostly with the periods corresponding to the maximum value of spectrum.

And, in the case of No. 14 house, the periods mentioned above generally correspond to the natural period of the house. On the other hand, in the case of No. 6 house, the periods mentioned above scarecely coincide with the natural period of the house because the amplitudes of the earthquake motion of short period corresponding to the natural period of the house were rather small.

Figs. 9∼16 show the amplitude ratio of the roof-floor to the ground-floor in each house which were obtained from the results of spectral analysis of Figs. 22∼29.

In the case of No. 6 house, the phenomena of excitement of free oscillation of the house are clearly seen from the amplitude ratio of the roof-floor to the ground-floor shown in Figs. 9∼12, though they are not

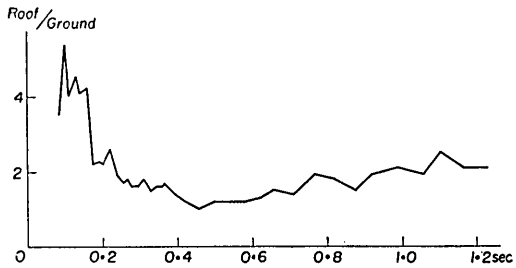

Fig. 9. Amplitude ratio of No. 7 earthquake at No. 6 house.

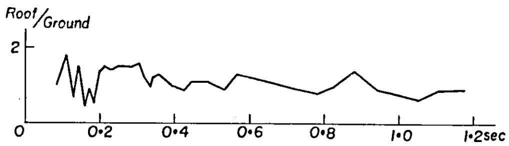

Fig. 10. Amplitude ratio of No. 27 earthquake at No. 6 house.

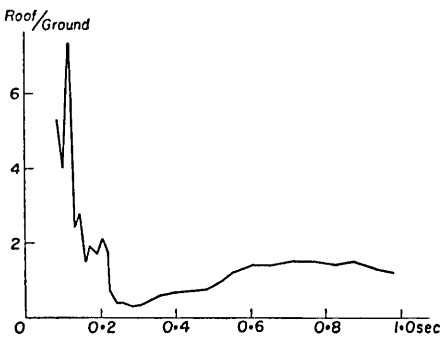

Fig. 11. Amplitude ratio of No. 34 earthquake at No. 6 house.

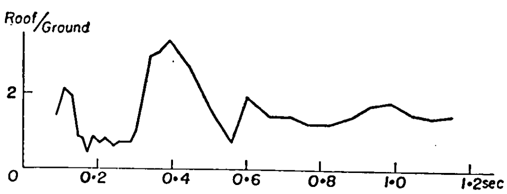

Fig. 12. Amplitude ratio of No. 35 earthquake at No. 6 house.

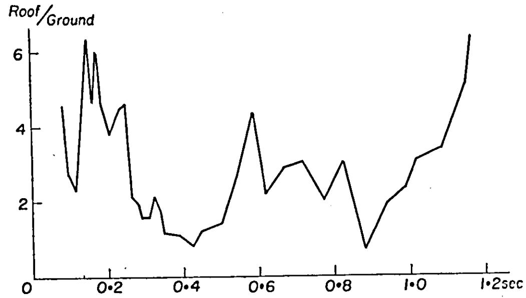

Fig. 13. Amplitude ratio of No. 7 earthquake at No. 14 house.

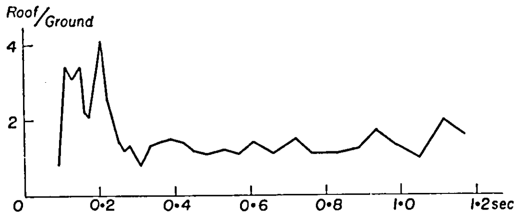

Fig. 14. Amplitude ratio of No. 27 earthquake at No. 14 house.

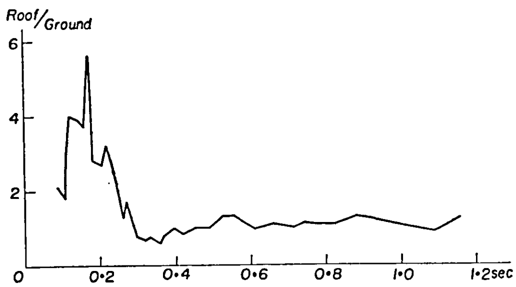

Fig. 15. Amplitude ratio of No. 34 earthquake at No. 14 house.

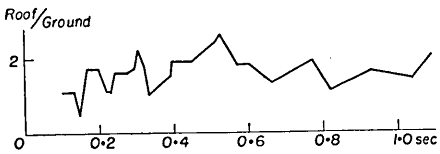

Fig. 16. Amplitude ratio of No. 35 earthquake at No. 14 house.

manifested by the results of the spectral analysis in Figs. $22\sim25$. Figs. $9\sim12$ tell us that the values of amplitude magnification at the roof exceed 7 times.

In the case of No. 14 house, the phenomena of the amplitude magnification are illustrated cleary in Figs. $13\sim16$, and from Figs. $13\sim16$ we know that the maximum values of the amplitude magnification at the roof become about 6 times larger than at the ground on which the house stands. Excepting the special cases of No. 35 earthquake in No. 6 house (see Fig. 12) and No. 7 earthquake in No. 14 house (see Fig. 13), the amplitude ratios of the roof-floor to the ground floor became nearly unity when the period of earthquake motion exceeded the natural periods of the houses.

The predominant periods of the houses obtained from the analysis of natural earthquakes as well as micro-tremor and the natural periods of them obtained from the results of the vibration experiments using vibration generator are shown in Table 3.

In Table 3, columns (F), (F') were derived from Figs. 5, 6 and columns (C) and (C') from Figs. $9\sim12$ and $13\sim16$. From Table 3, it is found that the predominant periods obtained from four kinds of examinations, that is, the observations of earthquakes and micro-tremors and the artificial vibration experiments, are nearly equal to each other. In

Table 3. Predominant periods (in sec.).

