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9. *Vibration of a Reinforced Concrete Building moved with Vibration Generators.*

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The building was constructed in Marunouchi, Tokyo, a short time before the Tokyo-Yokohama earthquake of 1923 and demolished in 1953. Its height was 27.7m and six storied, total floor area 1460m^2. At the great earthquake, fissures were formed in a screen wall at entresol and in a wall at porch. The width of the fissures became gradually smaller as their positions grew higher and higher, and over the 4th floor no fissures were found. Before demolishing the building was investigated for constructional conditions; not only vibration measurements, but measurement of the deflection of the floor by loading, study of corrosion of steel in cement and other experiments were carried out.

Measurements of vibration of the building

Two vibration generators were used for this investigation. One consisted of 3 wheels with two horizontal axes (property of the Earthquake Research Institute), and the other a horizontal wheel with a vertical axis and more powerful than the first (property of the Building Research Institute). The former excited vibrational force in one direction, but the latter generated revolving force.

The 3 wheel vibration generator was set on the 6th floor or 3rd

Table 1. Vibration generators.

Type	Eccentric mass	Eccentric radius	Eccentric Moment
Horiz. axes (E. R. I.)	40×1+20×2=80 kg	15 cm	21.7 kg.m.
		31	34.4
Vert. axis (B. R. I.)	176.9		136.6

floor. The direction of the axes was changed in the direction of beam, or in the direction of girder to change the direction of the vibration of the building. In some cases, the generator was put near the end of the floor to give the building torsional vibrations.

Instruments used for the measurements of vibrations

Nine vibrographs were prepared for the measurements, and the number of the instruments used was changed to answer the need of

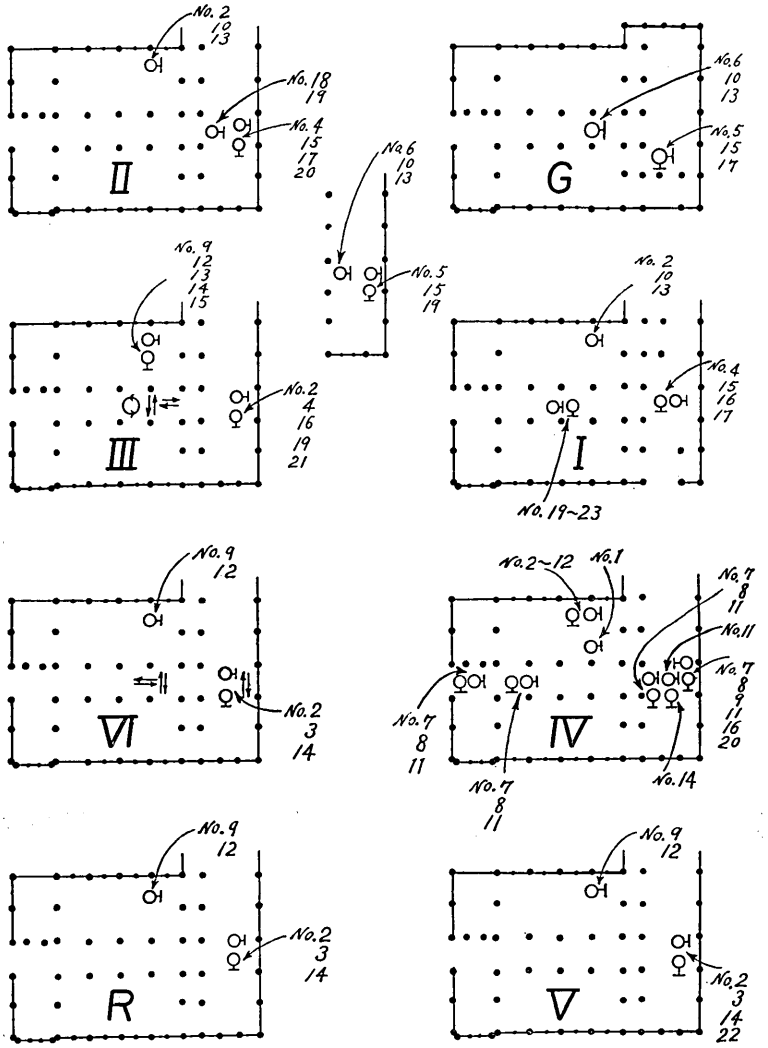


Fig. 1. Arrangement of the vibrographs on each floor at each No. of experiment.

the observation conditions. Type of the vibration generator, positions of the generator and vibrographs at each of the measurements are shown in Table 3. and Fig. 1.

Results of the observations

The relation between amplitude and period was studied, and the results are shown in Figs. 14~37.

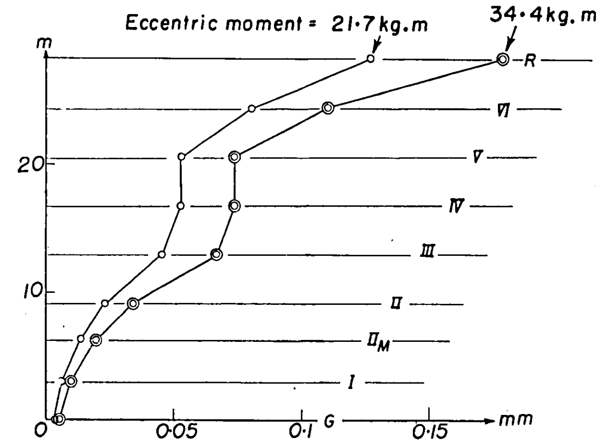


Fig. 2 Amplitudes distribution in beam direction. Experiment Nos.; 2, 6. Vibration generator; E.R.I. type set at the middle of the 6th-floor. Vibration direction; beam.

