8. *Relation between the Property of Building Vibration and the Nature of Ground.*

(Observation of Earthquake Motion at Actual Buildings.) II.

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1. Introduction

The property of earthquake-motion is varied according to the ground property. Therefore the value of earthquake force, which has to be taken into consideration in calculation of earthquake-proof construction, depends on the ground property. In order to get the standard of estimation of such a value, we made a simultaneous observation by installing seismographs both at the basements and the roof-floors of buildings of the same structure standing on ground of different properties.

The results of the comparative observations made at two places in Tokyo and two places in Hyōgo Prefecture, have already been given in the previous paper[1]. The main points revealed in that paper are; (i) natural vibrations of buildings are apt to be caused by earthquake-motion, (ii) the damping of building in case of earthquake is larger on softer ground, and (iii) the latter phenomenon is explained from the damping caused by the dissipation of vibrational energy of the building into the ground.

In the present paper, besides the results of comparative observation made at two places in Tokyo which the previous paper contains, the results of two times of comparative observations which include in each the observations made at three spots in Tokyo are given. Observations in eight places in total were made at the basements and roof-floors of the buildings of the same structure.

2. The method of earthquake observation

The observations were made in the four-storied apartment-houses

1) K. KANAI and T. SUZUKI, *Earthq. Res. Inst.*, **31** (1953), 305.

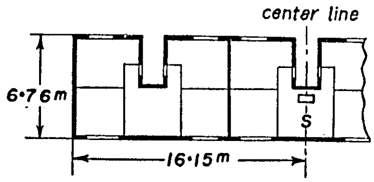

Fig. 2a. Plan view of the building of called 46-type.

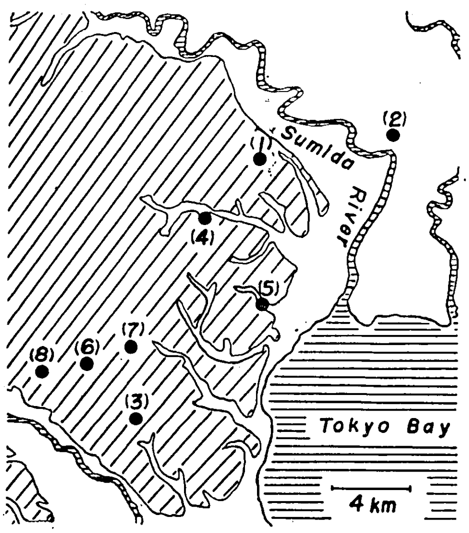

Fig. 1. The positions of the buildings.

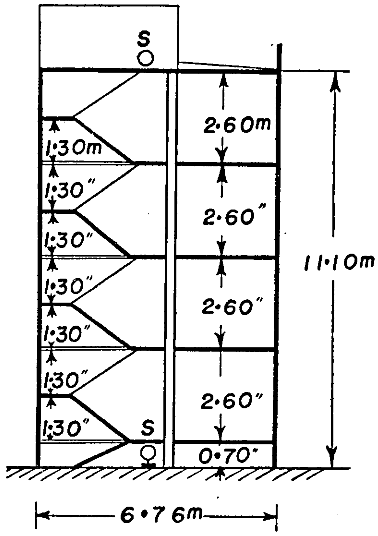

Fig. 2b. Side view of the building of called 46-type.

Table I. The names and positions of the buildings.

No.	Name	Position
(1)	Komagome Apertment	Komagome, Toshima-ku
(2)	Senju 〃	Senju-hashido-chō, Adachi-ku
(3)	Ishikawa-chō 〃	Ishikawa-chō, Ōta-ku
(4)	Totsuka 〃	Totsuka-machi, Shinjuku-ku
(5)	Honmura-chō 〃	Azabu-honmura-chō, Minato-ku
(6)	Gōtokuji 〃	Setagaya, Setagaya-ku
(7)	Taishidō 〃	Taishidō-machi, Setagaya-ku
(8)	Kyōdō 〃	Kyōdō-machi, Setagaya-ku

of reinforced concrete called "Tokyo-to Residential Association 46-type". The positions and the rough sketches of the buildings are shown in Figs. 1 and 2 respectively. The names and positions of the buildings are given in Table I.

