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

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1. Introduction.

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

On one hand the influence of the ground property on building vibration is made clear by giving forced vibration artificially to the building through a vibrator or other means, and on the other hand the property of earthquake motion itself is observed on the ground of various properties. Then these results may be combined so as to make it possible to presume the vibration of actual buildings caused by earthquake. Not a few studies from these two standpoints have been made and the relation between them is getting clearer.

Besides such an indirect method of study which can be applied generally, a direct method, that is the observation of earthquake motion in the buildings on various kinds of ground has been adopted. In Japan earthquake motions were observed in various wooden houses and a few reinforced concrete buildings by installing acceleration seismographs temporarily. In U. S. A., observations are made by means of strong motion seismographs installed at both the upper and lower parts of some buildings of reinforced concrete.

The present paper is intended to show systematically the relation of the property of building vibration in the course of earthquake to the ground property, which is obtained from the simultaneous observation made at the ground-floor and the roof-floor of the buildings of same structure standing on the ground of different properties.

2. Method of examination.

Two combinations of buildings of same structure with the ground of different properties are represented by A and B. In both A and B combinations, the buildings are four-storied apartments of bearing wall reinforced concrete construction. The building in A is called "49B of the Construction Ministry", the observation was made at two places: halfway up a mountain in Hyōgo Prefecture (the surface; piled up clay, bearing power; 6.5 t/m^2) and on the alluvium in the same prefecture (the surface; reclaimed land of a pond, bearing power; 7 t/m^2). In B, the type of building is called "Tokyo-to Residential Association 46" and observations were made on the diluvium and the thick alluvium in Tokyo.

The data concerning each building and place and the seismograph constants are shown in Table I. In Table I, the natural period of building is obtained from the results of vibration experiments made by using a vibrator[1].

Table I. (a; Earthquake No. B1–B3, b; B4–B8)

	Building			Seismograph				
	Type	Period (sec)	Position	Position	Period (sec)	Damp. ratio	Magnif. a	Magnif. b
A	49 B	0.20	Takaha-Takemaru, Nada-ku, Kōbe-city	Roof	1.0	13:1	160	
				Ground	〃	〃	208	
		0.27	Kita-Nagato-chō, Nishinomiya-city	Roof	〃	〃	186	
				Ground	〃	〃	246	
B	46	0.32	Komagome-chō, Toshima-ku, Tokyo	Roof	〃	〃	138	102
				Ground	〃	〃	174	98
		0.28	Senju-hashido-chō, Adachi-ku, Tokyo	Roof	〃	〃	198	117
				Ground	〃	〃	233	146

Figs. 1 and 2 illustrate the sketches of the buildings of type 49B and type 46, and Figs. 3 and 4 are the photographs of these buildings.

3. Results of observations.

The earthquakes in A and B are indicated in Tables II and III, and the epicenters are shown in Figs. 5 and 6.

The frequency-period relation of main shocks obtained from the seismograms of the earthquakes in A and B are shown in Figs. 7–16

1) K. KANAI, T. HISADA, K. NAKAGAWA and T. SUZUKI, *Res. Report, Architect. Inst., Japan*, No. **24** (1953), 185 (in Japanese).

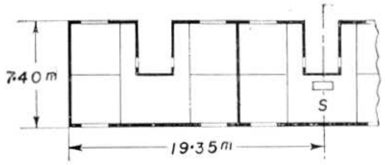


Fig. 1a. Plan view of type 49B.

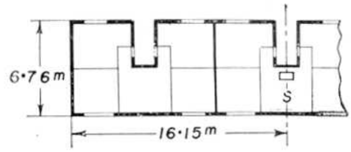


Fig. 2a. Plan view of type 46.

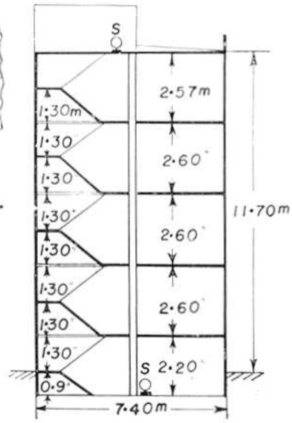


Fig. 1b. Side view of type 49B.