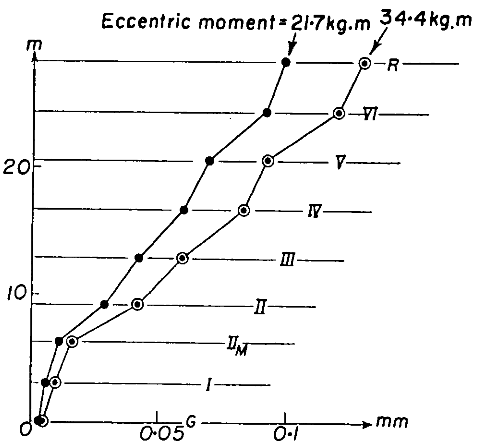


Fig. 3 Amplitudes distribution in girder direction. Experiment Nos.; 3,4,5. Vibration generator; E. R. I. type set at the middle of the 6th-floor. Vibration direction; girder.

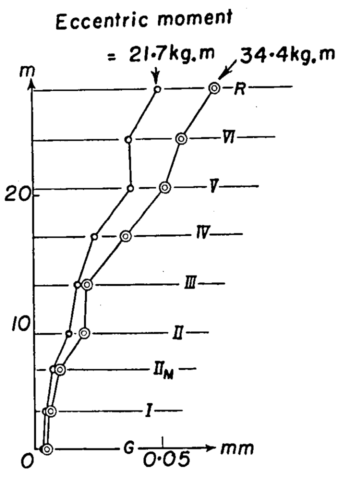


Fig. 4 Amplitudes distribution in beam direction. Experiment Nos.; 12 13. Vibration generator; E.R.I. type set at the middle of the 3rd-floor. Vibration direction; beam.

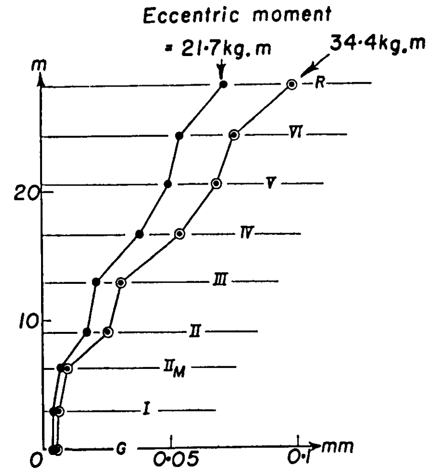


Fig. 5 Amplitudes distribution in girder direction. Experiment Nos.; 14, 15. Vibration generator; E.R.I. type set at the middle of the 3rd-floor in girder direction.

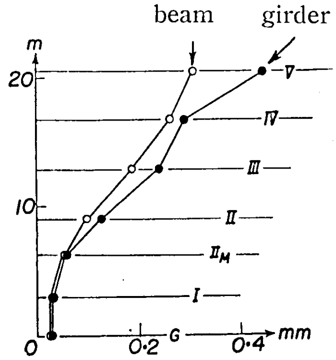


Fig. 6. Amplitudes distribution in beam and girder directions. Experiment Nos.; 17, 19, 20, 22. Vibration generator; B.R.I. type set at the middle of the 3rd-floor.

The amplitude variation with the height of the building was obtained from the data before mentioned and is shown in Figs. 2~6. Sometimes the horizontal axes vibrator was driven at the eastern end on the 6th floor to give the building torsional vibration. Amplitudes of the motion in the direction of beam on the 4th floor are shown in Fig. 7. from which we can see an evidence of the torsional vibrations.

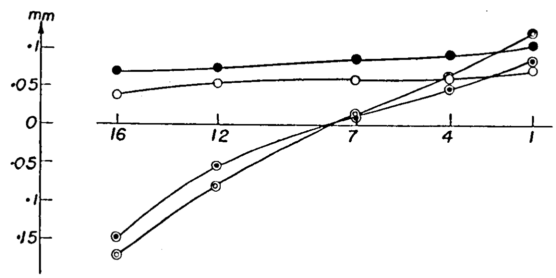


Fig. 7 Amplitudes distribution in beam direction on the 4th-floor. Experiment No.; 8. Vibration generator; E. R. I. type, set at the eastern end of the 6th-floor, in beam direction.

Amplitudes resonated by the vibrator at each of the measurements are shown in Table 4.

Consideration of the results of the measurements

The rigidity of columns on each floor was calculated from amplitude variation according to height and vibration period obtained, under the following assumptions: the feet of columns are fixed, the joints between floor and columns are rigid, the floor and girder are rigidly connected, the loads on the floor are concentrated, and the dissipation of the vibration energy of the building to the ground is negligible. The formula of K. Kanai was adopted to express relation between period, amplitude and mechanical properties of the building.

$$E_sI_s=\frac{1}{12}\left(\frac{2\pi}{T}\right)^2\frac{l_s^3}{y_s-y_{s-1}}\sum_{r=s}^{n}m_ry_r\ ,\ (s=1,\ 2,\cdots,\ n) \qquad (1)$$

where E: Young's modulus, I: moment of inertia, y: horizontal displacement, m: concentrated mass on a floor and l: height of column.

The data used for the calculations are tabulated in Table 6, and the results of the calculation in Table 7.

Test to examine rocking motion of the building accompanying its movement due to the vibration generator

Two vertical component tromometers were set up at the ends of the building in the direction of the vibrator motion to examine rocking motions of the building. If the building makes rocking vibration, vertical motions at the opposite ends of the building will be opposite in phase, or have a difference of phase angle 180°. The constants of the vertical tromometers used for the experiment were as follows:

$$T(\text{period})=3.0\ \text{sec.},\ v(\text{damping})=2.2,\ r(\text{friction})=0\ .$$

The ground floor may be the best place to put the instruments to observe the rocking motion, but there was no good place for setting up the tromometers, so the instruments were placed on the first floor.

Phase difference of vibrations between the two opposite places was recorded when the building resonated and the vibration became large. In such cases, the period of vibration was about 0.4 sec., probably the period of the fundamental vibration of the building. The phase difference measured was small (Figs. 8 and 9.) Then the writer at first deduced the building was not in rocking motion, but such consideration may be too hasty. The observations were made not on the underground floor, but on the first floor which may be flexed with vibrations of the building. Otherwise, it may be supposed that the building was too large to make rocking motions like a small rigid body, and the floor bended to adapt the movements of the upper structure and to the deformation of the ground.