The seismograph was installed on about the center of the basement and the roof-floor of each building and the component of beam direction of earthquake-motion was observed. The constants of seismographs used in the observation and the natural period of building obtained in the preliminary experiment are shown in Table II.

Fig. 3 illustrates the epicenters of earthquakes treated here and in Table III the date and position of the origins are shown.

Table II. The constants of seismographs and the natural period of building.

Building		Seismograph			
No.	Period (sec)	Position	Period (sec)	Damp. ratio	Magnif.
(1)	0.32	Roof	1.0	13:1	138 102
		Ground	〃	〃	174 98
(2)	0.28	Roof	〃	〃	198 117
		Ground	〃	〃	233 146
(3)	0.22	Roof	〃	〃	400
		Ground	〃	〃	400
(4)	0.33	Roof	〃	〃	100
		Ground	〃	〃	100
(5)	0.23	Roof	〃	〃	100
		Ground	〃	〃	100
(6)	0.32	Roof	〃	〃	92
		Ground	〃	〃	234
(7)	0.32	Roof	〃	〃	104
		Ground	〃	〃	212
(8)	0.32	Roof	〃	〃	100
		Ground	〃	〃	190

Table III. The date and position of the origin.

Earthq. No.	Date (1954)		Origin			Observation Building Number
			φ	λ	Depth(km)	
1∼8						(1), (2)
9	II	4	35.5	140.4	60	(3), (4), (5)
10	〃	5	35.6	140.5	60	
11	〃	14	35.6	139.9	40	
12	〃	20	35.4	140.1	40	
13	〃	21	35.7	140.9	40	
14	〃	22	34.3	141.7	60	
15	〃	〃	34.1	141.7	60	
16	〃	25	35.7	140.2	80	
17	〃	〃	36.0	139.9	40∼50	
18	〃	26	36.1	139.2	70	
19	〃	〃	34.2	141.1	30	
20	〃	27	36.1	139.7	50	
21	III	3	37.8	140.5	50∼60	
22	〃	4	36.2	139.8	50∼60	
23	〃	6	36.0	139.9	50∼60	
24	〃	8	36.1	140.1	65	
25	〃	11				
26	〃	〃	36.6?	139.9?	—	
27	IV	3	34.7?	140.5?	—	
28	〃	〃	35.4	139.3	50∼60	
29	〃	8	36.2	140.0	50	
30	〃	10	35.5	139.7	35	
31	〃	〃	35.5	139.7	40	
32	〃	12	36.2	140.0	65	
33	〃	16	37.1	141.3	40	
34	〃	25	34.0	141.0	80∼90	
35	V	3	36.2	140.0	40∼50	
36	〃	4	36.4	141.2	40	
37	〃	14	37.3	141.7	50	
38	VII	10	40.7	139.3	300	(6), (7), (8)
39	〃	18	36.4	140.9	40	
40	〃	〃	35.5	141.0	50	
41	〃	〃	35.6	141.0	40	
42	〃	19	35.6	140.9	40	
43	〃	〃	35.7?	139.7?	—	
44	〃	21	35.5	141.0	40	
45	〃	〃	33.8	140.3	—	
46	〃	〃	33.7	141.2	40	
47	〃	22	35.5	141.0	—	
48	〃	〃	35.6	140.2	60∼70	
49	〃	27	35.6	141.0	40	
50	VIII	1	34.0	141.0	—	
51	〃	2	37.6	141.7	50∼60	
52	〃	5	36.1	140.0	50	
53	〃	10	30.2	139.4	430	

(to be continued.)

(continued.)