No. of earth-quake	No. 6 house				No. 14 house			
	(C)	(D)	(E)	(F)	(C')	(D')	(E')	(F')
7	0.10				0.16			
27	—	0.10	0.09	0.09	0.15, 0.20	0.18	0.18	0.16
34	0.11				0.17			
35	0.11, 0.4				—			

(C) and (C') represent the periods corresponding to the maximum ratios of roof to ground from the spectral analysis. (See Figs. $9\sim16$.)

(D) and (D') represent the resonance periods obtained from the vibration experiment. (See Figs. 7 and 17 in the previous paper.)

(E) and (E') represent the predominant periods of micro-tremors at the roof-floor. (See Figs. 9 and 18 in the previous paper.)

(F) and (F') represent the periods when the ratios of roof to ground became maximmum. (See Figs. 5, 7 and 6, 8.)

Table 4. The largest values of the amplitude ratios of the roof-floor to the ground-floor.

No. of earthquake	No. 6 house			No. 14 house		
	(*G*)	(*H*)	(*I*)	(*G′*)	(*H′*)	(*I′*)
7	5.5	—		6.5	—	
27	2.0	—	9.5	4.0	—	
34	7.5	—		5.5	—	4.5
35	3.5	9.5		2.5	4.0	

(*G*) and (*G′*) represent the maximum values of the ratio of roof to ground from the results of spectral analysis. (See Figs. 9∼16.)

(*H*) and (*H′*) represent the maximum values of the ratio of roof to ground from the original records of No. 35 earthquake. (See Figs. 7 and 8.)

(*I*) and (*I′*) represent the maximum values of the ratio of maximum amplitudes of roof to ground. (See Figs. 5 and 6.)

the other words, these facts tell us that earthquake and micro-tremor will excite considerably the free oscillation of buildings.

(iii) Vibrational damping of building

The largest values of the amplitude ratio of the roof-floor to the ground-floor obtained from Figs. 9∼16 and Figs. 5∼8 are shown in Table 4. It will be noticed that the values of column (*G*) somewhat differ from those of (*G′*) according to each earthquake while those of (*H*) and (*I*) are nearly equal to those of (*H′*) and (*I′*), respectively. This seems to be due to the disregard of the phase difference in the results in spectral analysis. The relations between the predominant periods of the ground and the values of columns (*H*), (*I*) and (*H′*), (*I′*) are shown in Fig. 17. In Fig. 17 the values except those concerning No. 6 and No. 14 houses are the results obtained in the previous paper.[6] As the present houses and the previous houses are of the same style but of different height, in Fig. 17 the reduction of the effect of height has been made for the present houses.

Next, we try to obtain the damping coefficient of No. 6 house using that of No. 14 house obtained in the previous paper.[7]

As No. 6 and No. 14 houses are the same both in the upper construction and positions of seismographs, it may be considered as the first approximation that the value of the ratio of $9.5/4.5=2.1$ in (*I*) and

6) *loc. cit.*, 1), Part III, 77, Fig. 16.
7) loc. cit., 2), 188.

(I') columns of Table 4 is inversely proportional to the value of the ratio of h of No. 14 house to the h of No. 6 house, in which h is the fraction of critical damping.

After the above consideration, we obtain the value of h of No. 6 house in the following :

$$h_6 = h_{14} \times (4.5/9.5) = 0.032 \times 0.47 = 0.015 .$$

In spite of that the value of h of No. 6 house is about half of that of No. 14 house, there appeared only a little difference between the amplitude ratios of the roof to the ground concerning No. 6 and No. 14 houses obtained after spectral analysis as seen in the columns (G) and (G') of Table 4. The facts mentioned above may be explained as follows :

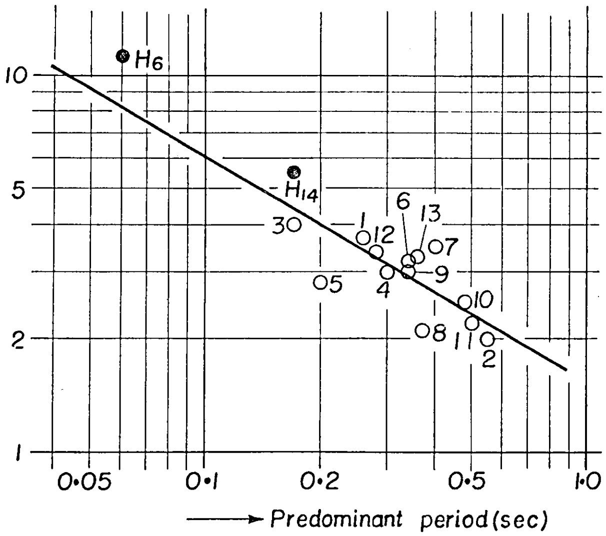

Fig. 17. Relation between the ratio of the largest amplitude of roof-floor to ground-floor and the predominant period of the ground on which the house stands.

When the succession number of waves having the same period of the natural period of a building are several, the amplitude of the building grow up nealy as large as under resonance condition. This is the case of No. 14 house. On the other hand, when the succession number of waves having the same period of the natural period of a building are only a few, the amplitude of the building varies considerably according to the succession number. As the waves of the period smaller than about 0.1 sec happen infrequently in earthquake motion, No. 6 house is the case under this condition, and the results are shown in the column (G) of Table 4 and Fig. 5.