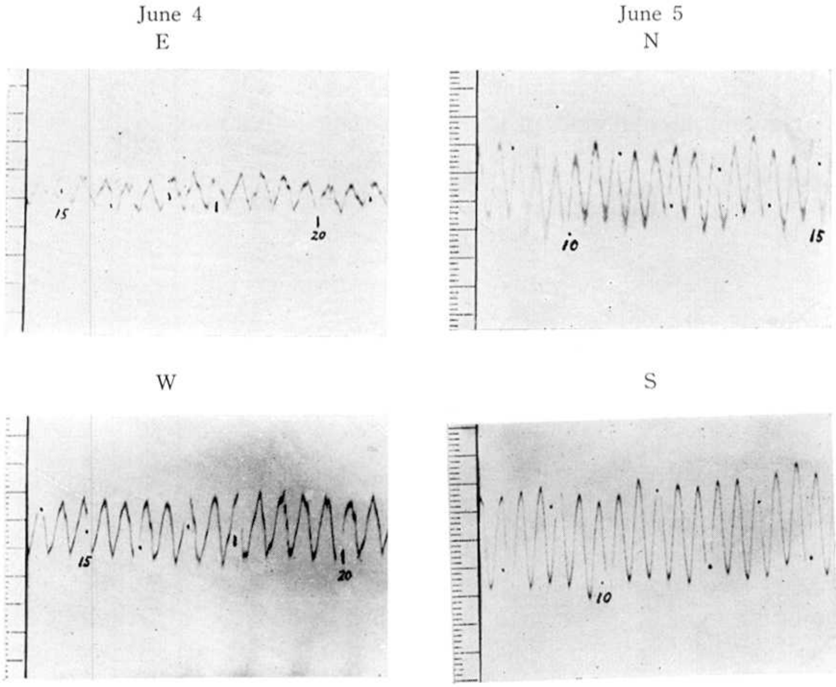


Fig. 8

Further the rocking motions were checked with two electromagnetic transducers and a 3 element electromagnetic oscillograph. On the ground floor horizontal component motion of the building was recorded side by side with vertical component. When the horizontal motion in the direction of beam was in resonance, the vertical component became in phase with them in rocking motions as shown in Figs. 10 and 12. When the building was moved in the direction of girder at first horizontal motions were observed with vertical motions as before, secondly vertical motions at the two ends of the building were recorded (Figs. 11, 12 and 13). In these cases rocking motion could not be found.

In this studies K. Kanai and N. Nasu were assigned the measurements of vibrations, F, Kishinouye, H. Kawasumi and E. Sima those of rocking motions, and the results were compiled by F. Kishinouye.

We wish to express our hearty thanks to Mr. Kyoji Nakagawa of the Building Research Institute, Dr. T. Naito of the Waseda University and Dr. R. Takahasi of our Institute with whose aid the studies were made.

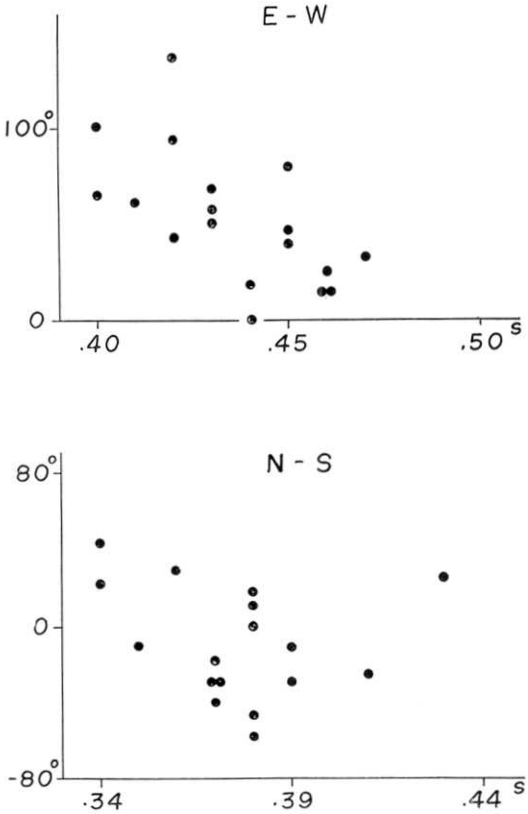


Fig. 9. Phase diffenence of vertical vibrations at two places.

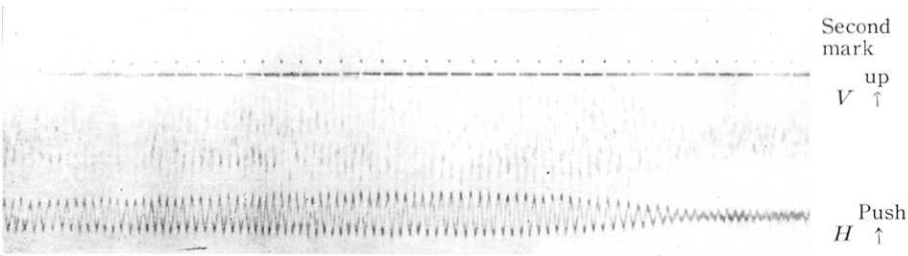


Fig. 10. Motions in the direction of beam on the ground floor. Horizontal and vertical transducers were set at opposite ends of the building in beam direction.