Earthq. No.	Date (1954)		Origin			Observation Building Number
			φ	λ	Depth(km)	
54	VIII	11	35.7?	139.7?	—	(6), (7), (8)
55	〃	12	35.8	140.9	50	
56	〃	〃	36.6	140.7	40～50	
57	〃	19	35 ?	140 ?	—	
58	〃	25	36.1	140.4	60	
59	〃	28	36.7	138.7	140	
60	〃	〃	36.7	141.1	40	
61	〃	30	37.2	140.7	80～90	
62	〃	31	42.8	143.8	60～80	
63	IX	1	35.7	141.0	40	
64	〃	2	35.6	140.9	30	
65	〃	6	35.8	141.0	Shallow	
66	〃	〃	36.8	139.3	20	
67	〃	11	36.2	139.9	40～50	
68	〃	12	36.1	140.0	70	
69	〃	〃	29.5	139.5	450	

3. Results of observations

In Table IV the maximum amplitude of the building at roof-floor and both the amplitude and the period at the basement in the time when the amplitude of roof-floor becomes maximum regarding each earthquake are shown. The representative seismograms are shown in Fig. 4.

Figs. 5～10 represent the relation between the values of the maximum amplitude of building at the roof-floor divided by the amplitudes at the basement in the time when the amplitude of roof-floor became maximum and the period of the buildings at the basement in the same time concerning each earth-

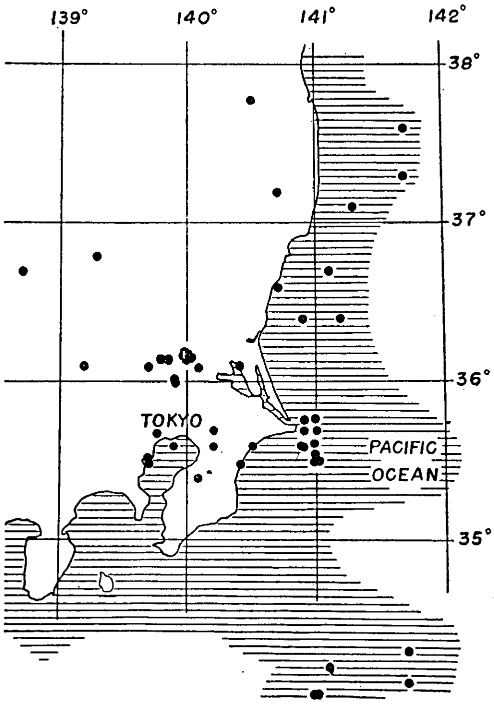

Fig. 3. The epicenters of earthquakes.

Table IV. The maximum amplitude of building and the period of earthquake-motion.

Earthq. No.	Position	Amplitude (micron) Roof	Amplitude (micron) Ground	Period (sec)
9	(5)	54	21	0.30
10	(5)	75	55	0.38
11	(4)	260	140	0.34
12	(4)	300	130	0.34
	(5)	270	110	0.24
13	(4)	60	30	0.42
	(5)	40	38	0.68
14	(4)	130	75	0.75
	(5)	63	63	0.84
15	(4)	95	55	0.60
	(5)	45	35	1.04
16	(3)	23	19	0.37
	(4)	75	25	0.34
	(5)	35	13	0.23
17	(4)	500	370	0.36
18	(3)	11	5.6	0.30
19	(3)	41	37	0.81
	(4)	100	70	0.95
	(5)	65	70	0.86
20	(5)	23	15	0.45
21	(4)	85	33	0.42
	(5)	38	30	0.59
22	(3)	28	19	0.51
	(4)	108	40	0.34
	(5)	35	18	0.38
23	(3)	13	5.6	0.34
	(5)	20	10	0.39
24	(3)	14	5.0	0.33
25	(3)	13	3.1	0.22
26	(3)	9.4	3.1	0.26
27	(3)	19	5.0	0.25
	(4)	15	5.0	0.27
	(5)	25	10	0.31
28	(4)	55	23	0.37
	(5)	90	45	0.31
29	(3)	11	6.3	0.33
	(5)	15	13	0.49
30	(5)	350	280	0.35
31	(5)	250	220	0.39
32	(3)	28	13	0.39
	(5)	30	15	0.39
33	(3)	15	13	0.54
	(4)	50	20	0.42
	(5)	20	7.5	0.39
34	(3)	11	10	1.06
	(4)	25	13	0.35
	(5)	30	15	0.65
35	(3)	38	11	0.25
	(4)	45	20	0.33
36	(3)	73	50	0.88
	(4)	180	65	0.39
	(5)	90	60	0.71

