6. *Relation between the Property of Building Vibration and the Nature of the Ground. (Observation of Earthquake Motion at Actual Buildings.) III.*

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1. Introduction

The property of building vibration has a variety according to the subsoil property even if the same vibrational force acts on buildings of the same construction, and the property of earthquake motion depends on the nature of the ground. Therefore it can be said that buildings in an earthquake are doubly influenced by the nature of the ground.

On one hand the influence of the nature of the ground on building vibration is made clear by giving forced vibration artificially to the building through a vibrator[1] or other means, and on the other hand the property of earthquake motion itself is observed on the ground of various natures[2]. Then these results may be combined so as to make it possible to presume the vibration of actual buildings caused by an earthquake.

In this investigation, besides such an indirect method of study which can be applied generally, a direct method, that is a simultaneous observation by installing seismographs both at the basement and the roof-floor of a total of thirteen buildings of the same construction standing

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[1] K. KANAI, T. HISADA, K. NAKAGAWA and T. SUZUKI, *Res. Report, Architect. Inst., Japan*, No. 24 (1953), 185 (in Japanese).
K. KANAI and K. NAKAGAWA, "Investigation of Fire-damaged Buildings occupied by the Allied Forces in Tokyo", (1949-1950).
T. NAITO and N. NASU, *Memo. Facul. Scie. Eng., Waseda Univ.*, **16** (1952), 54-61.

[2] M. ISHIMOTO, *Bull. Earthq. Res., Inst.*, **13** (1935), 592-607.
T. MINAKAMI, *Report Fukui Earthq, Commit.* (1950), 79-92.
T. MINAKAMI and S. SAKUMA, *Bull. Earthq. Res. Inst.*, **26** (1948), 61-66.
Subsoil Research Team, Earthq. Res. Inst., *Bull. Earthq. Res. Inst.*, **33** (1955), 471-545 (in Japanese).

on the ground of different properties was tried.

The present paper is intended to get the standard of estimation of the value of earthquake force, which has to be taken into consideration in calculation of earthquake-proof construction.

2. The method of earthquake observation

The observations were made in the four-storied apartment-houses of reinforced concrete called "Tokyo Metropolis Residential Association 46-type". Figs. 1 and 2 show the rough sketch and the photograph of such a building.

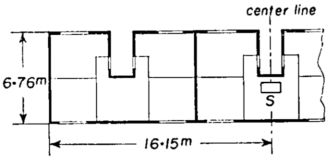

Fig. 1a. Plan view of the building of called 46-type.

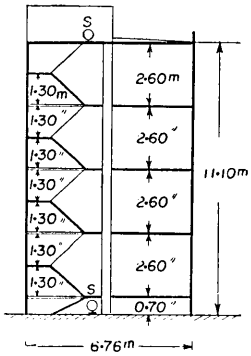

Fig. 1b. Side view of the building of called 46-type.

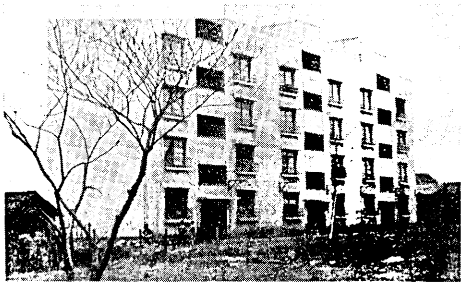

Fig. 2. Building of type 46.

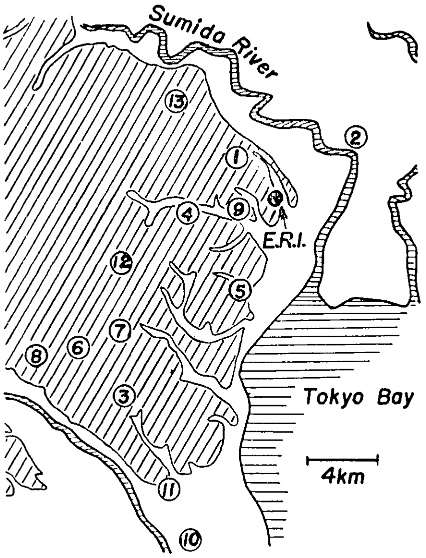

Fig. 3. The positions of the buildings.

The positions of the buildings are shown in Fig. 3 and Table I. In Table I, the natural periods of buildings 1–8 were obtained from the results of vibration experiments which were tried by means of a vibrator and those of buildings 9–13 were obtained from the results of analysis of building vibration caused by micro-tremor.[3]

Table I.

No.	Name	Position	Natural Period (sec)
1	Komagome	Komagome, Toshima-ku	0.32
2	Senju-hashido	Senju-hashido-chō, Adachi-ku	0.28
3	Ishikawa-chō	Ishikawa-chō, Ōta-ku	0.22
4	Totsuka	Totsuka-machi, Shinjuku-ku	0.33
5	Honmura-chō	Azabu-honmura-cho, Minato-ku	0.23
6	Gōtokuji	Setagaya, Setagaya-ku	0.32
7	Taishidō	Taishidō-machi, Setagaya-ku	0.32
8	Kyōdō	Kyōdō-machi, Setagaya-ku	0.32
9	Dairokuten-machi	Dairokuten-machi, Bunkyō-ku	0.31
10	Nakarokugō	Nakarokugo, Ōta-ku	0.30
11	Kugahara	Kugahara-machi, Ōta-ku	0.35
12	Sakae-chō	Sakae-chō, Nakano-ku	0.35
13	Maeno-chō	Shimura-maeno-chō, Itabashi-ku	0.37

The constants of seismographs used in the observation are as follows. The period of pendulum: 1.0 sec, the damping ratio: 1/13 and the magnification: 100–400.

The seismographs were installed on about the center of the basement and the roof-floor of each building as shown by S in Fig. 1 and the component of beam direction of the earthquake motion was observed.

In Table II the period and total number of earthquakes of each comparative observation time are shown. Table III illustrates the date and the position of the origin of earthquakes treated in the

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[3] It was reported at the following meetings that the values of the natural period of buildings in Table II are like the period of rocking vibration of the buildings and the period of elastic vibration of the buildings will appear as a shorter period.

K. KANAI, T. TANAKA, T. SUZUKI and K. NAKAGAWA, *Monthly Meeting of the Earthq. Res. Inst.*, (May 19, 1953).

Members of the Subsoil Research Team, the Earthq. Res. Inst., *Irregular Period Meeting of the Team*, (Nov. 30, 1954 and Dec. 14, 1954).

Table II.

Time	Building		Period	Total number of earthquakes
	No.	Name		
1	1 2	Komagome Senju-hashido	1953 I ～ 1953 II	21
2	3 4 5	Ishikawa-chō Totsuka Honmura-chō	1954 II ～ 1954 V	81
3	6 7 8	Gotokuji Taishidō Kyōdō	1954 VI ～ 1954 IX	77
4	9 10 11	Dairokuten-machi Nakarokugō Kugahara	1954 XI ～ 1955 III	61
5	12 13	Sakae-chō Maeno-chō	1955 IV ～ 1955 VII	64

Table III a. The date and position of the earthquake origin.