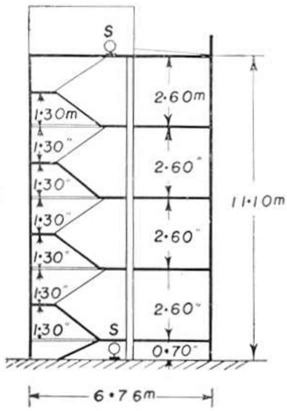


Fig. 2b. Side view of type 46.

Fig. 3. Building of type 49B.

Fig. 4. Building of type 46.

Table II.

Earthq. No.	Date	Origin		
		Depth (km)	φ	λ
A 1	1951 IX 23	40	34.3	136.2
A 2	〃 〃 27	20～30	33.9	135.1
A 3	〃 〃 30	0～10	34.3	134.1
A 4	〃 〃 31	0～10	34.3	134.1
A 5	〃 X 9	20	34.7	135.0
A 6	〃 〃 11	40	33.7	134.4
A 7	〃 〃 14	80	32.5	137.2
A 8	〃 〃 16	40～50	32.8	134.3
A 9	〃 〃 23	20	34.6	135.0
A10	〃 〃 27	10	34.5	135.9

Table III.

Earthq. No.	Date	Origin		
		Depth (km)	φ	λ
B 1	1953 I 20	40	36.9	141.4
B 2	〃 〃 22	60	36.2	141.3
B 3	〃 〃 26	40	36.1	139.8
B 4	〃 II 11	10	36.4	140.6
B 5	〃 〃 13	—	Chiba-Prefect?	
B 6	〃 〃 18	40	36.5	141.0
B 7	〃 〃 〃	60	35.3/4	140.1/2
B 8	〃 〃 22	—	Tochigi-Prefect.	

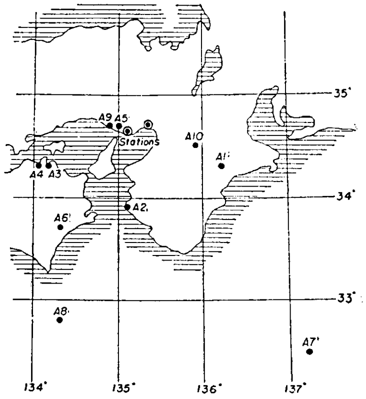


Fig. 5.

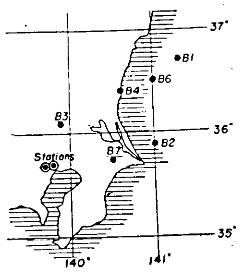
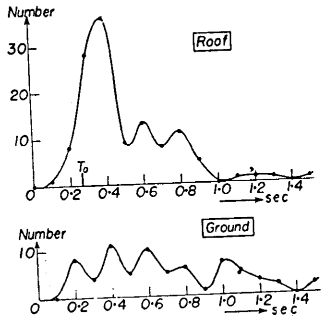
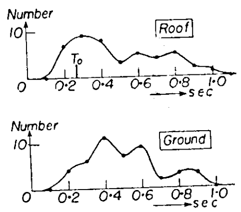


Fig. 6.



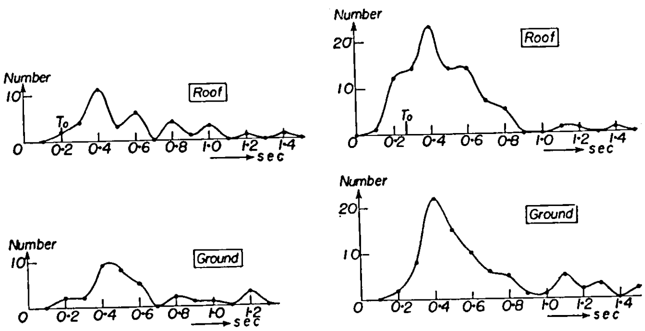
Nishinomiya

Fig. 7. Earthquake No. A1.



Nishinomiya

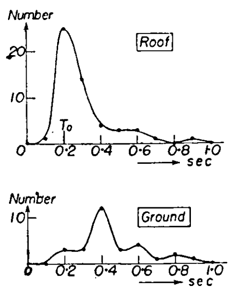
Fig. 8. Earthquake No. A2.