(iv) Vibration characteristic of ground

Figs. 18∼21 give the ratios between the amplitudes at the ground-floor of No. 14 and No.6 houses obtained from Figs. 22∼29. It will be seen in Figs. 18∼21 that the ratio mentioned above takes the maximum value at the period of about 0.2 sec in general. As the amplitude ratio of the roof-floor to the ground-floor at the period of about 0.2 sec is notquite so large as shown in Figs. 9∼12 and 16, the above mentioned fact seems

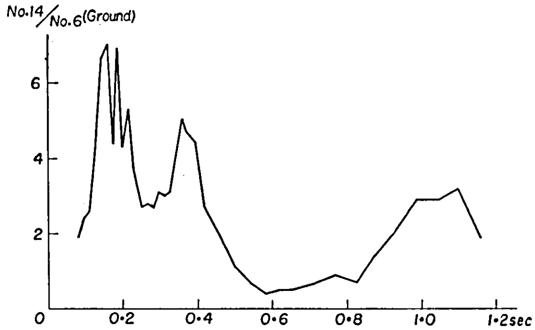

Fig. 18. Ratio between amplitudes at the ground-floor of No. 14 and No. 6 houses. Earthquake No. 7.

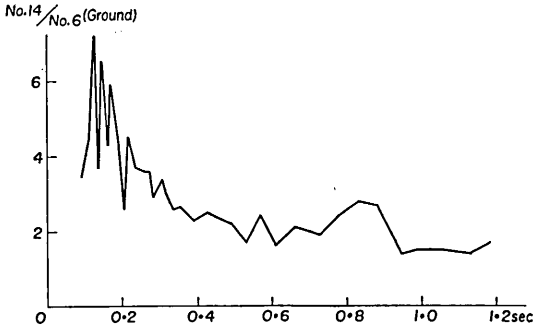

Fig. 19. Ratio between amplitudes at the ground-floor of No. 14 and No. 6 houses. Earthquake No. 27.

to have no relation to the natural period of the houses. It is natural that the period of about 0.2 sec is considered the natural period of the ground on which No. 14 house stands. In the case of No. 14 house, it may be considered that the natural periods of the house and the ground

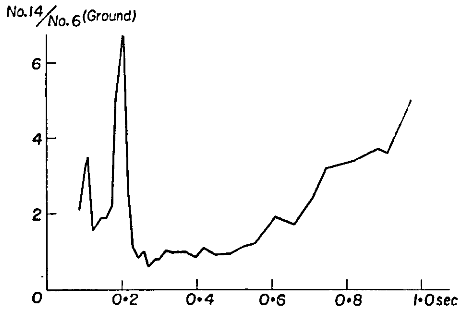

Fig. 20. Ratio between amplitudes at the ground-floor of No. 14 and No. 6 house Earthquake No. 34.

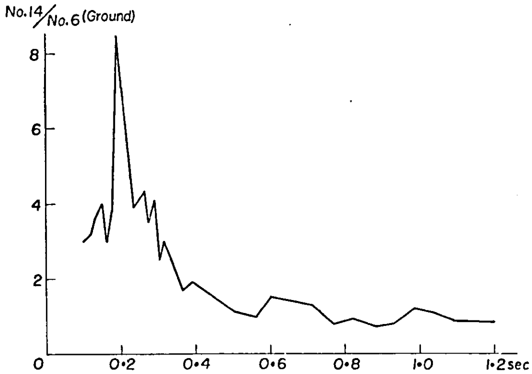

Fig. 21. Ratio between amplitudes at the ground-floor of No. 14 and No. 6 house. Earthquake No. 35.

on which the house stands are nearly equal, being about 0.2 sec. This is presumed from the fact that the amplitudes of the ground are largest at about 0.2 sec as seen in Figs. 26～29, and the amplitude ratios of the roof to the ground take the largest value at about 0.2 sec as shown in Figs. 13～16.

On the other hand, in the case of No. 6 house, the amplitude ratio of the roof to the ground is the largest at about 0.1 sec as shown in Figs. 9～12, and the amplitude of the ground itself is not so large at about 0.1 sec as shown in Figs. 22～25. Roughly speaking, the amplitude at the ground takes a large value at 0.4～0.6 sec, and this feature may be considered to be the vibration characteristics of the ground itself.[8]

Let A, ρ and v be the maximum amplitudes, density and velocity

8) K. KANAI, Monthly Meeting, Earthq. Res. Inst., (May, 1958).

of *S*-waves at the ground on which the houses stand and suffixes 6 and 14 represent the house numbers.

Considering $A_{14}/A_6=\rho_6 V_6/\rho_{14} V_{14}(\equiv 7)$ and assuming $\rho_6=\rho_{14}$ as well as adopting the equation $v_{14}=4\times 6.6/0.2=132\ m/s$ (thickness $=6.6$ m, period $=0.2$ sec), we obtain $v_6(\equiv$ base rock$)=132\times 7=924\ m/s$.[9)]

4. Conclusion

The results of the comparative observation of earthquakes made at reinforced concrete buildings standing on rock and on crushed stone, proved the following quite evidently.

(1) In general, the vibration amplitude of a building at the time of an earthquake must be considered under the resonance-like condition, that is to say, the vibration amplitude at the top of building is several times as large as that at the ground.

(2) In the special cases when the natural period of building is much smaller than the predominant period of the ground, the effect of the excitement of the free oscillation of the building seems to be negligibly small.

(3) The buildings standing directly on rock as well as on crushed stone with 2 or 3m piles make a rocking oscillation, relative horizontal movement against the ground at the basement together with elastic deformation of the members at the time of earthquake.

(4) The smaller the rigidity of the subsoil with which the foundation is surrounded, the larger the damping of the building vibration in case of an earthquake.

(5) Concerning only the vibration problem of building in case of an earthquake we come again to the conclusion that the best condition for buildings is for hard ground to extend considerably around a building and soft soil of a limited area to surround the foundation. (For reference the velocity and acceleration spectra are shown in Figs. 30～37 and 38～45, respectively.)

In conclusion, we wish to express our thanks to the Science Section of the Educational Ministry, for the financial aid granted us. Also thanks are due to the members of Motoyama-office, Hitachi Mine and Prof. R. Takahasi and Mr. I. Aida, for their cooperation in tho course of these investigations and to Mr. K. Osada and Miss S. Yoshizawa for the valuable assistance they offered in these investigations.