Earthq. No.	Date			Origin		
				φ	λ	Depth (km)
71	1954	XI	29	35.6	140.4	about 60
72	〃	XII	2	36.1	139.9	about 80
73	〃	〃	3	35.4	140.2	60
74	〃	〃	6	35.5	140.9	40
76	〃	〃	8	36.3	141.2	about 40
77	〃	〃	13	36.1	139.9	40～ 50
78	〃	〃	14	36.6	139.0	about 100
79	〃	〃	15	36.5	141.5	about 20
80	〃	〃	18	35.8	140.2	70～ 80
81	〃	〃	26	SW Part of Ibaraki-Prefect.		
82	〃	〃	30	36.0	139.3	about 60
83	1955	I	2	35.2	139.5	about 110
84	〃	〃	3	31.2	140.8	160
85	〃	〃	4	33.2	141.0	40
86	〃	〃	8	31.5	141.6	100～120
87	〃	〃	9	38.4	141.8	about 60
88	〃	〃	〃	36 ?	140 ?	70～ 80

(to be continued.)

(Table III a. continued.)

Earthq. No.	Date			Origin		
				φ	λ	Depth (km)
89	1955	I	11	34.2	141.2	20
90	〃	〃	〃	36.2	139.9	about 50
91	〃	〃	〃	Onahama		
92	〃	〃	12	Onahama		
95	〃	〃	19	36.4	140.7	about 50
96	〃	〃	21	36.0	139.9	50
97	〃	〃	22	35.4	139.4	20～ 30
98	〃	〃	〃	36.4	140.0	120～140
99	〃	〃	26	36.6	141.0	about 30
100	〃	〃	26	35.5	141.0	about 30
101	〃	〃	31	35.0	141.8	about 60
102	〃	II	2	41.9	142.6	60
103	〃	〃	8	34.3	141.0	about 40
104	〃	〃	〃	SSE off Boso Pen.		
105	〃	〃	〃	35.6	140.3	about 60
106	〃	〃	14	36.5	141.0	about 40
107	〃	〃	18	Kantō ?		
108	〃	〃	22	35.7	140.4	about 60
109	〃	〃	28	35.6	139.8	about 60
110	〃	〃	〃	33.2	138.3	about 320
111	〃	III	2	35.5	138.9	about 20
112	〃	〃	〃	35.5	138.9	abont 10
113	〃	〃	4	35.3	139.5	80～100

Table III b. The date and position of the earthquake origin.

Earthq. No.	Date			Origin		
				φ	λ	Depth (km)
114	1955	IV	9	37.2	141.7	about 40
115	〃	〃	13	35.5	141.1	about 40
116	〃	〃	15	36.3	141.2	about 40
117	〃	〃	19	S Part of Gunma-Prefect.		
118	〃	〃	24	27.8	140.4	about 500
119	〃	〃	30	Near Tokyo		
120	〃	V	1	39.8	143.8	about 60
121	〃	〃	〃	39.8	143.8	about 40
124	〃	〃	10	40.7	145.6	about 80
125	〃	〃	12	35.1	141.6	about 40

(to be continued.)

(Table III b. continued.)

Earthq. No.	Date			Origin		
				φ	λ	Depth (km)
126	1955	V	12	35.9	140.9	about 20
127	〃	〃	13	SE off Boso Pen.		
128	〃	〃	〃	35.7	140.3	about 40
129	〃	〃	14	27.8	140.2	about 500
130	〃	〃	16	S part of Kantō ?		
132	〃	〃	25	Sendai		
133	〃	〃	〃	Chiba-Prefect.		
134	〃	〃	〃	35.8	140.3	about 40
135	〃	〃	26	Off E coast of Fukushima-Prefect.		
136	〃	〃	〃	36.2	141.3	about 40
137	〃	〃	27	36.2	139.8	about 50
139	〃	〃	31	42.0	141.5	about 90
140	〃	VI	3	38.2	141.8	about 60
141	〃	〃	4	33.5	140.6	about 80
142	〃	〃	5	40.2	143.0	about 40
143	〃	〃	6	W Part of Kanagawa-Prefect.		
144	〃	〃	7	35.3	140.2	about 70
145	〃	〃	9	36.2	141.4	shallow
147	〃	〃	15	36.3	142.1	about 50
148	〃	〃	〃	36.3	142.1	about 40
149	〃	〃	〃	36.8	138.9	about 140
150	〃	〃	16	37.4	141.8	about 40
151	〃	〃	〃	35.5	140.0	about 40
152	〃	〃	21	29.2	140.3	about 350
155	〃	〃	28	36.2	139.9	about 50
156	〃	〃	30	Off E coast of Ibaraki-Prefect.		
157	〃	VII	6	36.2	139.7	110∼120
158	〃	〃	9	35.8	140.1	about 80

fourth and the fifth comparative observation time. (The same data for the first time were shown in Table III of our first paper[4)] and those for the second time and the third time were shown in Table III of our second paper[5)]).

Fig. 4 shows the epicenters of earthquakes treated here.

[4)] K. KANAI and T. SUZUKI, *Bull. Earthq. Res. Inst.*, **31** (1953), 305–316.

[5)] K. KANAI and T. SUZUKI, *Bull. Earthq. Res. Inst.*, **33** (1955), 109–120.

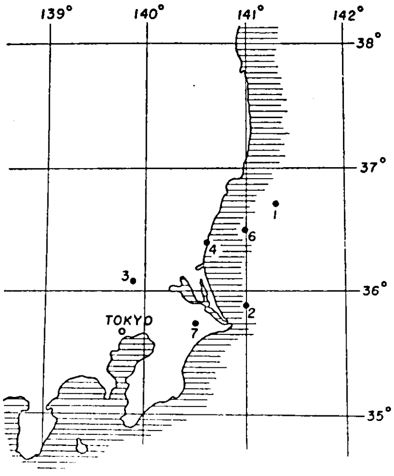

Fig. 4a.

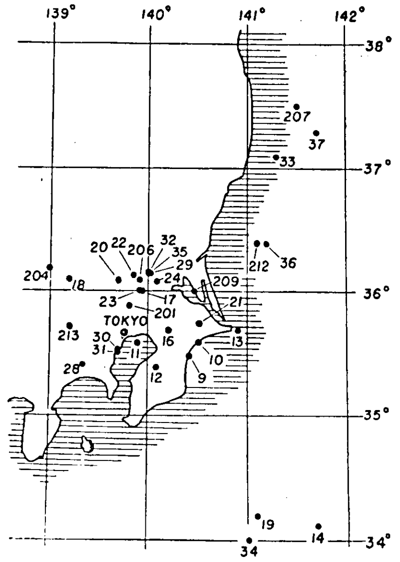

Fig. 4b.