Earthq. No.	Position	Amplitude (micron) Roof	Amplitude (micron) Ground	Period (sec)
37	(3)	19	10	0.40
	(4)	50	25	0.36
	(5)	25	15	0.46
38	(8)	18	13	0.72
39	(8)	118	85	0.38
40	(8)	175	120	0.50
41	(8)	115	78	0.48
42	(8)	40	26	0.42
43	(8)	25	12	0.34
44	(7)	27	13	0.33
	(8)	22	13	0.43
45	(6)	38	13	0.38
	(8)	30	18	0.36
46	(6)	170	66	0.32
	(7)	63	33	0.46
	(8)	110	75	0.34
47	(6)	54	24	0.38
	(7)	29	17	0.48
	(8)	38	26	0.40
48	(6)	120	36	0.36
	(7)	48	21	0.36
	(8)	95	66	0.34
49	(6)	160	52	0.35
	(7)	100	37	0.36
	(8)	83	54	0.46
50	(6)	47	18	0.40
	(8)	21	12	0.34
51	(6)	51	17	0.35
	(7)	33	11	0.38
	(8)	28	16	0.38
52	(6)	75	31	0.34
	(7)	52	21	0.29
	(8)	47	26	0.38
53	(6)	32	11	0.38
	(8)	15	11	0.38
54	(6)	40	20	0.38
	(7)	19	12	0.32
	(8)	20	12	0.33
55	(6)	38	15	0.43
	(7)	41	17	0.41
	(8)	50	33	0.38
56	(6)	59	29	0.38
	(7)	41	14	0.33
	(8)	22	14	0.33
57	(6)	26	12	0.38
	(7)	23	9.4	0.44
58	(6)	71	45	0.32
	(7)	100	35	0.31
	(8)	74	46	0.42
59	(8)	20	13	0.36

(to be continued.)

(continued.)

Earthq. No.	Position	Amplitude (micron) Roof	Amplitude (micron) Ground	Period (sec)
60	(6)	410	170	0.38
	(7)	290	170	0.48
	(8)	250	160	0.76
61	(6)	63	22	0.35
	(7)	43	15	0.46
62	(6)	60	24	0.34
	(7)	49	14	0.33
	(8)	25	16	0.36
63	(6)	64	24	0.35
	(8)	26	14	0.36
64	(6)	24	11	0.38
65	(6)	24	10	0.29
	(8)	20	12	0.38
66	(6)	40	15	0.44
	(8)	27	18	0.56
67	(6)	96	41	0.36
	(8)	84	50	0.33
68	(6)	200	75	0.43
	(7)	310	150	0.38
	(8)	150	90	0.43
69	(8)	26	16	0.38

quake. In these figures the strips indicate the natural period of the buildings.

From Figs. 5~10 it is found that in each building the period wherein the ratio of 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 of roof-floor to basement varies even when the period of the

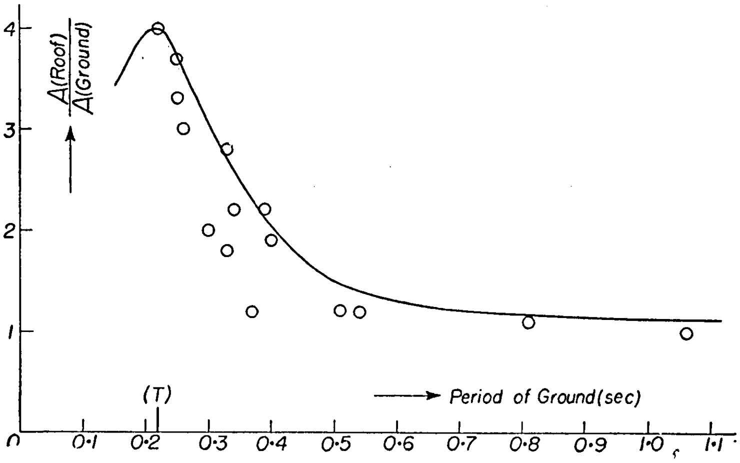

Fig. 5. Relation between the maximum amplitude and the period at (3) Ishikawa-chō.