9) K. KANAI, "The Result of Observation of Wave Velocity in the Ground", *Bull. Earthq. Res. Inst.*, **29** (1951), 503.

Table 5. The origins of earthquakes and the locations of seismographs.

No. of earthquake	Time of occurrence	Origin			No. 6 house		No. 14 house	
		°*N*	°*E*	*D* (in km)	roof	ground	roof	ground
1	1956 II				○	○	○	○
2	〃 〃 27				○	○	○	○
3	〃 III				○	○	○	○
4	〃 〃				—	—	○	○
5	〃 III 30				○	○	○	○
6	〃 IV 1				—	—	○	○
7	〃 〃 2	37.0	141.2	40～50	○	○	○	○
8	〃 〃 12	37.5	140.2	very shallow	—	—	○	○
9	〃 〃 12				—	—	○	○
13	〃 〃 25	36.6	141.2	about 40	○	○	○	○
14	〃 〃 26	35.8	140.8	about 30	○	○	○	○
15	〃 〃				—	—	○	○
17	〃 IV 29				○	○	○	○
18	〃 V				○	○	○	○
20	〃 〃 15	36.5	141.2	about 30	○	○	×	—
22	〃 〃 17				○	○	—	—
23	〃 〃 18	36.5	141.3	about 40	○	○	×	○
24	〃 〃				—	—	○	○
25	〃 〃				○	○	○	○
26	〃 〃				—	—	○	○
27	〃 VI 6	36.1	139.7	about 90	○	○	○	○
28	〃 〃 10	39.9	141.5	40～50	○	○	○	○

(to be continued.)

(Table 5. continued.)

No. of earth-quake	Time of occurrence	Origin			No. 6 house		No. 14 house	
		°*N*	°*E*	*D* (in km)	roof	ground	roof	ground
29	1956 VI 18				—	—	○	○
30	〃 〃				—	—	○	○
32	〃 〃 23				—	—	○	○
33	〃 〃 26	36.2	139.1	about 160	○	○	○	○
34	〃 〃 26	36.1	139.8	about 60	○	○	○	○
35	〃 〃 29	37.3	139.3	about 20	○	○	○	○
36	〃 VII				—	—	○	○
37	〃 〃				○	○	○	○
38	〃 〃				○	○	○	○
39	〃 〃				○	○	○	○
40	〃 〃				—	○	○	○
41	〃 〃				○	—	○	○
42	〃 〃				○	○	○	○
43	〃 〃				○	○	○	○
44	〃 〃				○	○	○	○
45	〃 〃				○	○	○	○
46	〃 〃				—	○	○	○
47	〃 〃				○	—	○	○
48	〃 〃				○	—	○	○
49	〃 〃				○	○	○	○
50	〃 〃				—	—	○	○
51	〃 〃				○	○	○	○
52	〃 〃				○	—	○	○
53	〃 〃				○	○	○	○

(to be continued.)

(Table 5. continued.)

No. of earth-quake	Time of occurrence	Origin °N	Origin °E	Origin D (in km)	No. 6 house roof	No. 6 house ground	No. 14 house roof	No. 14 house ground
54	1956 VII				○	○	○	○
55	〃 〃 28				○	○	—	—
56	〃 〃 30	36.1	139.9	about 50	○	○	—	○
57	〃 〃				○	○	○	○
58	〃 VIII 2	36.8	142.1	40	○	○	○	○
59	〃 〃				—	—	○	○
60	〃 〃 8	36.2	140.0	60～70	—	○	○	○
61	1956 VIII				—	—	○	○
62	〃 〃	35.9	140.6	about 40	○	○	○	○
63	〃 〃 15				○	—	○	○
65	〃 〃 16	35.6	140.1	about 70	○	○	○	○
66	〃 〃 20	36.1	141.4	20～30	○	○	○	○
67	〃 〃 24	35.8	141.6	about 60	○	○	○	○
68	〃 〃				—	—	○	○
69	〃 〃 30	36.5	141.1	about 60	○	○	○	○
70	〃 IX				○	—	○	○
71	〃 〃				○	○	○	○
72	〃 〃				○	○	○	○
73	〃 〃				—	—	○	○
74	〃 〃				○	—	○	○
75	〃 〃 24				○	—	○	○
76	〃 〃 24	36.1	139.9	about 70	○	—	○	○
77	〃 〃				○	—	○	○
78	〃 〃 26				○	○	○	○
80	〃 X 8	35.5	140.2	about 80	○	—	○	○

(to be continued.)

(Table 5. continued.)

No. of earth-quake	Time of occurrence	Origin			No. 6 house		No. 14 house	
		°N	°E	D (in km)	roof	ground	roof	ground
81	1956 X 11	44.5	150.5	about 100	○	○	○	○
85	〃 〃 17	36.8	142.3	about 40	○	○	○	○
87	〃 〃 14	35.3	140.6	about 40	—	○	○	○
88	〃 XI 16	36.8	140.7	about 100	—	○	○	○
89	〃 〃 〃				—	○	○	○
90	〃 〃 17				—	○	○	○
91	〃 〃 21	38.3	142.1	about 70	—	○	○	○
92	〃 〃 26	36.3	140.9	about 40	○	○	×	○
93	〃 XII 7	36.3	139.9	60	○	○	×	○
94	〃 〃 10	36.7	139.3	20	○	○	○	○
95	〃 〃 13	37.3	141.8	about 40	○	○	—	○
96	〃 〃 14	36.3	140.2	about 50	○	○	○	○
98	〃 〃 22	33.8	139.6	about 20	○	○	○	○
100	〃 〃 26	36.3	141.0	shallow	○	○	○	○
103	〃 〃 9	35.4	141.5	about 40	○	○	○	○
104	〃 〃 17	35.5	141.2	about 10	○	○	×	○
105	〃 〃 19				○	○	—	○
106	〃 〃 20				○	○	—	○
107	〃 〃 21	37.1	141.0	about 70	○	○	—	○
108	〃 〃 〃	36.6	141.0	about 50	○	○	—	○
109	〃 〃 24				○	○	○	○
110	〃 〃 〃				○	○	○	○

Table 6. The values of the amplitudes (in micron) and the periods (sec) of the largest vibrations.