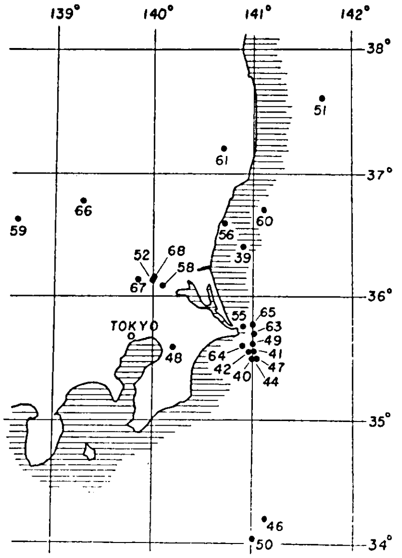

Fig. 4c.

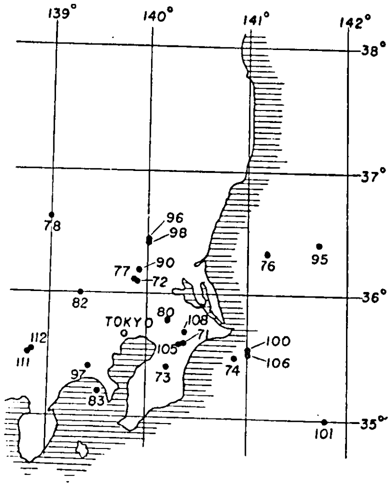

Fig. 4d.

3. Relation between the amplitude of building vibration and the period of earthquake motion

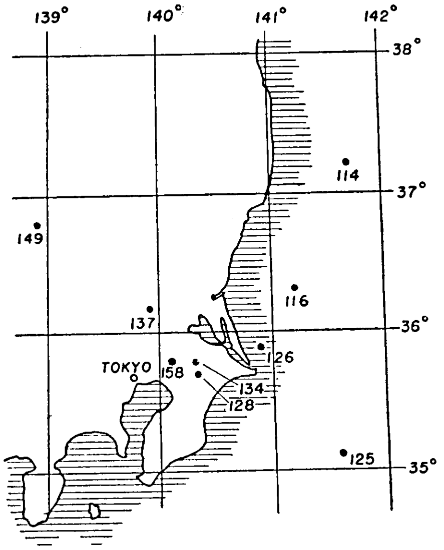

Fig. 4e.

Table IV shows both the maximum amplitude of the building at the roof-floor and at the basement, and the period at the basement, at the time when the amplitude becomes maximum for each earthquake in the fourth and the fifth time. (The same results for the first time were shown in table V, foot note 3) and those for the second and the third time were shown in Table IV, foot note 4)).

The representative seismograms of the fourth comparative observation time are shown in Fig. 5.

Figs. 6–10 represent the relation between the values of the maximum amplitude of the building at the roof-floor divided by the maximum amplitude at the basement and the period of the earthquake motion at the time when the amplitude of the basement became maximum for each earthquake. In these figures the vertical strip on the abscissa indicates the natural period of the buildings obtained by the preliminary experiments. (The same results for the first time were shown in Fig. 28, foot note 3) and those for the second and the third time were shown in Figs. 5–10, foot note 4)).

From Figs. 6–10 it is also found that in each building the period wherein the ratio of maximum amplitude of the roof-floor to that of the basement becomes maximum nearly corresponds to the natural period of the building.

It seems that the principal reason why the amplitude ratio roof-floor to basement varies even when the period of the ground vibration coincides with the natural period of the building is correlated to the succession number of the earthquake motion of the same period. This is explained from the fact that if the earthquake motion of the period which coincides with the natural period of the building occurs more than several times in succession, the amplitude of building vibration

Table IV a.

Earthq. No.	Position		Amplitude (micron)		Roof/Ground	Period (sec)
	No.	Name	Roof	Ground		
71	9	Dairo.	70	41	1.7	0.38
	10	Nakar.	80	32	2.5	0.39
	11	Kugah.	67	33	2.0	0.46
72	9	Dairo.	29	14	2.0	0.38
73	9	Dairo.	32	17	1.8	0.38
	10	Nakar.	65	47	1.4	0.62
	11	Kugah.	69	41	1.7	0.48
74	9	Dairo.	56	30	1.8	0.48
	10	Nakar.	51	29	1.8	0.61
	11	Kugah.	72	31	2.3	0.50
76	10	Nakar.	27	21	1.3	0.76
	11	Kugah.	22	14	1.6	0.48
77	9	Dairo.	230	126	1.8	0.38
	10	Nakar.	110	55	2.0	0.82
	11	Kugah.	200	140	1.4	0.57
78	9	Dairo.	14	5	2.8	0.38
	11	Kugah.	19	12	1.6	0.48
79	11	Kugah.	15	9	1.6	0.57
80	10	Nakar.	180	92	2.0	0.70
81	9	Dairo.	36	14	2.5	0.32
	11	Kugah.	24	14	1.7	0.48
82	9	Dairo.	53	54	1.0	0.33
	11	Kugah.	91	47	1.9	0.51
83	9	Dairo.	140	77	1.8	0.38
	10	Nakar.	120	43	2.5	0.48
	11	Kugah.	120	63	1.9	0.48
84	9	Dairo.	36	15	2.4	0.38
85	9	Dairo.	24	12	2.0	0.48
	11	Kugah.	31	19	1.6	0.48
86	9	Dairo.	16	9	1.8	0.38
	11	Kugah.	28	19	1.5	0.43
87	9	Dairo.	19	12	1.6	0.38
	11	Kugah.	15	12	1.3	0.48

(to be continued.)

(Table IV a. continued.)

Earthq. No.	Position		Amplitude (micron)		Roof / Ground	Period (sec)
	No.	Name	Roof	Ground		
88	9	Dairo.	35	22	1.6	0.32
	10	Nakar.	22	13	1.7	0.67
	11	Kugah.	33	16	2.1	0.43
89	9	Dairo.	25	11	2.3	0.32
	11	Kugah.	44	24	1.8	0.52
90	9	Dairo.	320	210	1.5	0.38
	10	Nakar.	330	270	1.2	0.63
	11	Kugah.	250	210	1.2	0.46
91	9	Dairo.	65	66	1.0	0.33
92	9	Dairo.	98	44	2.3	0.31
	10	Nakar.	49	30	1.6	0.69
	11	Kugah.	120	73	1.6	0.43
95	10	Nakar.	22	11	2.0	0.38
96	10	Nakar.	51	23	2.2	0.57
97	10	Nakar.	85	39	2.2	0.66
	11	Kugah.	120	79	1.5	0.50
98	10	Nakar.	180	120	1.5	0.67
	11	Kugah.	230	170	1.4	0.49
99	9	Dairo.	87	60	1.5	0.43
	10	Nakar.	34	28	1.2	0.71
	11	Kugah.	50	29	1.7	0.53
100	9	Dairo.	10	8	1.3	0.38
	10	Nakar.	11	11	1.0	0.81
	11	Kugah.	26	15	1.7	0.48
101	10	Nakar.	22	19	1.1	0.57
	11	Kugah.	28	20	1.4	0.48
102	9	Dairo.	18	15	1.2	0.62
	10	Nakar.	25	21	1.1	0.76
	11	Kugah.	41	25	1.6	0.63
103	9	Dairo.	18	11	1.6	0.38
	11	Nakar.	21	20	1.0	0.60
104	9	Dairo.	19	11	1.7	0.38
	11	Nakar.	50	28	1.7	0.48

(to be continued.)