Kōbe

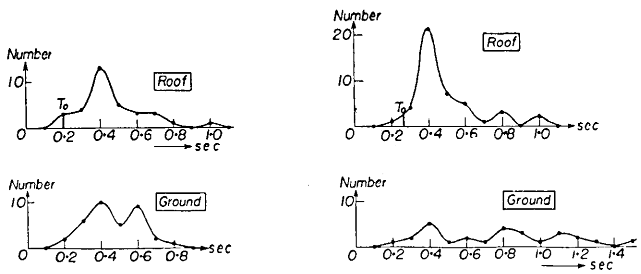
Nishinomiya

Fig. 9. Earthquake No. A3.



Kōbe

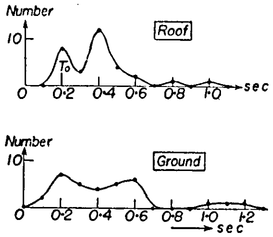
Fig. 10. Earthquake No. A4.



Kōbe

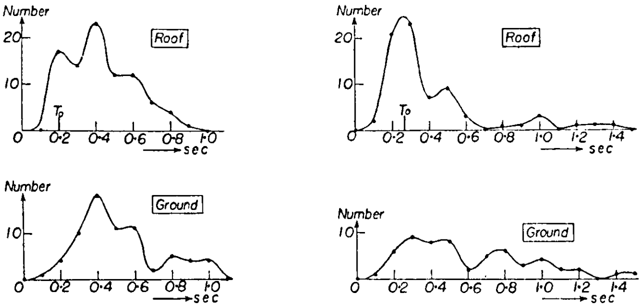
Nishinomiya

Fig. 11. Earthquake No. A5.



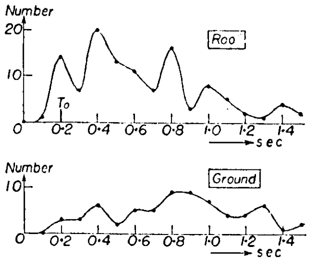
Kōbe

Fig. 12. Earthquake No. A6.



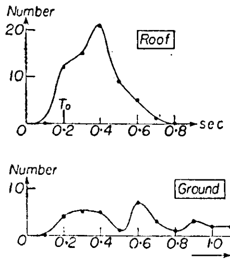
Kōbe Nishinomiya

Fig. 13. Earthquake No. 7.



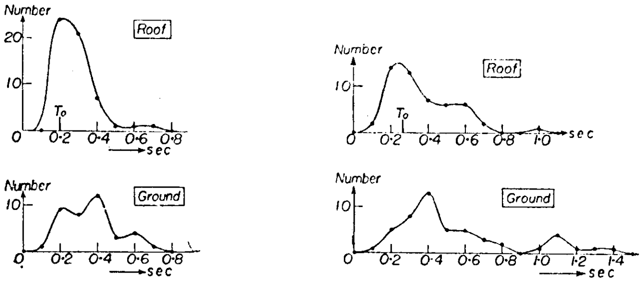
Kōbe

Fig. 14. Earthquake No. A8.



Kōbe

Fig. 15. Earthquake No. A9.



Kōbe Nishinomiya

Fig. 16. Earthquake No. A10.

and Figs. 17–24 respectively. Among these earthquakes, the representative seismograms concerning A and B are shown in Figs. 25 and 26 respectively.

As for the frequency-period curves of Kōbe, Nishinomiya and Senju, it can be seen that generally the frequency at roof-floor has peaks at both periods corresponding to the maximum of frequency at the ground-floor and to the natural period of the building. At Komagome, as the natural period is very approximate to that of the building, such a phenomenon can not be seen so clearly.

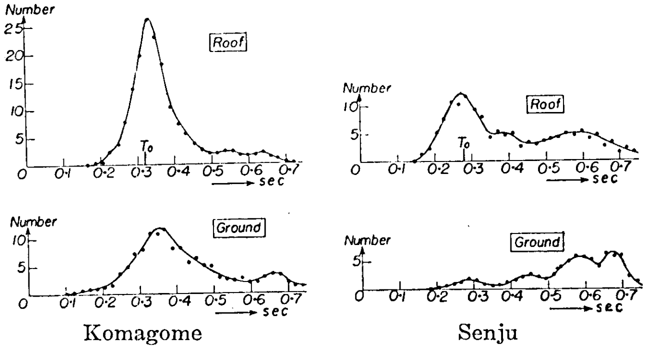


Fig. 17. Earthquake No. B1.