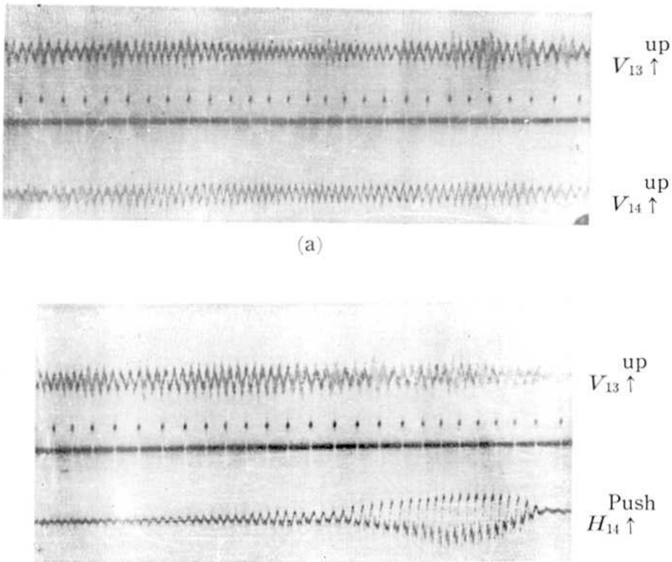


Fig. 11. Motions in the direction of girder on the ground floor.

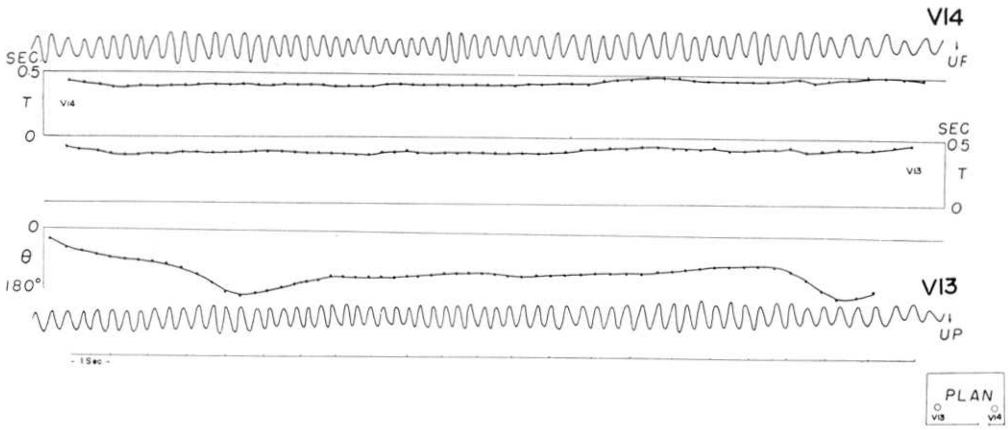


Fig. 12. Motions in the direction of girder on the ground floor. (enlarged from Fig. 11,(a))

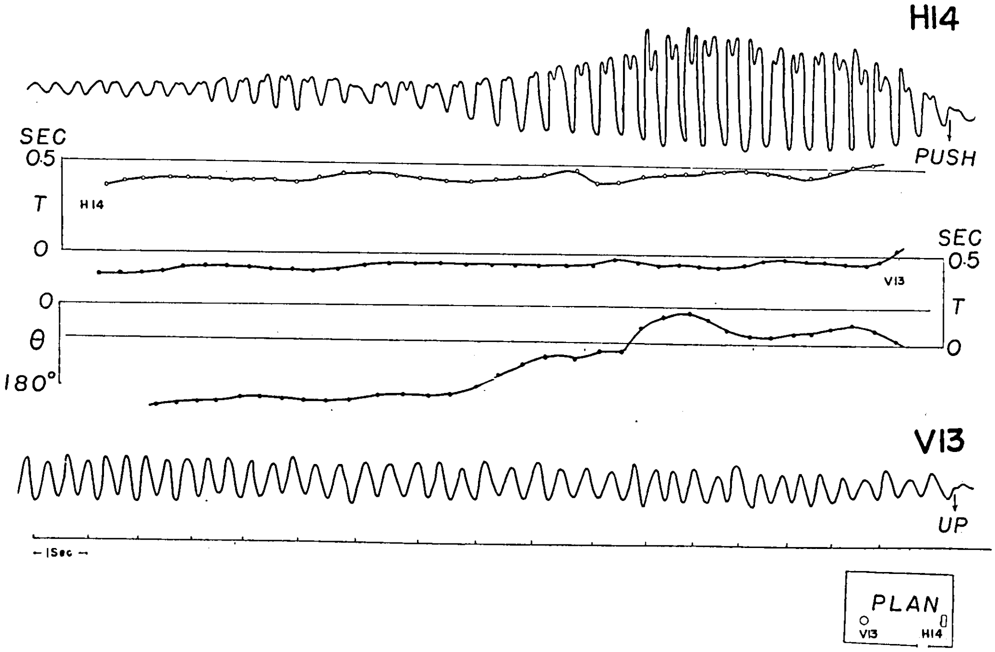


Fig. 13. Motions in the direction of girder on the ground floor. (enlarged from Fig. 12,(b))

Table 2. Constants of the vibrographs.

No. of vibrograph	Self-vibration period (sec)	Damping ratio	Magnification
1	1.0	13:1	120
2	〃	〃	130
3	〃	〃	150
4	〃	〃	200
5	〃	〃	180
6	〃	〃	175
7	〃	〃	180
8	5.0	〃	20
9	〃	〃	18

Table 3. Arrangements of the instruments in the building. (ERI: Earthquake Research Institute, BRI: Building Research Institute, VI_M: middle of the 6th floor, VI_E: eastern end of the 6th floor, III_M: middle of the 3rd floor, B: beam direction, G: girder direction, T: torsion.)