(Table IV a. continued).

Earthq. No.	Position		Amplitude (micron)		$\frac{\text{Rroof}}{\text{Ground}}$	Period (sec)
	No.	Name	Roof	Ground		
105	9	Dairo.	26	15	1.7	0.35
	11	Nakar.	39	26	1.5	0.38
106	9	Dairo.	32	15	2.1	0.38
	11	Nakar.	27	19	1.4	0.67
107	9	Dairo.	23	9	2.9	0.33
108	9	Dairo.	32	19	1.6	0.41
	10	Nakar.	51	42	1.2	0.67
	11	Kugah.	100	53	1.9	0.48
109	10	Nakar.	130	75	1.7	0.57
	11	Kugah.	200	120	1.7	0.53
110	10	Dairo.	14	11	1.3	0.48
	11	Kugah.	48	28	1.7	0.52
111	10	Nakar.	270	190	1.4	0.57
112	11	Kugah.	160	100	1.6	0.52
113	9	Dairo.	108	66	1.6	0.35
	10	Nakar.	86	57	1.5	0.57
	11	Kugah.	140	85	1.6	0.39

Table IV b.

Earthq. No.	Position		Amplitude (micron)		$\frac{\text{Roof}}{\text{Ground}}$	Period (sec)
	No.	Name	Roof	Ground		
114	12	Sakae.	28	9	3.3	0.34
	13	Maeno.	25	13	2.0	0.38
115	12	Sakae.	85	33	2.6	0.45
	13	Maeno.	80	60	1.3	0.57
116	12	Sakae.	92	26	3.5	0.33
	13	Maeno.	85	34	2.5	0.64
117	12	Sakae.	15	5	3.0	0.38
118	12	Sakae.	34	13	2.6	0.41
	13	Maeno.	26	13	2.0	0.48
119	12	Sakae.	12	6	2.0	0.36
120	13	Maeno.	43	37	1.2	0.57

(to be continued.)

(Table IV b. continued.)

Earthq. No.	Position		Amplitude (micron)		$\frac{\text{Roof}}{\text{Ground}}$	Period (sec)
	No.	Name	Roof.	Ground		
121	12	Sakae.	18	13	1.5	0.67
	13	Maeno.	22	20	1.1	1.20
124	13	Maeno.	14	7	2.0	0.86
125	12	Sakae.	136	83	1.6	1.00
	13	Maeno.	150	95	1.6	0.76
126	13	Maeno.	75	46	1.6	0.74
127	12	Sakae.	10	3	3.3	0.48
	13	Maeno.	18	11	1.6	0.76
128	13	Maeno.	260	110	2.4	0.50
129	12	Sakae.	44	26	1.7	0.51
	13	Maeno.	46	34	1.4	0.62
130	12	Sakae.	55	26	2.1	0.38
	13	Maeno.	49	21	2.3	0.50
132	12	Sakae.	53	17	3.1	0.38
133	12	Sakae.	19	12	1.6	0.28
134	12	Sakae.	42	16	2.6	0.36
	13	Maeno.	21	11	1.9	0.68
135	12	Sakae.	9	5	1.8	0.44
	13	Maeno.	13	5	2.6	0.43
136	12	Sakae.	31	10	3.1	0.34
	13	Maeno.	36	19	1.9	0.86
137	12	Sakae.	130	47	2.7	0.38
139	12	Sakae.	10	3	3.3	0.48
	13	Maeno.	6	4	1.5	0.48
140	12	Sakae.	10	5	2.0	0.38
	13	Maeno.	15	8	1.9	0.48
141	12	Sakae.	103	47	2.2	0.36
	13	Maeno.	44	26	1.7	0.48
142	12	Sakae.	21	10	2.1	0.38
	13	Maeno.	33	21	1.6	0.48
143	12	Sakae.	9	3.6	2.5	0.34
144	12	Sakae.	19	6	3.1	0.38

(to be continued.)

(Table IV b. continued.)

Earthq. No.	Position		Amplitude (micron)		Roof / Ground	Period (sec)
	No.	Name	Roof	Ground		
144	13	Maeno.	17	6	2.8	0.48
145	12	Sakae.	17	5.4	3.1	0.33
	13	Maeno.	15	5	3.0	0.43
147	12	Sakae.	29	12	2.4	0.38
	13	Maeno.	31	9	3.4	0.91
148	12	Sakae.	97	86	1.1	0.67
	13	Maeno.	160	80	2.0	0.67
149	12	Sakae.	57	17	3.3	0.31
	13	Maeno.	35	12	2.8	0.38
150	13	Maeno.	15	5	3.0	0.41
151	12	Sakae.	60	25	2.4	0.29
	13	Maeno.	17	9	1.8	0.57
152	12	Sakae.	41	14	2.9	0.31
	13	Maeno.	24	7	3.4	0.35
155	12	Sakae.	12	4	3.0	0.38
	13	Maeno.	45	14	3.2	0.36
156	12	Sakae.	22	12	1.8	0.43
	13	Maeno.	12	11	1.0	0.52
157	13	Maeno.	30	14	2.1	0.48
158	12	Sakae.	90	31	2.9	0.51
	13	Maeno.	75	31	2.4	0.57

may become larger up to the value of resonance, while if the succession number of earthquake motion in the same period is less than a few times, the increase rate of amplitude of building vibration may be smaller in connection with the succession number.[6]

Therefore, it may be assumed that the amplitude ratio of the roof-floor to the basement becomes maximum when the building vibration comes near to the resonance phenomenon by the earthquake motion.

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6) K. KANAI and S. SHIMIZU, "Transient Vibration Problem of a Structure solved with Operational Calculus" *Monthly Meeting of the Earthq. Res, Inst.* (Oct. 15, 1946).