No. of earthquake	No. 6 house				No. 14 house			
	amplitude		period	roof/ground	amplitude		period	roof/ground
	roof	ground	ground		roof	ground	ground	
1	5.5	6.0	0.33	0.9	22	9	0.21	2.5
2	25	2.6	0.08	9.4	45	16	0.13	2.7
3	6.0	5.5	0.76	1.1	13	16	0.80	0.8
4	—	—	—	—	8.2	3.9	0.18	2.1
5	12	1.6	0.07	7.6	32	11	0.21	2.9
6	—	—	—	—	20	8.9	0.18	2.2
7	9.8	7.0	0.21	1.4	48	13	0.17	3.7
8	—	—	—	—	40	13	0.18	3.1
9	—	—	—	—	22	7	0.14	3.1
13	14	12	0.41	1.2	55	22	0.18	2.5
14	21	20	0.64	1.1	60	19	0.15	3.1
15	—	—	—	—	12	3.1	0.14	3.9
17	7.5	1.1	0.09	7.1	18	4.6	0.13	3.8
18	4.8	1.2	0.10	4.0	12	5.3	0.24	2.2
20	11	13	0.30	1.0	—	—	—	—
22	13	3.1	0.15	3.7	—	—	—	—
23	110	63	0.23	1.8	—	167	0.25	—
24	—	—	—	—	31	13	0.17	2.7
25	7.5	7.0	0.50	1.1	6.5	7.0	0.53	0.9
26	—	—	—	—	13	4.4	0.15	2.9
27	19	22	0.33	0.9	71	42	0.29	1.7
28	6.5	4.8	0.31	1.4	19	5.5	0.20	3.4
29	—	—	—	—	20	6.0	0.17	3.3
30	—	—	—	—	13	3.1	0.12	4.3
32	—	—	—	—	27	9.0	0.16	3.0
33	8.0	3.8	0.36	2.1	23	8.0	0.14	2.9
34	9.0	11	0.46	0.8	25	8.0	0.16	3.2
35	38	40	1.0	1.0	50	45	1.0	1.1
36	—	—	—	—	42	14	0.18	3.1
37	11	1.9	0.21	5.8	34	11	0.18	3.1
38	2.3	3.1	0.19	0.7	13	5.0	0.17	2.5
39	1.0	0.7	0.17	1.5	4.2	1.4	0.18	3.0
40	—	8.3	0.39	—	26	18	0.18	1.4
41	1.0	—	—	—	3.2	1.4	0.17	2.3

(to be continued.)

(Table 6. continued.)

No. of earthquake	No. 6 house				No. 14 house			
	amplitude		period	roof/ground	amplitude		period	roof/ground
	roof	ground	ground		roof	ground	ground	
42	1.0	0.7	0.14	1.5	8.7	3.3	0.14	2.6
43	3.4	2.4	0.12	1.4	22	8.6	0.17	2.5
44	4.3	2.1	0.14	2.0	13	4.5	0.14	2.9
45	2.0	0.7	0.11	2.8	5.3	2.8	0.15	1.9
46	—	2.6	0.11	—	22	10	0.15	2.2
47	0.5	—	—	—	4.7	1.9	0.17	2.5
48	0.3	—	—	—	2.6	1.4	0.17	1.9
49	2.5	2.1	0.10	1.2	30	9.2	0.17	3.3
50	—	—	—	—	12	3.3	0.15	3.5
51	2.0	1.4	0.12	1.4	10	4.7	0.17	2.2
52	7.5	—	—	—	16	5.0	0.16	3.2
53	2.0	0.5	0.12	4.0	6.6	3.1	0.18	2.1
54	120	26	0.17	4.6	—	42	0.18	—
55	5.0	1.0	0.10	5.3	—	—	—	—
56	23	8.1	0.12	2.8	—	27	0.17	—
57	11	11	0.10	1.0	14	11	0.17	1.3
58	4.8	1.9	0.10	2.5	7.6	3.1	0.17	2.5
59	—	—	—	—	12	3.1	0.16	4.0
60	—	1.7	0.18	—	22	9.2	0.18	2.4
61	—	—	—	—	7.9	2.5	0.13	3.2
62	9.0	4.8	0.31	1.9	28	11	0.17	2.7
63	3.4	—	—	—	14	4.7	0.11	2.9
65	4.0	1.4	0.15	2.9	30	11	0.17	2.7
66	1.5	2.6	0.21	0.6	18	8.9	0.18	2.0
67	5.5	2.9	0.24	1.9	11	6.4	0.18	1.6
68	—	—	—	—	2.4	0.8	0.17	2.9
69	2.3	1.7	0.24	1.4	5.3	1.9	0.14	2.7
70	0.5	—	—	—	5.0	1.9	0.17	2.6
71	2.8	1.0	0.12	3.0	27	9.7	0.17	2.8
72	3.0	1.2	0.18	2.5	16	4.7	0.13	3.4
73	—	—	—	—	9.2	3.6	0.13	2.6
74	5.0	—	—	—	28	9.4	0.16	2.9
75	3.5	—	—	—	3.4	1.9	0.17	1.8
76	2.3	—	—	—	3.5	2.5	0.18	1.4
77	0.5	—	—	—	2.6	0.8	0.15	3.1

(to be continued.)

(Table 6. continued.)