ground vibration coincides with the natural period of 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 building occurs more than several times in succession, the amplitude of building vibration may become larger up to the value of resonance, while if the succession number of earthquake-motion of the same period is less

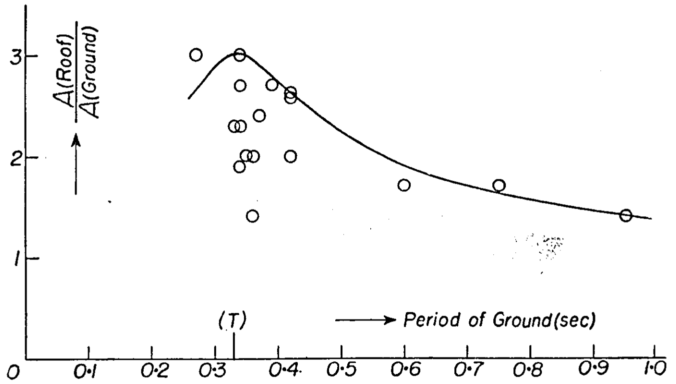

Fig. 6. Relation between the maximum amplitude and the period at (4) Totsuka.

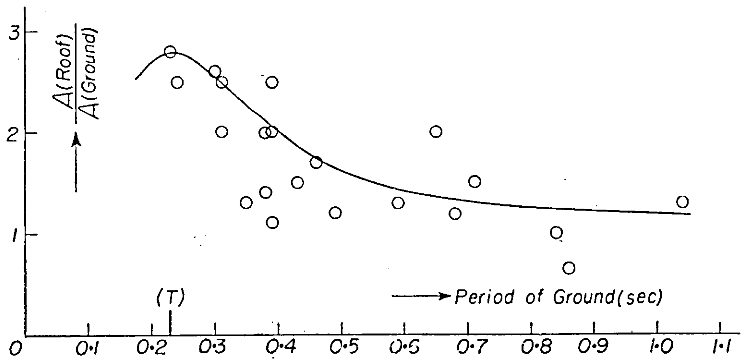

Fig. 7. Relation between the maximum amplitude and the period at (5) Honmura-chō.

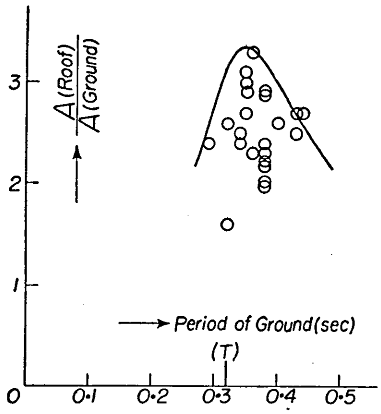

Fig. 8. Relation between the maximum amplitude and the period at (6) Gōtokuji.

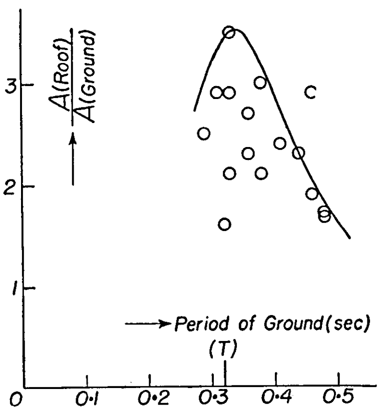

Fig. 9. Relation between the maximum amplitude and the period at (7) Taishidō.