K. KANAI and S. KANEKO, "Experimental Study of the Transient Vibration Problem of Structure" *ditto.*

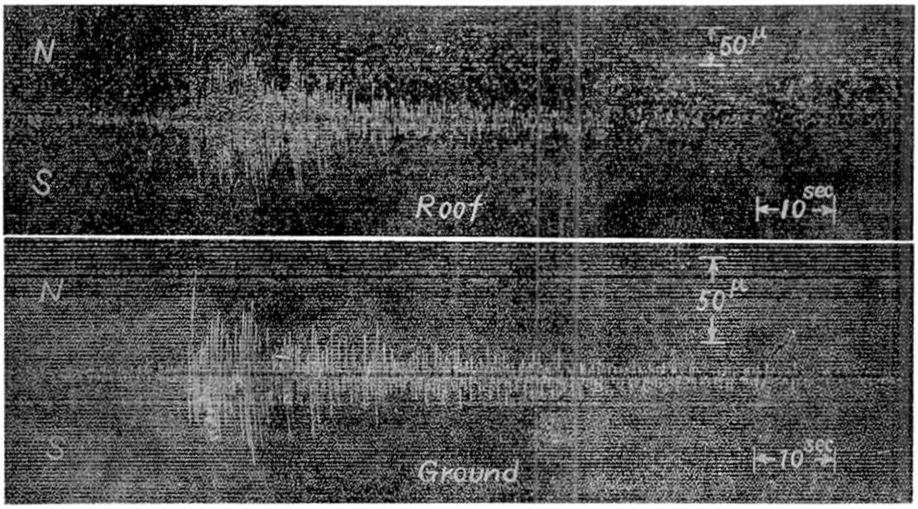


Fig. 5 a. The representative seismograms at (9) Dairokuten-machi.
(Earthquake No. 92) Original × 1.1

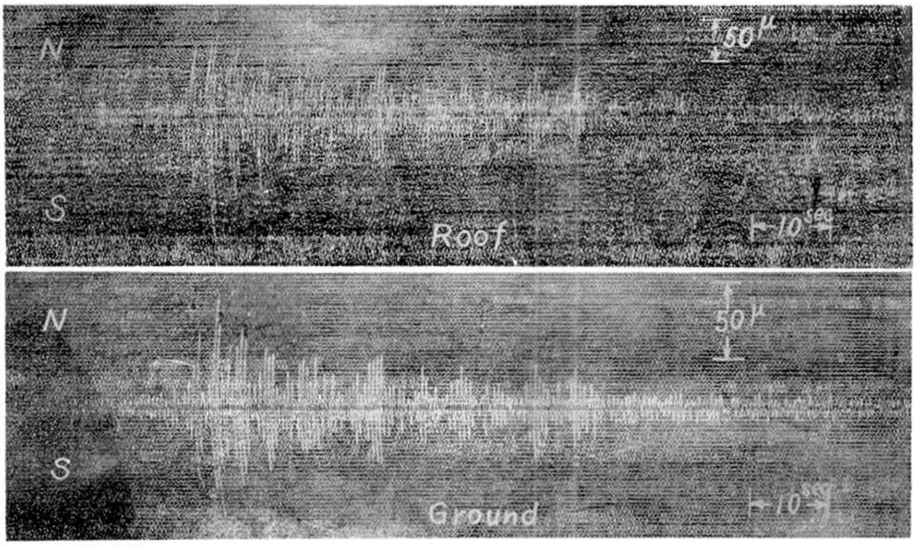


Fig. 5 b. The representative seismograms at (11) Kugahara.
(Earthquake No. 92) Original × 1.1

In other words, the value of the maximum ratio as mentioned above corresponds to the amplitude of roof-floor in case the building resonates by the simple harmonic ground motion of unit amplitude. It means that the value of the maximum ratio as mentioned above is inversely proportional to the damping of building vibration in case of an earthquake.

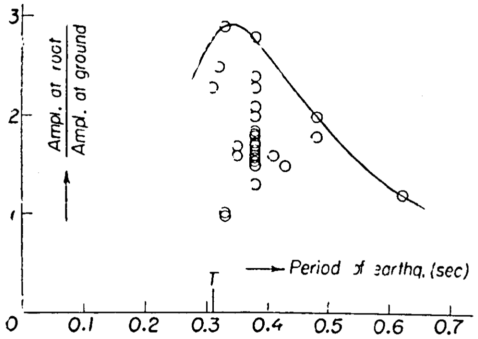


Fig. 6. Relation between the maximum amplitude and the period at (9) Dairokuten-machi.

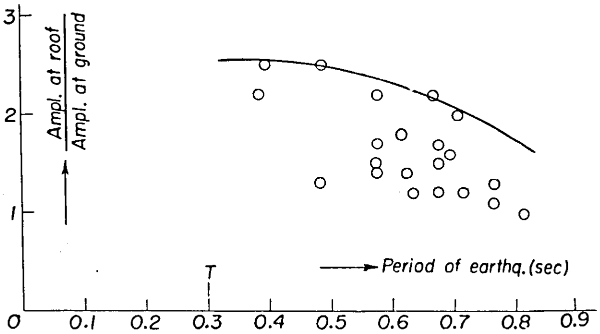


Fig. 7. Relation between the maximum amplitude and the period at (10) Nakarokugō.

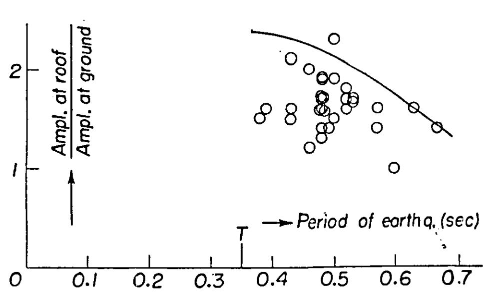


Fig. 8. Relation between the maximum amplitude and the period at (11) Kugahara.

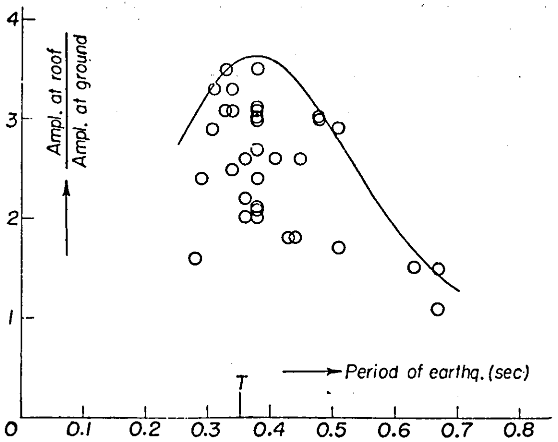
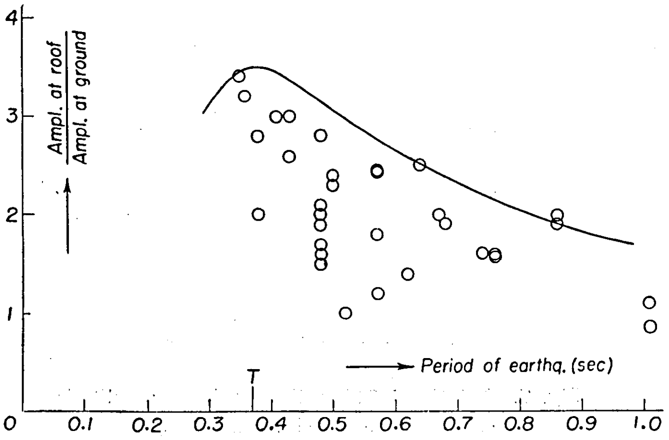


Fig. 9. Relation between the maximum amplitude and the period at (12) Sakae-chō.



Fig, 10. Relation between the maximum amplitude and the period at (13) Maeno-chō.