No. of earthquake	No. 6 house				No. 14 house			
	amplitude		period	roof / ground	amplitude		period	roof / ground
	roof	ground	ground		roof	ground	ground	
78	—	—	—	—	30	12	0.17	2.5
80	8.3	—	—	—	57	21	0.20	2.7
81	11	4.5	0.38	2.4	22	22	0.57	1.0
85	6.5	8.3	0.33	0.8	18	8.6	0.15	2.1
87	—	9.8	0.47	—	26	11	0.21	2.4
88	—	7.1	0.24	—	27	10	0.14	2.7
89	—	5.7	0.38	—	20	6.1	0.14	3.2
90	—	8.6	0.31	—	24	7.5	0.14	3.2
91	—	27	1.04	—	33	24	0.86	1.4
92	33	77	0.74	0.4	—	33	0.46	—
93	24	27	0.34	0.9	—	31	0.19	—
94	4.5	5.2	0.25	0.9	32	11	0.18	2.9
95	5.0	11	0.48	0.5	—	11	0.17	—
96	5.5	11	0.48	0.5	14	9.2	0.35	1.5
98	8.5	5.7	0.57	1.5	6.6	5.3	0.90	1.2
100	3.8	4.0	0.36	1.0	23	7.2	0.12	3.1
103	21	15	0.70	1.4	22	20	0.86	1.1
104	22	37	0.41	0.6	—	27	0.17	—
105	56	30	0.40	1.8	—	22	0.34	—
106	30	26	0.67	1.2	—	16	0.13	—
107	7.5	7.6	0.40	1.0	—	19	0.16	—
108	9.0	13	0.40	0.7	—	14	0.54	—
109	2.5	2.4	0.31	1.0	9.5	3.6	0.16	2.6
110	3.0	3.3	0.24	0.9	18	6.9	0.15	2.5

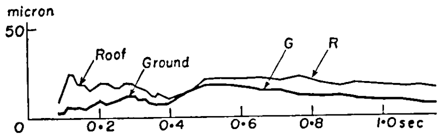

Fig. 22. Displacement spectra of No. 7 earthquake at No. 6 house.

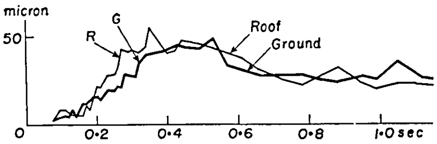

Fig. 23. Displacement spectra of No. 27 earthquake at No. 6 house.

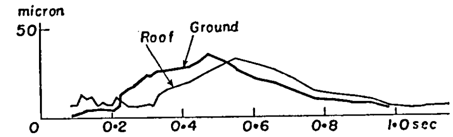

Fig. 24. Displacement spectra of No. 34 earthquake at No. 6 house.

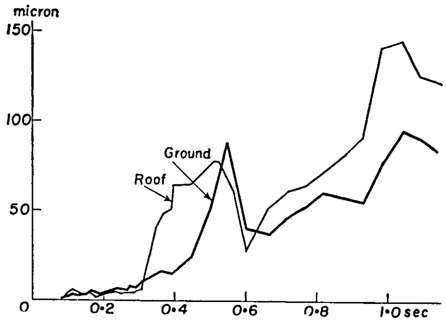

Fig. 25. Displacement spectra of No. 35 earthquake at No. 6 house.

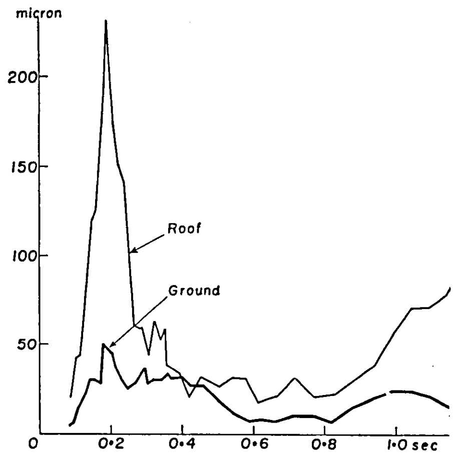

Fig. 26. Displacement spectra of No. 7 earthquake at No. 14 house.

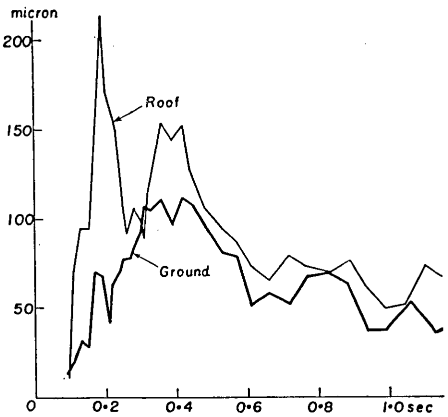

Fig. 27. Displacement spectra of No. 27 earthquake at No. 14 house.

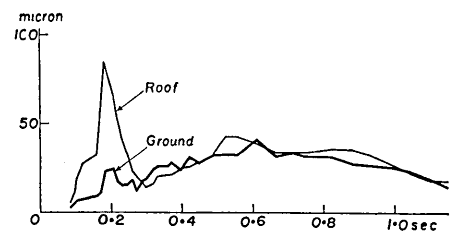

Fig. 28. Displacement spectra of No. 34 earthquake at No. 14 house.

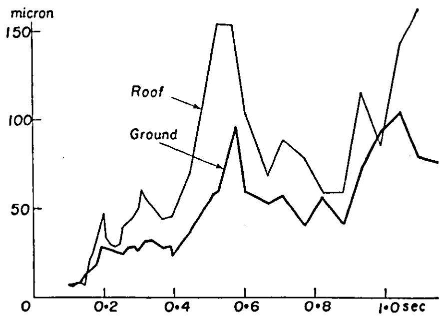

Fig. 29. Displacement spectra of No. 35. earthquake at No. 14 house.

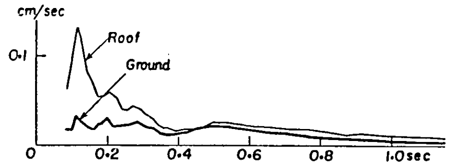

Fig. 30. Velocity spectra of No. 7 earthquake at No. 6 house.