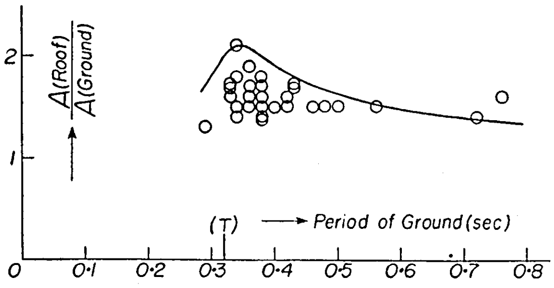

Fig. 10. Relation between the maximum amplitude and the period at (8) Kyōdō.

than several times, the increase rate of amplitude of building vibration may be smaller in proportion to the succession number.

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. In other words, the value of the maximum ratio of the amplitude of roof-floor to that of basement corresponds to the amplitude of roof-floor in case the building resonates by the simple harmonic ground motion of unit amplitude.

4. The relation between the property of building vibration and the property of ground

Figs. 11～16 show the relation of the frequency to period of micro-tremor observed on the ground on which the buildings treated here stand. If there are more than two periods corresponding respectively to the maximum frequency of period, the largest one of them is called, for convenience sake, the natural period.

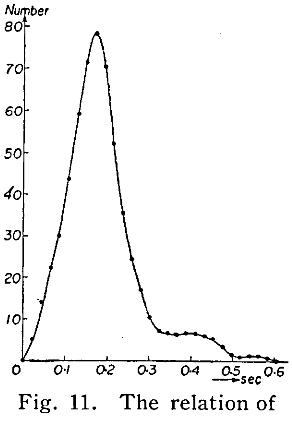

Fig. 11. The relation of the frequency to period of micro-tremor at (3) Ishikawa-chō.

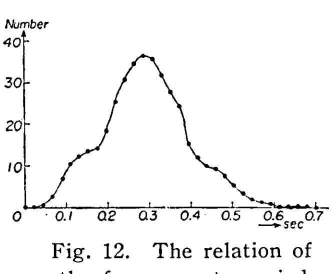

Fig. 12. The relation of the frequency to period of micro-tremor at (4) Totsuka.

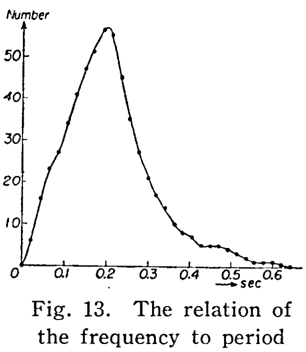

Fig. 13. The relation of the frequency to period of micro-tremor at (5) Honmura-chō.

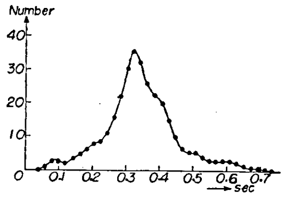

Fig. 14. The relation of the frequency to period of micro-tremor at (6) Gōtokuji.

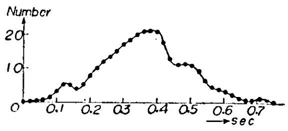

Fig. 15. The relation of the frequency to period of micro-tremor at (7) Taishidō.

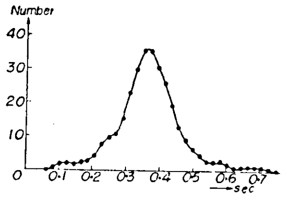

Fig. 16. The relation of the frequency to period of micro-tremor at (8) Kyōdō.

The relation between the maximum ratio of the amplitude of roof-floor to that of basement in case of earthquake and the natural period of the ground on which the building stands is derived from Figs. 5–10 and Figs. 11–16 as shown in Fig. 17. From Fig. 17, it is found that as the natural period of the ground is longer, the building standing on the place has the smaller maximum ratio as mentioned above, that is the damping of building vibration at the time of earthquake is larger. From Fig. 17 the empirical formula can be written as follows:

$$M \propto T_0^{-0.5} \qquad (1)$$

where M indicates the maximum ratio of amplitude of roof-floor to that of basement in case of earthquake and T_0 the natural period of the ground.