4. The relation between the property of the building vibration and the nature of the subsoil

The distribution of periods of micro-tremor shows a definite form for respective districts. This form coincides with the distribution of periods of earthquake motion in the same district and has a close relation with the geology of the district.[7]

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[7] K. KANAI, T. TANAKA and K. OSADA, *Bull. Earthq. Res. Inst.*, **32** (1954), 199-209. Subsoil Research Team, *Earthq. Res. Inst.*, *ditto*, **33** (1955), 492-495.

Figs. 11–15 show the distribution of periods of micro-tremor observed on the ground on which the buildings treated here stand.

The relation between the maximum ratio of the maximum amplitude of the roof-floor to that of the basement in case of an earthquake and the predominant period of the ground on which the building stands is

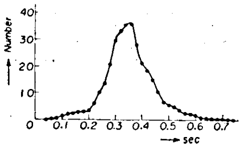

Fig. 11. The relation of the frequency to period of micro-tremor at (9) Dairoku-ten-machi.

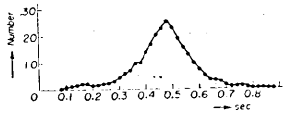

Fig. 12. The relation of the frequency to period of micro-tremor at (10) Naka-rokugō.

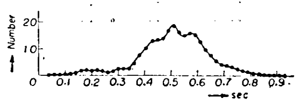

Fig. 13. The relation of the frequency to period of micro-tremor at (11) Kugahara.

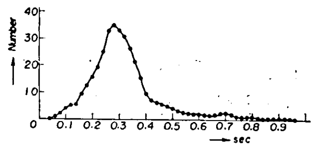

Fig. 14. The relation of the frequency to period of micro-tremor at (12) Sakae-chō.

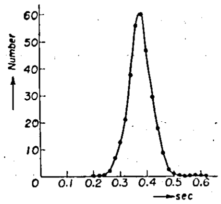

Fig. 15. The relation of the frequency to period of micro-tremor at (13) Maeno-chō.

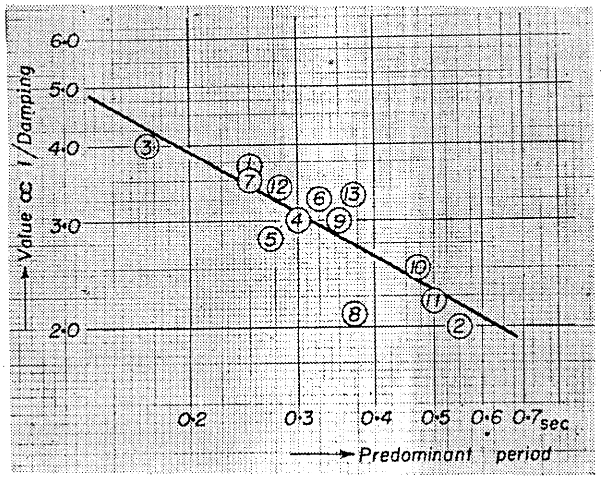

Fig. 16.

derived from Figs. 6–10 and Figs. 11–15 as shown in Fig. 16. (The same results are shown in Fig. 17, foot note 4)).

From Fig. 16, it is found that as the predominant period of the ground is larger, the building standing on the place has a smaller maximum ratio as mentioned above. It can be said qualitatively that the smaller the rigidity of the subsoil is, the larger will be the damping of the building standing on that spot in case of an earthquake.

From Fig. 16 the empirical formula can be written as follows :

$$M \propto T_0^{-0.55} \tag{1}$$

where M indicates the maximum ratio of maximum amplitude of the roof-floor to that of the basement in case of an earthquake, that is, the value inversely proportional to the damping of building vibration in case of an earthquake and T_0 the predominant period of micro-tremor observed on the ground on which the building stands, T_0 has a close connection with the rigidity of subsoil.

5. Relation between the maximum amplitude of earthquake motion and the nature of the ground

The maximum amplitude of earthquake motion at every place on which the buildings treated here stand and the ratio of the maximum amplitude at each place to that at the Earthquake Research Institute are shown in Tables V–IX.[8]

The earthquake numbers in Tables V–IX correspond to those in Table III of foot note 3), Table III of foot note 4), Table II and Fig. 3.

The relation between the mean value of the ratio of the maximum amplitude as mentioned above and the predominant period of micro-tremor observed on the ground is shown in Fig. 17.

From Fig. 17, it seems that the amplitude of earthquake motion is larger at a place where the predominant period of micro-tremor is longar.

From Fig. 17 the empirical formula can be written as follows:

$$D \propto T_0^{1.1} \tag{2}$$

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[8] The values at the Earthq. Res. Inst. in the case of the first time are adopted from the following data:

S. MIYAMURA, *Bull. Earthq. Res.* Inst., **33** (1955), p.p. 515, 516, Table V-11.

As the seismograph used at Earthq. Res. Inst. in the case of the fourth time only was of a different type, some reductions were made to its records.

Table V.

Earthq. No.	Maximum Amplitude (micron)			Maximum Amplitude ratio	
	(1) Komag.	(2) Senju	(0) E.R.I.	(1)/(0)	(2)/(0)
4	17	42	12	1.4	3.5
5	12	12	9.5	2.2	2.2
6	20	37	8.6	2.3	4.3
7	21	51	42	0.49	1.2
Mean				1.7	2.8

Table VI.

Earthq. No.	Maximum Amplitude (micron)				Maximum Amplitude ratio		
	(3) Ishik.	(4) Totsu.	(5) Honmu.	(0) E.R.I.	(3)/(0)	(4)/(0)	(5)/(0)
9			21	7.7			2.9
10			55	105			0.5
11		140		80		1.7	
27	5.0	5.0	10	3.8	1.3	1.3	2.6
28		23	45	6.5		3.5	6.9
29	6.3		13	9.0	0.7		1.5
33	13	20	7.5	11	1.2	1.8	0.7
34	10	13	15	15	0.7	0.9	1.0
36	50	65	60	58	0.9	1.1	1.0
37	10	25	15	13	0.8	1.9	1.2
201	8.4	25	12	14	0.6	1.9	0.9
202		16		10		1.5	
203	4.9	21		4.3	1.1	4.9	
204	5.0	8.0	4.5	8.5	0.6	0.9	0.5
205	15	8.0	24	8.8	1.7	0.9	2.7
206	12.4			10	1.2		
207	3.0			3.3	0.9		
208	9.5	17	17	10	1.0	1.7	1.7
209	4.0	13	9.5	5.8	0.7	2.2	1.6
210	5.8	23	15	8.5	0.7	2.7	1.7
211	3.3	9.5	5.5	6.0	0.6	1.6	0.9
212	2.9	11		6.3	0.5	1.7	
213		31		33		0.9	
Mean					0.9	1.9	1.7

Table VII.