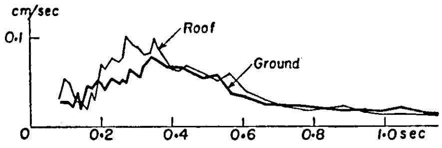

Fig. 31. Velocity spectra of No. 27 earthquake at No.6 house.

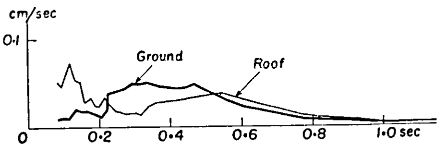

Fig. 32. Velocity spectra of No. 34 earthquake at No. 6 house.

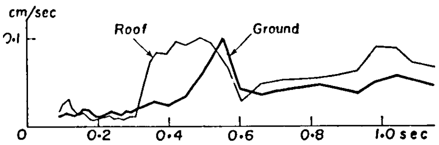

Fig. 33. Velocity spectra of No. 35 earthquake at No. 6 house.

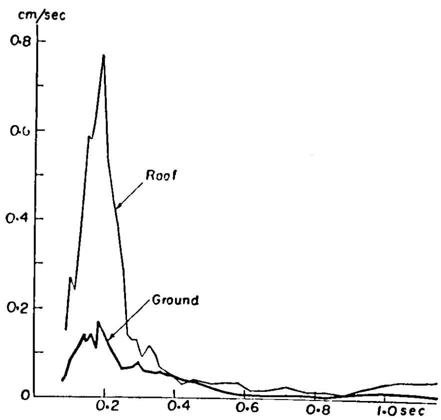

Fig. 34. Velocity spectra of No. 7 earthquake at No. 14 house.

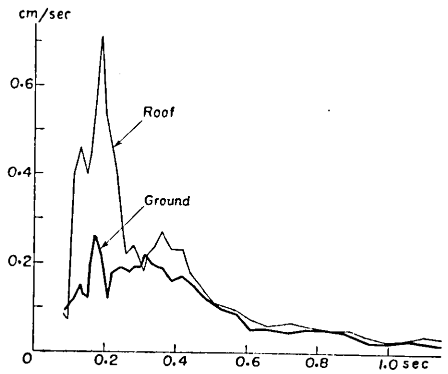

Fig. 35. Velocity spectra of No. 27 earthquake at No. 14 house.

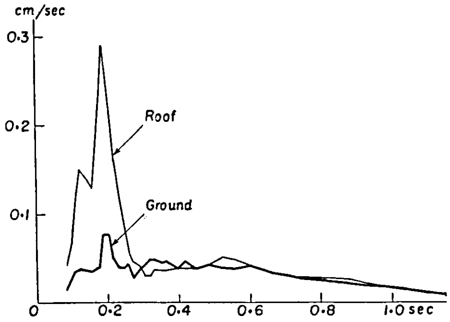

Fig. 36. Velocity spectra of No. 34 earthquake at No. 14 house.

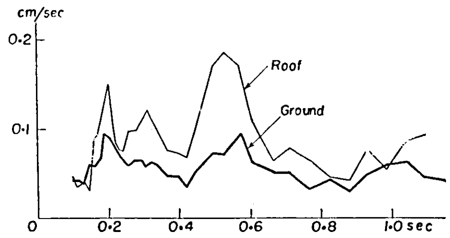

Fig. 37. Velocity spectra of No. 35 earthquake at No. 14 house.

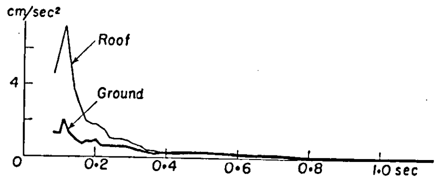

Fig. 38. Acceleration spectra of No. 7 earthquake at No. 6 house.

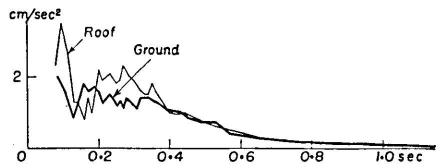

Fig. 39. Acceleration spectra of No. 27 earthquake at No. 6 house.

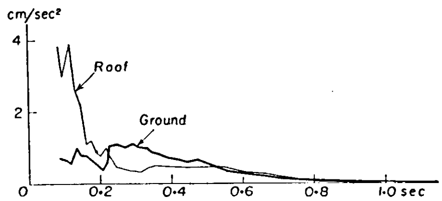

Fig. 40. Acceleration spectra of No. 34 earthquake at No. 6 house.

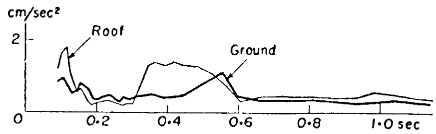

Fig. 41. Acceleration spectra of No. 35 earthquake at No. 6 house.

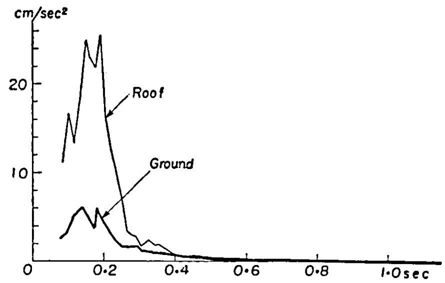

Fig. 42. Acceleration spectra of No. 7 earthquake at No. 14 house.

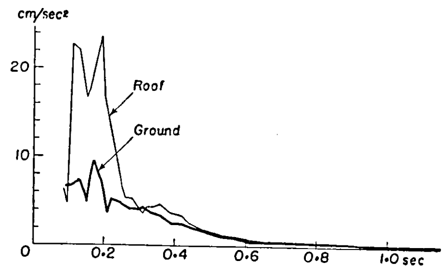

Fig. 43. Acceleration spectra of No. 27 earthquake at No. 14 house.