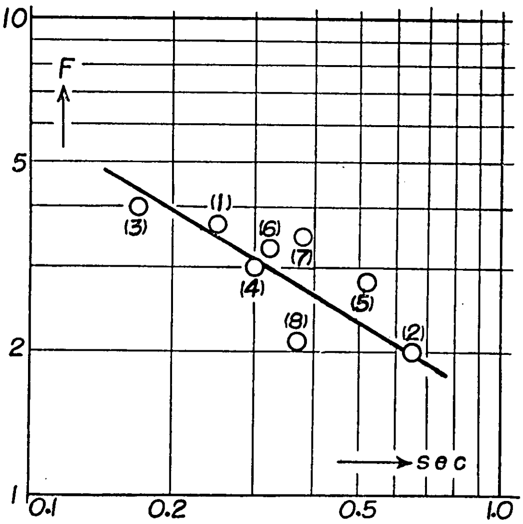

Fig. 17. The relation between the maximum amplitude of building and the proper period of ground.

Fig. 18 shows the relation between the natural period of the ground and the velocity of S-waves near the ground surface. Though the propriety of deriving an empirical formula from only three measured values of the velocity of S-waves may be questioned, the following empirical formula may be given for convenience sake;

$$T_0 \propto V_s^{-1.6} \qquad (2)$$

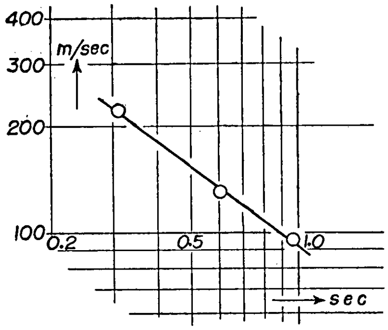

Fig. 18. The relation of the proper period of the ground and the velocity of S-waves.

where V_s is the velocity of S-waves.

From equations (1) and (2), the relation of the maximum ratio of amplitude of roof-floor to that of basement at the time of earthquake to the velocity of S-waves near the ground surface may be expressed in the following formula:

$$M \propto V_s^{0.8} \qquad (3)$$

The data concerning the velocity of S-waves is so few that we cannot expect much reliability from that formula, but at least qualitatively it can be said that the smaller the rigidity of the material around the ground surface is, the larger the damping of the building standing on that spot in case of earthquake will be.

5. Conclusion

It is found from the results of observations made at eight buildings of the same structure standing on ground of different properties that the maximum ratio of roof-floor to that of basement becomes smaller as the rigidity of the ground on which the building stands becomes smaller. In other words, the smaller the rigidity of the ground, the greater the damping of the building standing on that place in case of earthquake.

Having yet only a few data concerning the rigidity of the ground at hand, we will discuss quantitatively about the damping of buildings in case of earthquake and the property of the ground in our next report.

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-to for their help and to Mr. K. Nakagawa and others, members of the Architectural Institute of Construction Ministry, for their cooperation in the course of these observations and to Miss S. Yoshi zawa who assisted us in preparing this paper.

8. 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2報

地震研究所 {金井 清 / 鈴木富三郎}

異種地盤上に建つ同種の 8 建物 (4 階建鉄筋コンクリートのアパート) において，地震の比較観測を行つた．その結果として，地盤の剛性が小さい程，その上に建つ建物の地震時における振動減衰性が大きいことがわかつた．ここで云う地盤の剛性とは，建物の基礎が接している土地附近の平均剛性にあたる．従つて，ここでは，地盤の地表面にごく近いところの性質が直接問題になる訳である．いづれにしても，本研究において，地震時における建物の振動減衰性の主要部分は，建物の震動勢力が基礎から地中に逸散するために生ずることが，いよいよ明かになつた．

今後は，地表面附近の物質の剛性の資料の数を何とかふやして，地震時における建物の振動減衰性と地盤の剛性との関係を定量的にきめて，地盤の性質を耐震設計上に有効に導入する道をひらいてゆきたい．