Earthq. No.	Maximum Amplitude (micron)				Maximum Amplitude ratio		
	(6) Gōtok.	(7) Taish.	(8) Kyōdō.	(0) E.R.I.	(6)/(0)	(7)/(0)	(8)/(0)
38			13	7.0			1.9
39			85	56			1.5
40			120	57			2.1
41			78	83			0.9
42			26	16			1.6
44	7.9	13	13	8.0	1.0	1.6	1.6
45	13	7.1	18	8.0	1.6	0.9	2.3
46	66	33	75	33	2.0	1.0	2.3
47	24	17	26	10	2.4	1.7	2.6
48	36	21	66	16	2.3	1.3	4.1
49	52	37	54	17	3.1	2.2	3.2
53	11	8.0	11	8.8	1.3	0.9	1.3
54	20	12	12	14	1.4	0.8	0.8
55	15	17	33	8.0	1.9	2.1	4.1
56	29	14	14	11	2.6	1.3	1.3
58	45	35	46	31	1.5	1.1	1.5
59	10	5.2	13	5.5	1.8	1.0	2.4
60	170	170	160	163	1.1	1.1	1.0
62	24	14	16	9.3	2.6	1.5	1.7
63	24	10	14	10	2.4	1.0	1.4
64	11	6.1	10	8.3	1.3	0.7	1.2
65	8.0	10	12	5.3	1.9	1.5	2.3
66	15	8.5	18	12	1.3	0.7	1.5
67	41		50	16	2.6		3.2
68	75	150	90	109	0.7	1.4	0.8
69	8.5	6.1	16	5.8	1.5	1.1	2.8
70	19	5.7	17	20	1.0	0.3	0.9
Mean					1.7	1.1	1.9

Table VIII.

Earthq. No.	Maximum Ampiltude (micron)			Maximum Amplitude ratio	
	(9) Dairo.	(10) Nakar.	(11) Kugah.	(10)/(9)	(11)/(9)
71	41	32	33	0.8	0.8
73	17	47	41	2.8	2.4
74	30	29	31	1.0	1.0
77	126	55	140	0.4	1.1
78	5.5		12		2.3
80	76	92	140	1.2	1.8
81	14		14		1.0
82	54	34	47	0.6	0.9
83	77	43	63	0.6	0.8
84	15		22		1.5
85	12		19		1.6
86	9.0	25	19	2.8	2.1
87	12		12		1.0
88	22	13	16	0.6	0.7
89	11		24		2.2
90	210		210		1.0
91	66	47		0.7	
92	44	30	73	0.7	1.7
95	19	11	24	0.6	1.3
96	45	23	47	0.5	1.1
97	22	39	79	1.8	3.6
98	170	120	170	0.7	1.0
99	60	28	29	0.5	0.5
100	8.0	11	15	1.4	1.9
101	10	19	20	1.9	2.0
102	15	21	25	1.4	1.7
103	11		20		1.8
104	11		28		2.6
105	15		26		1.7
106	15		19		1.3
108	19	42	53	2.2	2.8
113	66	57	85	0.9	1.3
Mean				1.1	1.6

Table IX.

Earthq. No.	Maximum Amplitude (micron)			Maximum Amplitude ratio	
	(12) Sakae.	(13) Maeno.	(0) E.R.I.	(12)/(0)	(13)/(0)
120	24	37	25	1.0	1.5
125	83	95	95	0.9	1.0
127	3.0	11	6.0	0.5	1.8
129	26	34	26	1.0	1.3
134	16	11	9.0	1.8	1.2
135	5.0	5.0	3.0	1.7	1.7
136	10	19	12	0.8	1.6
140	5.0	8.0	5.0	1.0	1.6
144	6.0	6.0	2.0	3.0	3.0
148	86	80	67	1.2	1.2
149	17	12	8.0	2.1	1.5
150	5.0	5.0	2.0	2.5	2.5
152	7.0	14	7.0	2.0	1.0
158	31	31	40	0.8	0.8
Mean				1.6	1.5

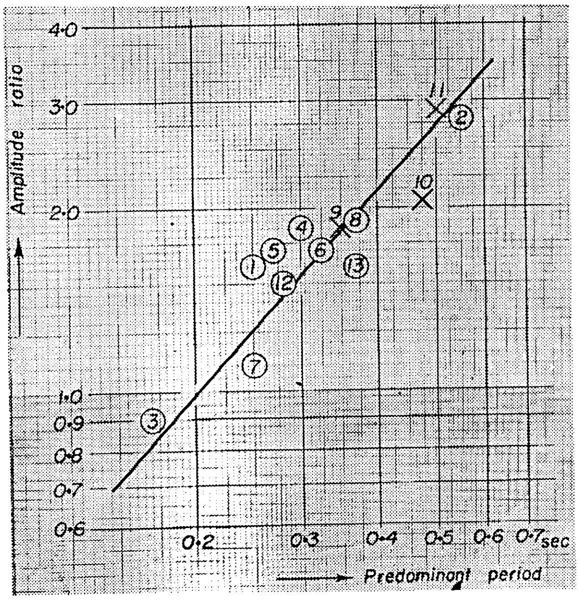


Fig. 17

where D indicates the rate of the maximum amplitude of earthquake motion at a place and T_0 the predominant period of micro-tremor in that place.

From this investigation it was ascertained fairly clearly that the smaller the rigidity of the ground is, the larger will be the maximum amplitude of earthquake motion.

6. Relation between the property of building vibration and the nature of the ground

The relation between the value of the rate of the resonance amplitude of building vibration, M, and the ratio of the maximum amplitude of earthquake motion at the ground on which the building stands to that of the standard place, D, is derived from Fig. 16 and Fig. 17 as shown in Fig. 18.

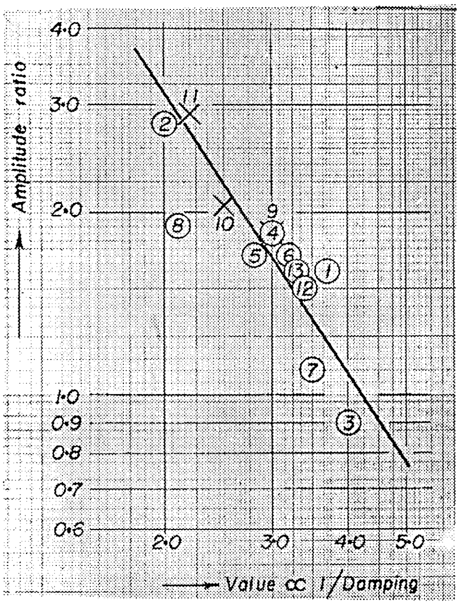


Fig. 18.

From Fig. 18, it will be understood that the larger the rate of the maximum amplitude of earthquake motion at the ground on which the building stands, the smaller the resonance amplitude of that building by the unit amplitude of ground motion, that is, the damping of building vibration at the time of the earthquake is larger.

From Fig. 18, the relation of D to M may be expressed in the following formula:

$$D \propto M^{-1.51} \qquad (3)$$

The rate of the largest strain to which the building is subjected at the time of the earthquake may be considered as proportional to the product of the rate of the resonance amplitude of the building and the rate of the maximum amplitude of earthquake motion of the ground on which the building stands.