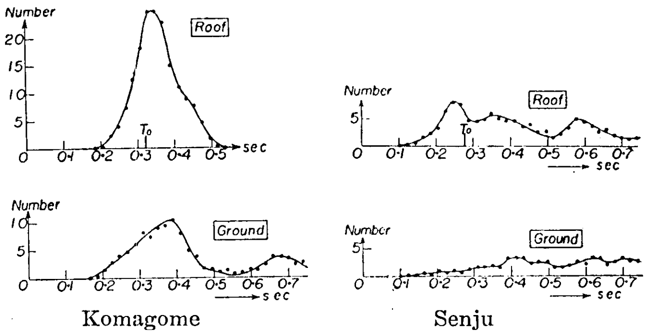


Fig. 18. Earthquake No. B2.

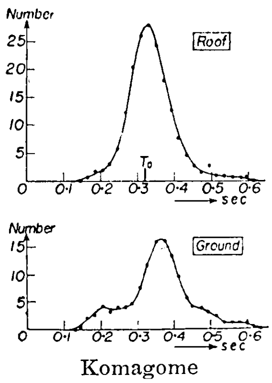


Fig. 19. Earthquake No. B3.

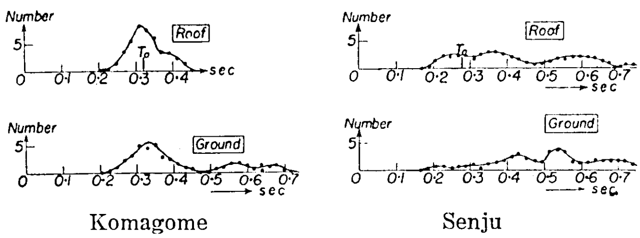
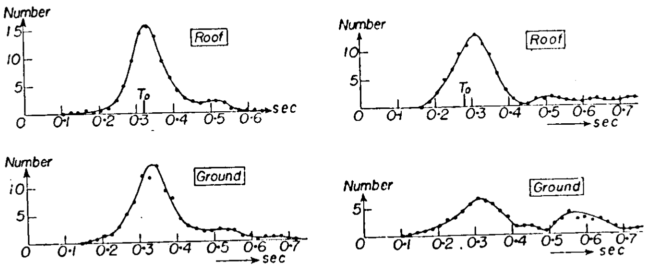
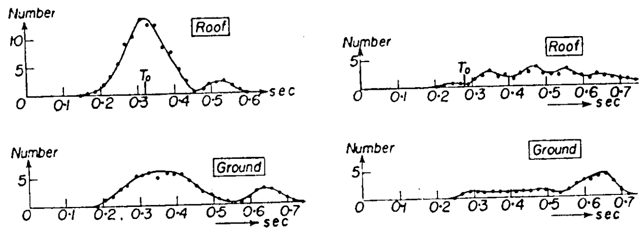


Fig. 20. Earthquake No. B4.



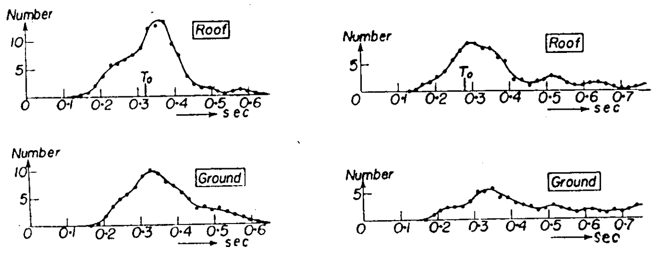
Komagome Senju

Fig. 21. Earthquake No. B5.



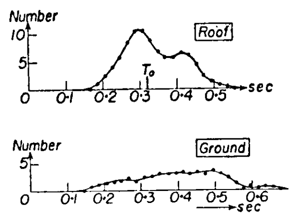
Komagome Senju

Fig. 22. Earthquake No. B6.



Komagome Senju

Fig. 23. Earthquake No. B7.



Komagome

Fig. 24. Earthquake No. B8.

Tables IV and V show the respective largest amplitudes, the mean amplitudes and periods of five waves including the wave of largest amplitude both on the roof-floor and the ground-floor in the course of the earthquakes shown in Tables II and III.