なお，坑打ちなどの基礎部分の構造上の条件は，建物の振動減衰性の本質を支配する因子とはならないものと考えられるが，その影響についての詳しい検討を行いつつあるから，次の機会に報告する．

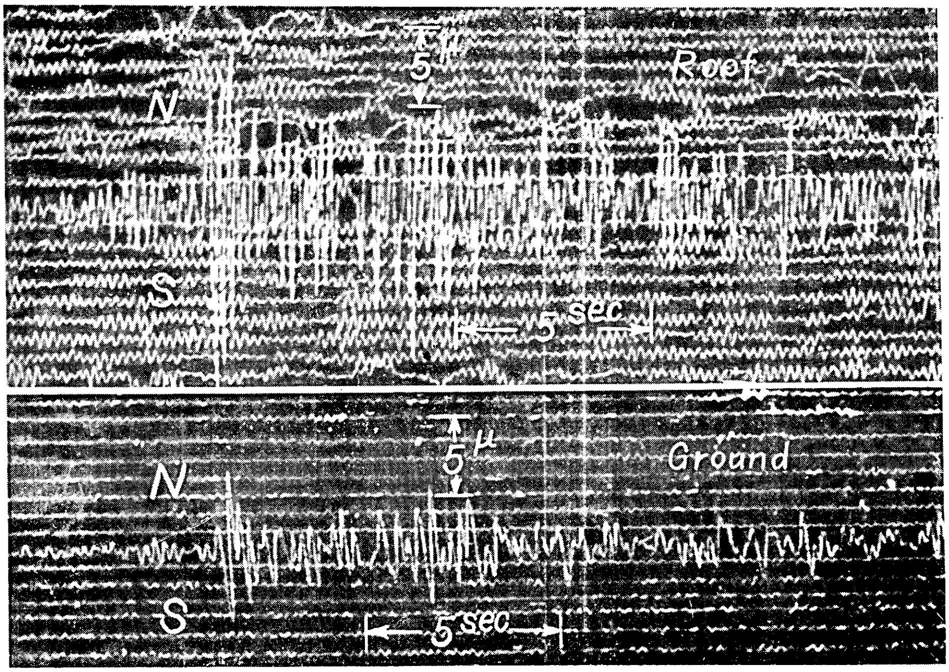

Fig. 4a. The representative seismograms at (3) Ishikawa-chō.
(Earthquake No. 29)

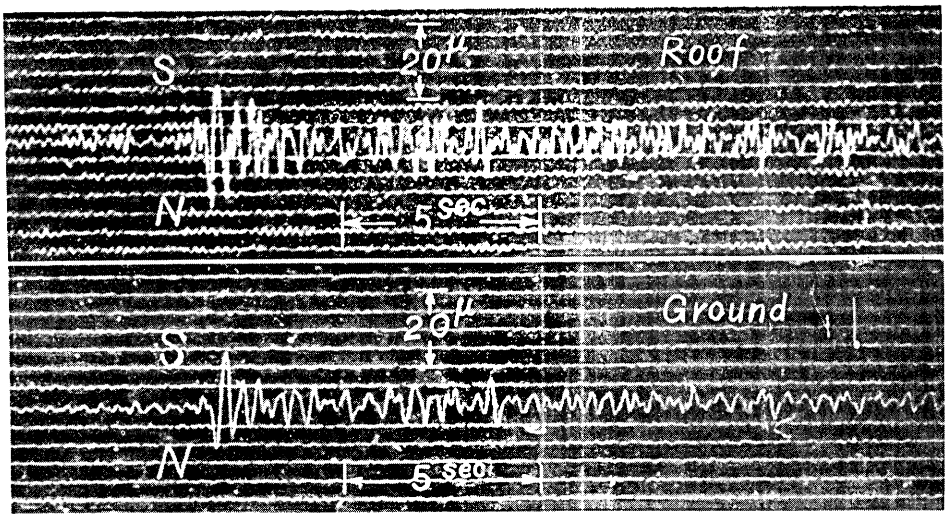

Fig. 4b. The representative seismograms at (5) Honmura-chō.
(Earthquake No. 29)