The rate of the largest strain to which the building is subjected at the time of the earthquake will correspond to the scale of the earthquake force which has to be taken into consideration in calculation of earthquake-proof consideration.

The relation between the scale of earthquake force as mentioned above and the rate of the maximum amplitude of earthquake motion is derived from Fig. 18 as shown in Fig. 19.

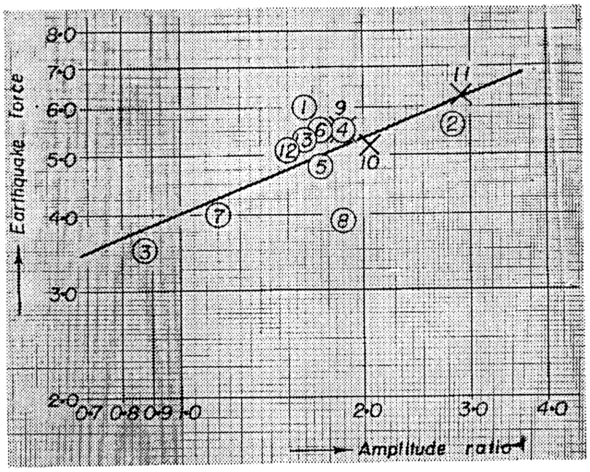


Fig. 19.

From Fig. 19 the empirical formula can be written as follows:

$$\alpha \propto D^{0.4} \qquad (4)$$

where α indicates the scale of earthquake force and D the maximum amplitude rate.

From Fig. 19 and equation (4), we now arrive at the conclusion that the earthquake force which has to be taken into consideration in calculation of earthquake-proof construction is not in linear relation to the maximum amplitude of the earthquake motion.

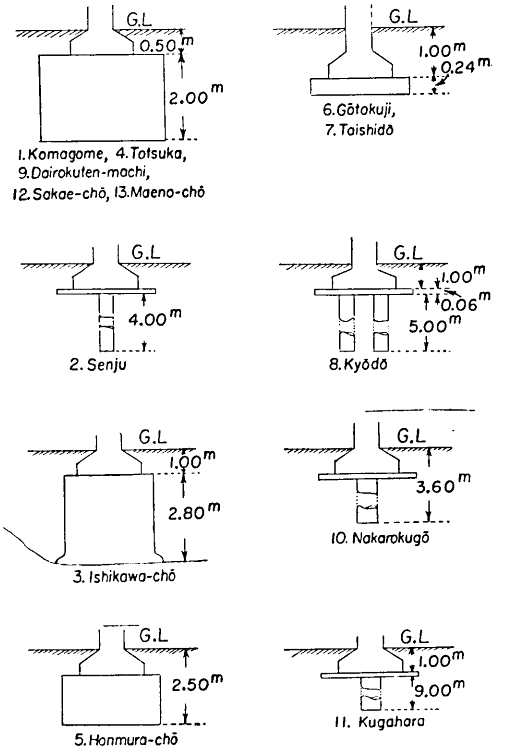
When the natural period of building is considerably smaller than the period of earthquake motion, that is when the building is of rigid construction like the buildings treated here, the earthquake force as mentioned above is nearly proportional to the square root of the value of the maximum amplitude of earthquake motion.

7. Effect of the construction of the foundation on the building vibration in case of an earthquake

The construction of the foundation of buildings treated here are shown in Fig. 20.

From this investigation, it was found that the effect of the properties of the subsoil which surrounds the foundation on damping of building vibration in case of an earthquake is very serious. As the illustrations will show, when the foundations of the building are directly on bed rock like the Ishikawa-chō apartment house, building No. 3, the damping of building vibration is small. On the contrary, when the foundations of the building are surrounded by very soft soils like the Kyōdō apartment house, building No. 8, or Senju apartment house, building No. 2, the damping of building vibration is large as shown in Fig. 16.

Figs. 17 and 18 show that the conditions in which a somewhat large area of ground on which building stands is hard and soils of a limited area surrounding the foundation are soft, are the best for building vibration in case of an earthquake. The conditions of the Kyōdō apartment house, building No. 8, are a practical example of this.



Fig, 20.

8. Conclusion

From this investigations, we found that the smaller the rigidity of the subsoil with which surround the foundation is, the larger the damping of the building vibration will be in case of an earthquake.

It was also ascertained that the smaller the rigidity of the ground is, the larger the maximum amplitude of earthquake motion will be.

From the consideration of these two results, it now seems established that the scale of earthquake force which has to be taken into consideration in calculation of earthquake-proof construction is nearly proportional to the square root of the value of the rate of the maximum amplitude of earthquake motion as shown in Fig. 19 and equation (4).

Concerning only the vibration problem of building in case of an earthquake, we come now to the conclusion that the conditions in which a somewhat large area of ground on which the building stands is hard and the soils of a limited area surround the foundation are soft, are the best for building.

The problem of earthquake force regarding the case in which the natural period of elastic vibration is comparable to the period of earthquake motion are now in the course of study the results of which investigation will be published later.

In conclusion, we wish to express our thanks to the Science Section of the Educational Ministry, for the financial aid (Research Funds) granted us. Also thanks are due to the members of the Residential Association of Tokyo Metropolis for their help and to Mr. K. Nakagawa and others, members of the Architectural Institute of the Construction Ministry, for their cooperation in the course of these observations and to Mr. T. Tanaka and Mr. K. Osada who assisted us in preparing this paper.

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6. 建物の振動的性質と地盤の性質との関係

(実在建物における地震動観測) 第3報

地震研究所 金井　清
鈴木富三郎
吉沢静代

異種地盤上に建つ13ヶの同種建物において，地震動の比較観測を行つた結果，軟かい地盤に建つ建物程地震時における振動減衰性が大きいことがよく確められた．又，同じ観測結果から，地盤が軟かい程，地震動の振幅が大きいということに対する定量的な結果も得られた．

そこで建物の振動減衰性と地震動の振幅とを綜合して，建物の設計に使う地震力の地盤差による割合として(4)式のような結果が得られた．

即ち，地震力の地盤差による割合は地震動振幅の地盤差による割合の約平方根に比例することがわかつた．建物の不同沈下などを考慮の外に置いて，単に振動学的立場だけから考えると，建物の基礎の形状，抗打の有無が建物の耐震性に与える影響は大きくない．基礎の接する部分の土が軟かい程，建物の振動減衰性は大きい．しかし，一般に地盤が軟かいと地震動が大きいから，たとえ建物の減衰性は大きくても，地盤が軟いことは振動学的立場からだけでも耐震的に有利とは言えない．

振動学的立場だけから言うと，周囲が堅くて，基礎の部分の土だけが軟いという条件は建物の耐震上相当に有利なことになる．

なお，本研究は建物の弾性振動による固有周期が相当に短いものについての観測結果である．地震動の周期と建物の固有周期との関係並びに振動勢力の地下逸散による振動減衰性を考慮に入れると，高層建物では，地盤が軟いと只今の結果よりも条件が悪くなる傾向になる．

これらの事については，目下研究中であるから，次の機会に報告する．