No. of experiment	Date. 1954	Vibration generators			Vibragraphs									
		Type	Position	Direction	Direction	No. R	VI	V	IV	III	II	II_M	I	G
1	April 19	ERI	VI_M	B	B	—	—	—	1~7	—	—	—	—	—
2	〃	〃	〃	〃	〃	1	2	3	4	5	6	—	7	—
3	20	〃	〃	G	G	1	2	3	4	—	—	—	—	—
4	〃	〃	〃	〃	〃	—	—	—	4	3	2	—	1	—
5	22	〃	〃	〃	〃	—	—	—	4	—	—	2	—	5
6	〃	〃	〃	B	B	—	—	—	4	—	—	2	—	5
7	23	〃	〃	〃	〃	—	—	—	1~5	—	—	—	—	—
8	〃	〃	VI_E	〃	〃	—	—	—	1~5	—	—	—	—	—
9	〃	〃	〃	〃	〃	1	2	3	4	5	—	—	—	—
10	24	〃	〃	〃	〃	—	—	—	4	—	3	2	1	5
11	〃	〃	〃	〃	〃	—	—	—	4	—	—	—	—	—
					G	—	—	—	1~5	—	—	—	—	—
12	25	〃	III_M	〃	B	1	2	3	4	5	—	—	—	—
13	〃	〃	〃	〃	〃	—	—	—	—	5	3	2	1	4
14	27	〃	〃	G	G	1	2	3	4	5	—	—	—	—
15	〃	〃	〃	〃	〃	—	—	—	—	5	3	2	1	4
16	June 3	BRI	III_M	T	B	—	—	—	1	3	—	—	5	—
					G	—	—	—	2	4	—	—	—	—
17	〃	〃	〃	〃	B	—	—	—	—	—	1	—	—	3
					G	—	—	—	—	—	2	—	5	4
18	4	〃	〃	〃	B	—	—	—	—	—	1~5 8,9	— —	— —	— —
18'	〃	ERI	〃	B	B	—	—	—	—	—	1~5 8,9	— —	— —	— —
19	〃	BRI	〃	T	B	—	—	—	—	8	—	1	3	—
					G	—	—	—	—	9	—	2	4	—
19′	〃	ERI	〃	G	B	—	—	—	—	8	—	1	3	—
					G	—	—	—	—	9	5	2	4	—
20	5	BRI	〃	T	B	—	—	—	8	—	1	—	3	—
					G	—	—	—	9	—	2	—	4	—
21	〃	〃	〃	〃	B	—	—	—	—	8	—	—	3	—
					G	—	—	—	—	9	—	—	4	—
21′	〃	ERI	〃	B	B	—	—	—	—	8	—	—	3	—
					G	—	—	—	—	9	—	—	4	—
22	〃	BRI	〃	T	B	—	—	8	—	—	—	—	3	—
					G	—	—	9	—	—	—	—	4	—
23	〃	〃	〃	〃	B	—	—	—	—	—	—	—	3	—
					G	—	—	—	—	—	—	—	4	—

Table 4. Resonance Amplitudes in mm. (L and S represent the cases of the eccentric moment of 2.17kg.m and 3.44kg.m, respectively.)

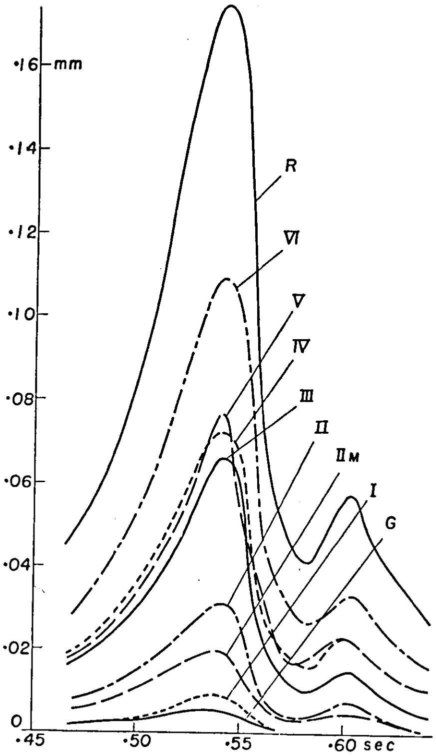
Vibration generator	E R I type										B R I type	
Position	middle of the 6th floor				eastern end of the 6th floor		middle of the 6th floor				middle of the 6th floor	
Direction	beam		girder		beam		beam		girder		beam	girder
kg. m	L	S	L	S	L	S	L	S	L	S		
R	0.175	0.124	0.130	0.101	0.142	0.105	0.075	0.048	0.102	0.075		
VI	0.111	0.080	0.117	0.091	0.113	0.085	0.060	0.037	0.078	0.056		
V	0.074	0.052	0.100	1.081	0.106	0.076	0.055	0.036	0.070	0.050	0.308	0.444
IV	0.074	0.052	0.083	0.063	0.082	0.055	0.040	0.025	0.055	0.038	0.257	0.284
III	0.066	0.045	0.063	0.048	0.056	0.036	0.025	0.015	0.030	0.019	0.184	0.238
II	0.031	0.023	0.042	0.032	0.040	0.028	0.020	0.013	0.026	0.017	0.098	0.124
II_M	0.020	0.014	0.015	0.012	0.021	0.015	0.009	0.007	0.009	0.006	0.055	0.055
I	0.009	0.006	0.009	0.007	0.011	0.008	0.006	0.004	0.006	0.005	0.028	0.030
B	0.006	0.005	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.024	0.024

Table 5. Constants of the building. (No.=No. of floor, l_s=floor height, m_s=concentrated mass.)

No.	G	I	II	III	IV	V	VI
l_s(m)	2.97	6.15	3.79	3.19	3.79	3.79	3.94
m_s(ton)	1100	297	192	184	184	175	288

Table 6. The values of effective stiffness of all vertical members of the building, EI calculated by equation (1). (L=eccentric moment of 34.4kg.m., S=21.7kg.m.)