From Tables IV and V, it is seen that, regarding each earthquake,

Table IV. (Kb; Kōbe, N; Nishinomiya)

Earthq. No.	Amplitude (micron)						Mean Period (sec)			
	Largest						Roof		Ground	
	Roof		Ground		Kb/N					
	Kb	N	Kb	N	Roof	Ground	Kb	N	Kb	N
A 1	—	236	—	146	—	—	—	0.24	—	0.60
A 2	—	19	—	10	—	—	—	0.30	—	0.36
A 3	104	63	69	37	1.7	1.9	0.36	0.31	0.44	0.40
A 4	58	—	25	—	—	—	0.29	—	0.40	—
A 5	90	53	54	20	1.7	2.7	0.22	0.28	0.46	0.26
A 6	31	—	17	—	—	—	0.29	—	0.40	—
A 7	30	30	16	11	1.0	1.5	0.31	0.27	0.50	0.30
A 8	159	—	180	—	—	—	0.44	—	0.70	—
A 9	116	—	62	—	—	—	0.25	—	0.50	—
A10	100	86	36	39	1.2	0.92	0.22	0.32	0.22	0.40

Table V. (Km; Komagome, S; Senju)

Earthq. No.	Amplitude (micron)										Mean Period (sec)			
	Largegt						Mean				Roof		Ground	
	Roof		Ground		S/Km		Roof		Ground					
	Km	S	Km	S	Roof	Gro-und	Km	S	Km	S	Km	S	Km	S
B 1	135	86	65	81	0.64	1.2	113	63	48	60	0.32	0.49	0.46	0.60
B 2	69	101	43	70	1.5	1.6	53	73	34	58	0.33	0.46	0.45	0.87
B 3	127	—	34	34	—	1.0	90	—	32	27	0.34	—	0.37	0.41
B 4	28	49	17	42	1.8	2.5	18	35	11	31	0.35	0.47	0.45	0.56
B 5	83	74	42	42	0.89	1.0	71	57	32	29	0.34	0.28	0.41	0.31
B 6	76	104	40	73	1.4	1.8	49	81	27	53	0.33	0.31	0.44	0.46
B 7	67	133	41	102	2.0	2.5	55	103	32	79	0.43	0.57	0.49	0.63
B 8	91	—	51	—	—	—	64	—	32	—	0.31	—	0.47	—

the mean period of five waves including the wave of the largest amplitude on the ground-floor does not always coincide with the mean period on the roof-floor. But, the period of such meaning on the roof-floor of each earthquake becomes constant in general, and the value agrees roughly with the natural period of the building.

Such a property of frequency-period and the mean period as relation here implies that an actual building has a tendency to cause a resonance selecting the waves of which the period corresponds to its natural period from the earthquake motion with irregular wave-form.

Fig. 27 and 28 show the ratio of largest amplitude obtained both on the ground-floor and the roof-floor to the mean period of five waves

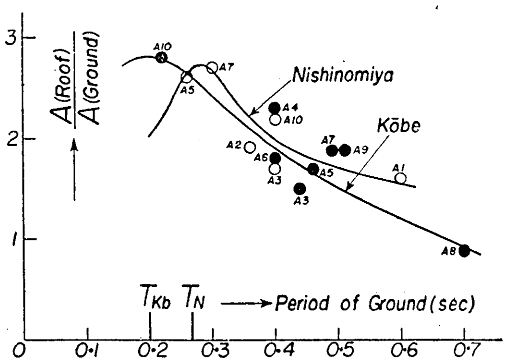


Fig. 27. *A* and *T* represent the largest amplitude and the natural period of building respectively.

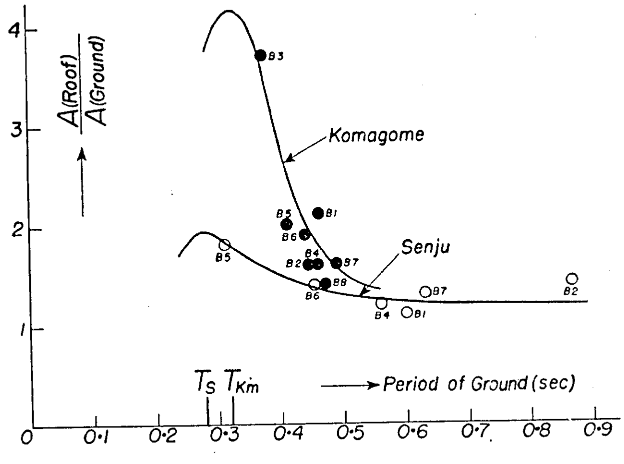


Fig. 28. *A* and *T* represent the largest amplitude and the natural period of building respectively.

including the largest amplitude on the ground-floor. (This relation is unchanged in the case of the mean amplitude of five waves including the wave of the largest amplitude observed both of the ground and roof floors). These figures indicate that the relation between the amplitude of building vibration and the period of earthquake motion strongly resembles that of the amplitude to the period of the building to which the forced vibration is exerted sinusoidally.