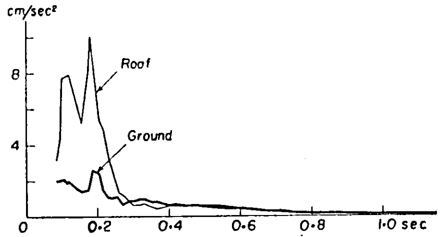

Fig. 44. Acceleration spectra of No. 34 earthquake at No. 14 house.

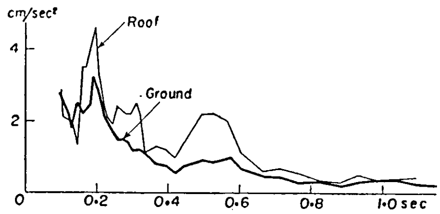

Fig. 45. Acceleration spectra of No. 35 earthquake at No. 14 house.

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11. 建物の動揺，弾性振動 第2報(地震観測)

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茨城県日立鉱山の岩盤上，砕石上に建つ2棟の3階建鉄筋コンクリート造アパートについての起振機による振動実験の結果は，第1報で報告した．本研究は，それらの建物の屋上並びに地階で地震観測を行つたものである．100個に余る地震について，いろいろな方法で解析を行つた結果，次の事柄がわかつた．

(i) 一般に，地震時の建物振動では，自己振動が誘発されやすく，上部では土地の振幅の数倍になる．

(ii) 建物の振動増巾度は地盤が硬い程大きい．言い換えると，地震時の建物の振動減衰性は地盤が硬い程小さい．

(iii) 地震動の卓越震動周期と建物の固有周期とが非常に離れている場合でも，建物の自己振動は誘発されるが，耐震的に問題にするほどにはならない．

(iv) 要するに，建物に対して最も不利な地震動は，大振巾の地動周期が建物の固有周期に近い場合である．

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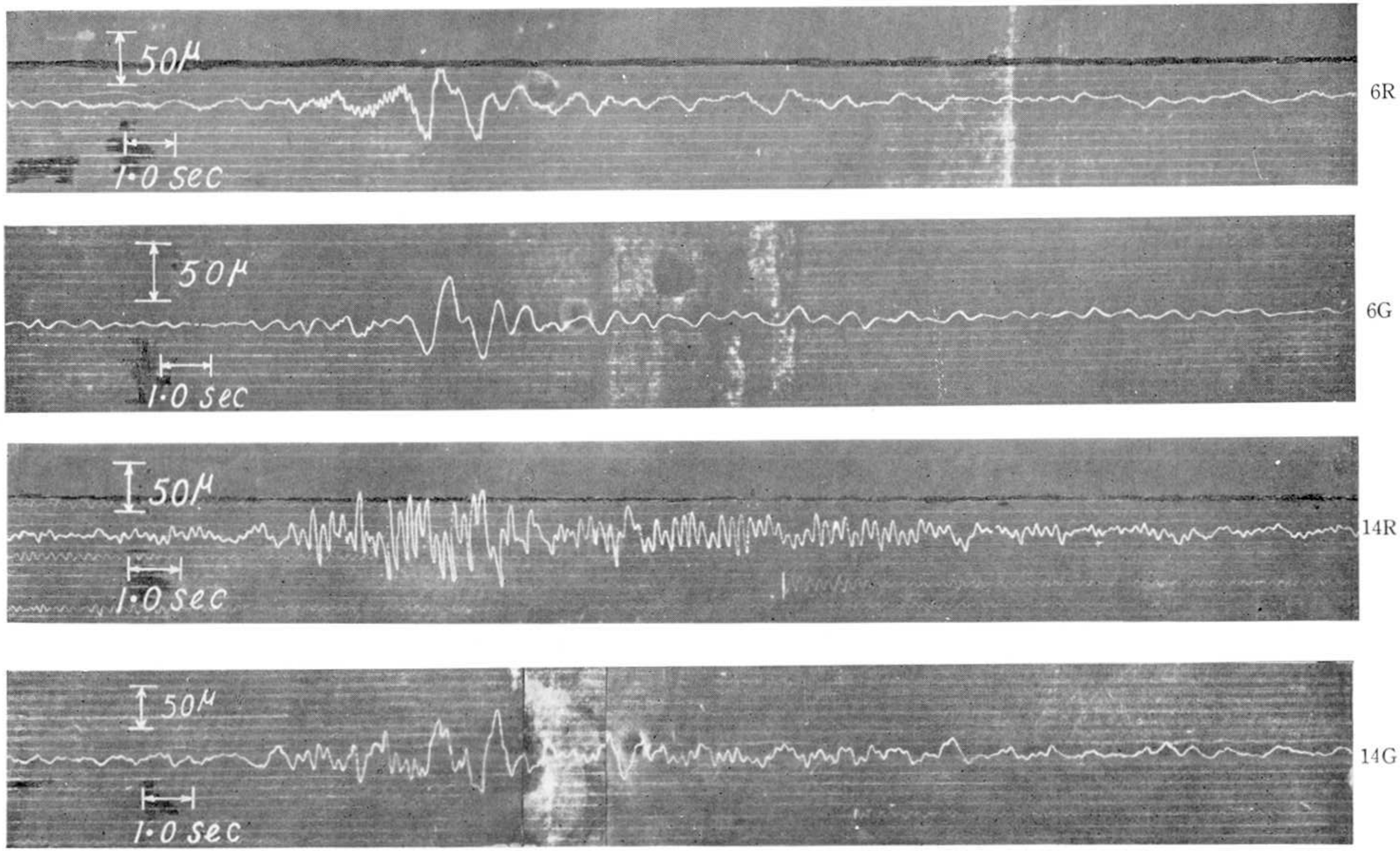

Fig. 4. Representative seismograms.

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