EI $\times 10^{-18}$ C.G.S.	ERI type								BRI type	
	middle of the 6th-floor				middle of the 3rd-floor				middle of the 3rd-floor	
	beam direction		girder		beam		girder		beam	girder
	L	S	L	S	L	S	L	S		
E_6I_6	0.6	0.6	1.8	1.9	1.2	1.1	0.8	0.8		
E_5I_5	1.1	1.2	1.9	2.6	4.8	15.2	3.3	3.3		
E_4I_4	∞	∞	2.5	1.9	2.1	1.8	2.3	2.1	3.1	1.0
E_3I_3	7.4	6.5	2.6	2.7	2.5	2.4	1.6	1.6	2.9	4.6
E_2I_2	1.9	2.3	2.8	2.9	8.1	12.9	11.4	16.0	3.0	2.2
E_1I_1	14.2	14.0	8.4	8.8	13.7	13.7	10.8	12.6	17.9	13.1
E_0I_0	12.7	29.1	6.8	6.8	12.0	15.5	26.4	18.7	39.8	25.5



Explanation of notations in Figs. 14~37;

Exp. = Experiment number
Type=Type of the vibration generator (eccentric moment)
Position=Position of the vibration generator
Vibration=Vibration direction of the vibration generator
Measurement=Measurement direction of ʌibrographs

Fig. 14. Exps.; 2, 6
Type; ERI (34.4kg.m.)
Position; middle of the 6th-floot
Vibration; beam
Measurement; beam.

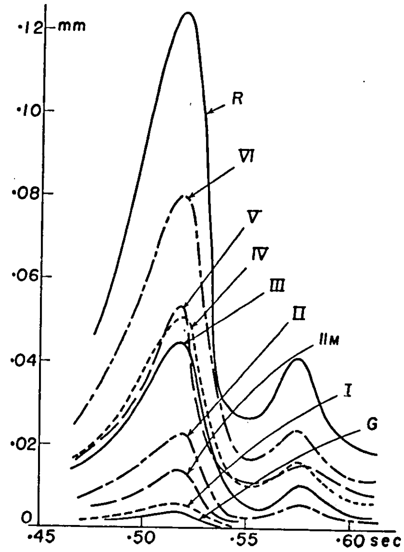


Fig. 15. Exps.; 2, 6
Type; ERI (21.7kg.m.)
Position; middle of the 6th-floor
Vibration; beam
Measurement; beam.

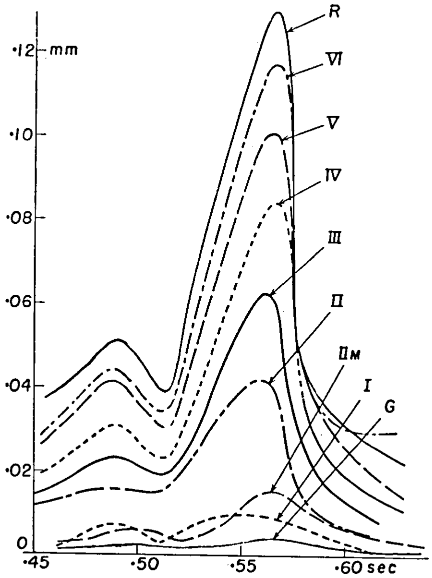


Fig. 16. Exps.; 3, 4, 5
Type; ERI (34.4kg.m.)
Position; middle of the 6th-floor
Vibration; girder
Measurement; girder.

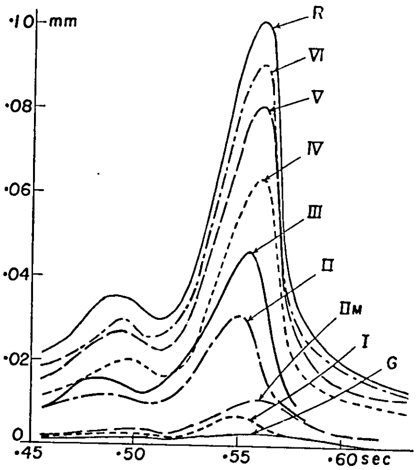


Fig. 17. Exps.; 3, 4, 5
Type; ERI (21.7kg.m.)
Position; middle of the 6th-floor.
Vibration; girder
Measurement; girder.

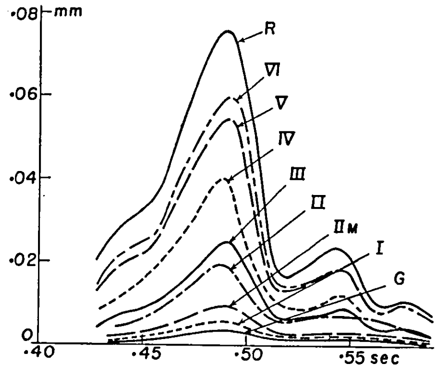


Fig. 18. Exps.; 12, 13
Type; ERI (34.4kg.m.)
Position; middle of the 3rd-floor
Vibration; beam
Measurement; beam.

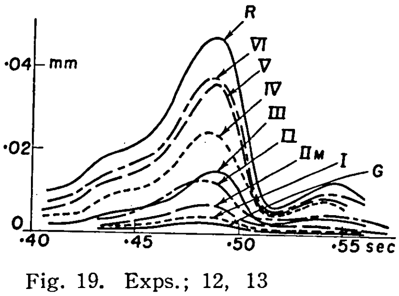


Fig. 19. Exps.; 12, 13
Type; ERI (21.7kg.m.)
Position; middle of the 3rd-floor
Vibration; beam
Measurement; beam.

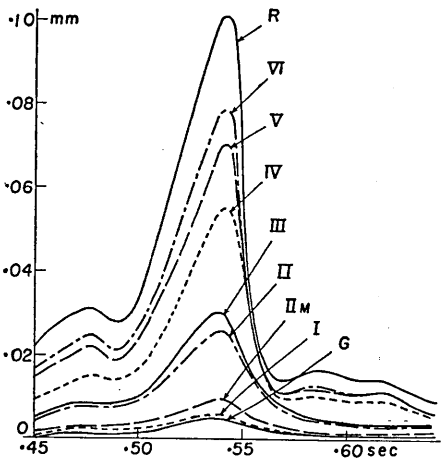


Fig. 20. Exps.; 14, 15
Type; ERI (34.4kg.m.)
Position; middle of the 3rd-floor
Vibration; girder
Measurement; girder.