From the results related above it is found that the quasi-resonance amplitude obtained on the roof-floor becomes 2–4 time larger than that of the ground motion and the value gets smaller as the ground increases its softness. This is easily explained qualitatively from the nature of vibrational energy of building into the ground during earthquake[2].

4. Conclusion.

From the observation of vibration property of buildings of same structure standing on the ground of different properties, the following results were obtained.

(i) The relation between the largest amplitude of buildings in actual earthquakes and the mean period in the neighbour of the largest amplitude is approximate to the resonance curves which are obtained when sinusoidal forced vibration is exerted to the buildings. Therefore, from the point of earthquake-proof construction, it is needed that the resonance amplitude of the building is considered before it is possible to presume the period of destructive earthquake.

(ii) The ratio between the amplitude of quasi-resonance of building and that of earthquake motion varies according to the property of ground even when the buildings are of the same structure. The value of the above-mentioned becomes smaller as the ground gets softer. This can be explained from the fact that the damping caused by the vibrational energy of the building which dissipates into the ground becomes larger as the ground gets softer.

(iii) On the roof-floor, the amplitude of quasi-resonance of the four-storied buildings of bearing-wall type of reinforced concrete becomes 2–4 times larger than that of earthquake motion. Roughly speaking, it is 4-times larger on diluvium, 3-times larger on alluvium and 2-times larger on a specially soft ground.

2) K. SEZAWA and K. KANAI, "Improved Theory of Energy Dissipation in Seismic Vibrations of a Structure", *Bull. Earthq. Res. Inst.*, **14** (1936), 168.

(iv) The extent of the amplitude of ground vibration depends on the property of ground in case of earthquake is related to the period of seismic waves which reach the boundary surface between base rock and surface layer. Moreover, as seen from Tables IV and V, the ratio between the respective largest amplitudes obtained on the ground-floor of the buildings of same structure which stand on different kind of ground depends on the property of earthquake, but, generally speaking, on softer ground the value gets larger.

Therefore, at the time of earthquake, the effect of the amplitude of ground vibration on buildings counteracts the effect of damping of building vibration, and the difference among the largest amplitudes of buildings due to the ground property is not so great.

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 Building Section of Hyōgo Prefectural Office and of the Residential Association of Tokyo-to for their help and to Mr. K. Nakagawa and others of the Architectural Institute of Construction Ministry, for their cooperation in the course of these observations and to Miss S. Yoshizawa who assisted us in preparing this paper.

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29. 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)

地震研究所 {金井清 / 鈴木富三郎

地震による建物の振動の性質が地盤の性質の影響を受けることは概念としては既によく知られているところである．わが国の建築方面では，既に建物の設計に使う地震力に，構造の種類と，地盤の性質の差違とを考慮に入れることになつている． しかし，地震時の建物の振動と地盤の性質との量的な関係は，今後の研究にまつところが非常に多い．

同種の構造の建物に同じ形の強制力を与えた場合でも， 地盤の性質がちがうと， 建物の振動性状は異る．又，地盤の性質がちがうと，同じ地震についても，地表面の震動が異る．従つて，地震時の建物の振動は，地盤の性質の影響を 2 重に受けることになる．

前者の研究については，建物に人工的な強制力，例えば偏心荷重の廻転による力を与えて，建物の振動的性質と地盤の性質との関係をしらべる方法がとられている．又，後者については，このことを直接の目的とする地震動の理論的， 験震的研究並びに震害の統計的研究があるほかに， 地震動の性質をしらべるためのいろいろな立場からの研究の中に自然に数多くふくまれている．しかし，現在までのところ，両者をむすびつけて，量的な結果を得るための研究はあまり試みられていない．