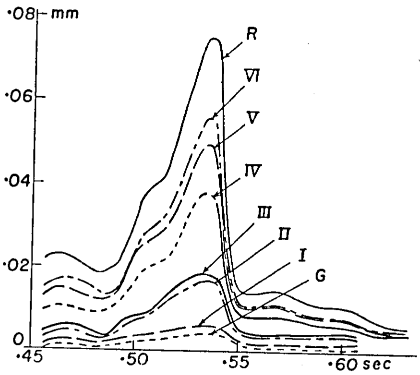


Fig. 21. Exps.; 14, 15
Type; ERI (21.7kg.m.)
Position; middle of the 3rd-floor
Vibration; girder
Measurement; girder.

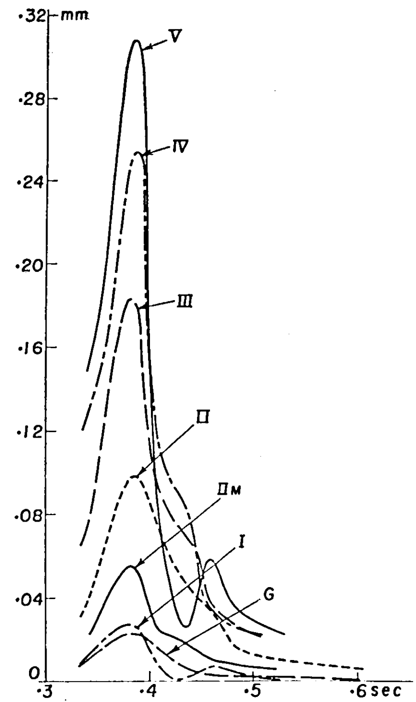


Fig. 22. Exps.; 17, 19, 20, 22
Type; ERI (136.6kg.m.)
Position; middle of the 3rd-floor
Measurement; beam.

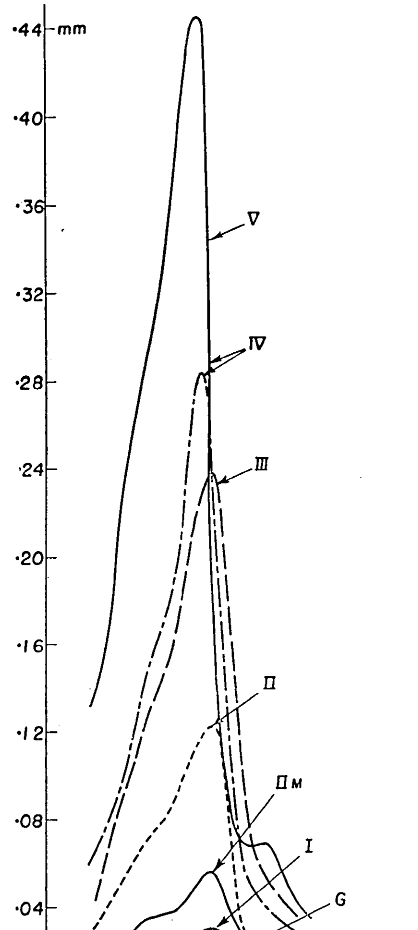


Fig. 23. Exps.; 17, 19, 20, 22
Type; BRI (136.6kg.m.)
Position; middle of the 3rd-floor
Measurement; girder.

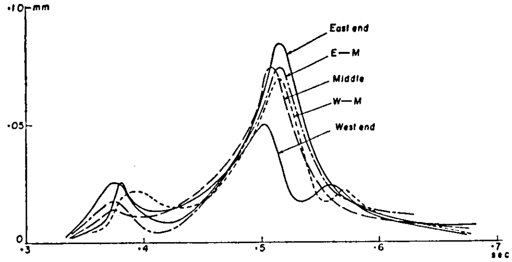


Fig. 24. Exp.; 7
Type; ERI (34.4kg.m.)
Position; middle of the 6th-floor
Vibration; beam
Measurement; girder, 4th-floor.

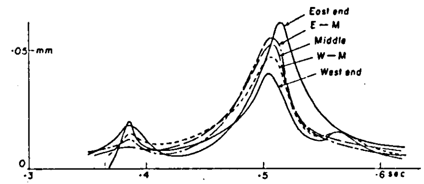


Fig. 25. Exp.; 7
Type; ERI (21.7 kg.m.)
Position; middle of the 6th-floor
Vibration; beam
Measurement; girder, 4th-floor.

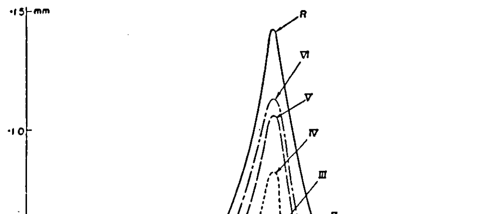


Fig. 26. Exps.; 9, 10
Type; ERI (34.4kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; beam, 6th-floor.

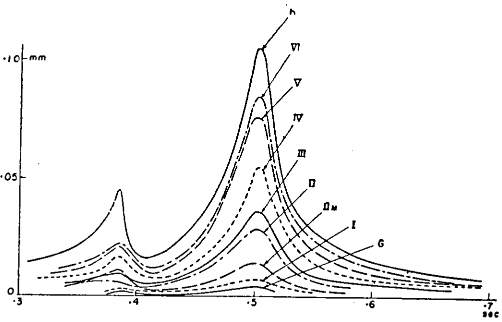


Fig. 27. Exps.; 9, 10
Type; ERI (21.7kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; beam, 6th-floor.

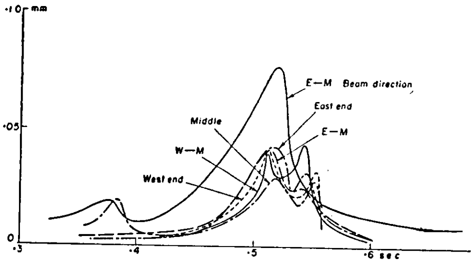


Fig. 28. Exp.; 11
Type; ERI (34.4kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; girder, 6th-floor.