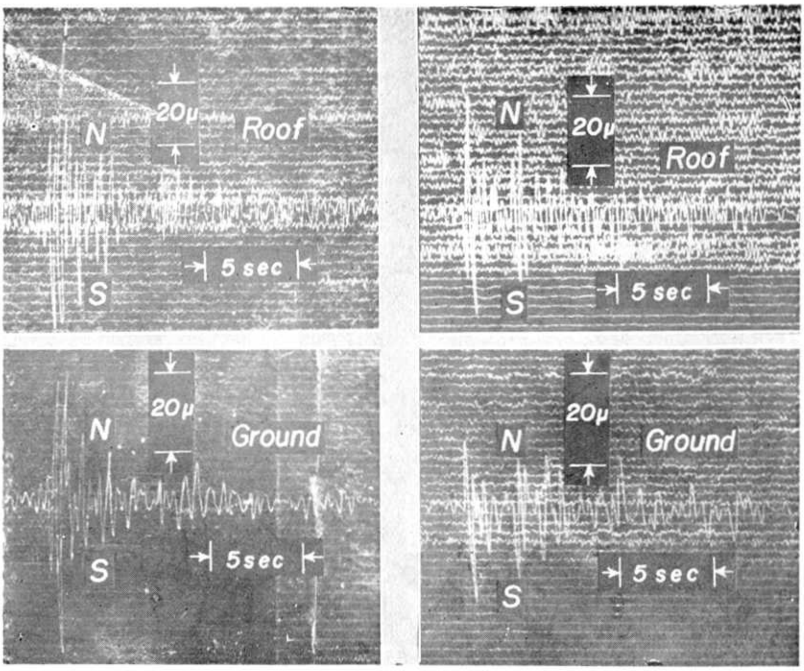
本研究は，耐震設計上の地盤係数を求めるために，性質の異る地盤の上に建つ同種構造の建物の地階と屋上とで地震動の比較観測を行つたものである．

あらゆる地盤について，地震時の建物の振動は，地階と屋上では波形が異る．最も手軽な地震記録の解析方法として，いわゆる頻度一周期曲線を作つて見ると，屋上の頻度一周期曲線には，地階の頻度一周期曲線の山のできるところと建物の固有周期にあたるところとの，少くとも 2 つの山ができる．又，屋上の最大動附近の数波の平均周期は，多くの地震について建物の固有周期に近い．この 2 つのことは，地震時に建物は自己振動を起し安い性質のあることを示すものである．

次に，最大動について，地階の振動周期に対する，屋上変位と地階変位との比の関係を求めてみると，その形は，あたかも，建物に正弦波形の強制力を加えた場合に得られる共振曲線によく似ている．このことは，起振機のようなものを使つて求めた建物の振動特性は，地震時の建物の振動特性として，工学的には採用できることを意味する．

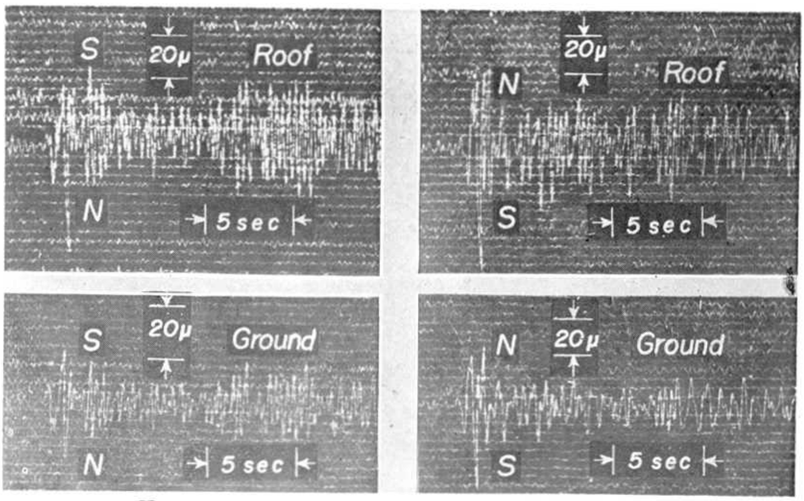
今回の研究結果によると，地動変位に対するこの種の建物の屋上の変位の比は 2～4 倍となり，地盤が堅い程大きい値をとる．その原因は，地震時に建物の振動勢力が地中に逸散するための振動減衰性によると考えられる．他方において，地震動振幅は一般に地盤が軟いほど大きくなる．

従つて，地震時における建物の振動に対する地盤の影響としては，建物の振動減衰性と地盤の性質との関係と，基礎の振動振幅と地盤の性質との関係が互に消し合う傾向になる．



Kōbe Nishinomiya

Fig. 25. Earthquake No. A3.



Komagome Senju

Fig. 26. Earthquake No. B6.

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