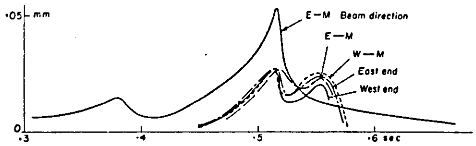


Fig. 29. Exp.; 11
Type; ERI (21.7kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; girder, 6th-floor.

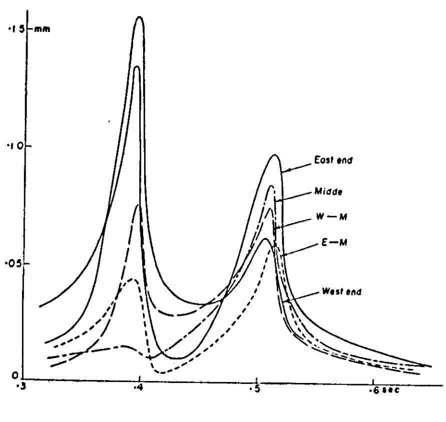


Fig. 30. Exp.; 8
Type; ERI (34.4kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; girder, 4th-floor.

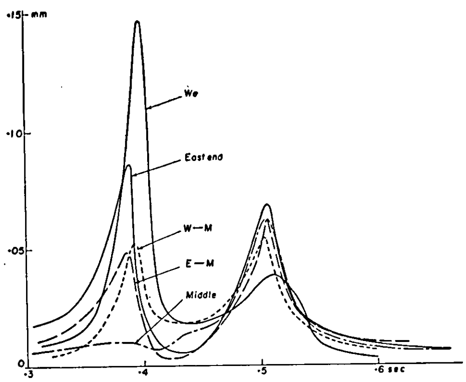


Fig. 31. Exp.; 8
Type; ERI (21.7 kg.m.)
Position; eastern end of the 6th-floor
Vibration; beam
Measurement; girder, 4th-floor.

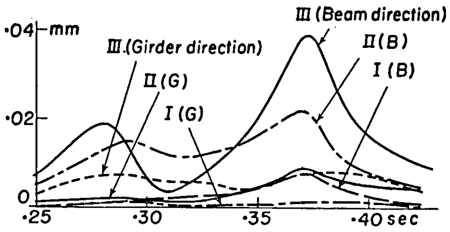


Fig. 32. Exp.; 21′
Type; ERI (34.4kg.m.)
Position; middle of the 3rd-floor
Vibration; beam.

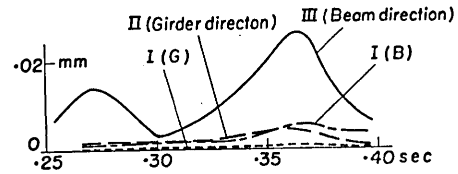


Fig. 33. Exp.; 21′
Type; ERI (21.7kg.m.)
Position; middle of the 3rd-floor
Vibration; beam.

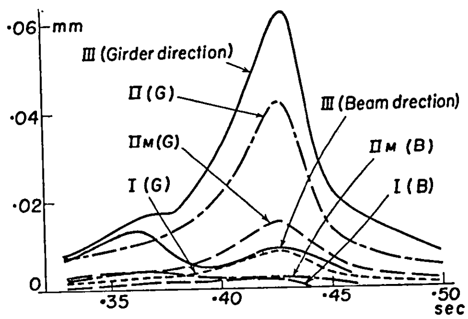


Fig. 34. Exp.; 19′
Type; ERI (34.4kg.m.)
Position; middle of the 3rd-floor
Vibration; girder.

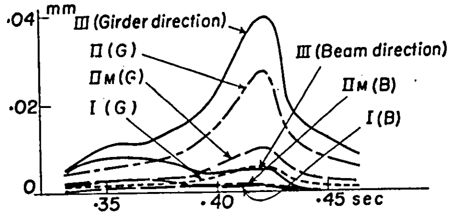


Fig. 35. Exp.; 19′
Type; ERI (21.7kg.m.)
Position; middle of the 3rd-floor
Vibration; girder.

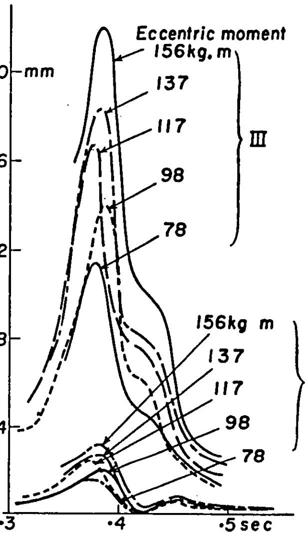


Fig. 36. Exp.; 23
Type; BRI (136.6 kg.m.)
Position; middle of the 3rd-floor
Measurement; beam.

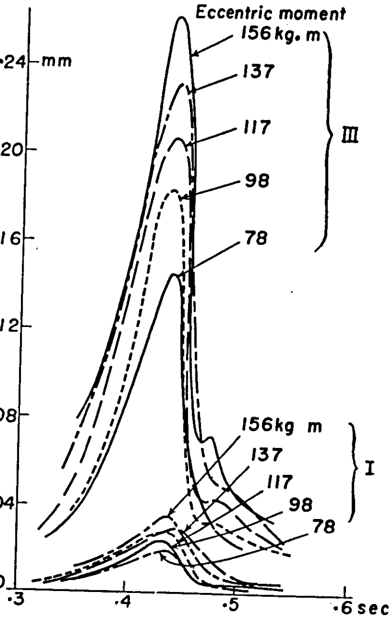


Fig. 37. Exp.; 23
Type; BRI (136 kg.m.)
Position; middle of the 3rd-floor
Measurement; girder.

9. 鉄筋コンクリート造建物の振動実験

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東京丸ノ内にあつた高さ 27.7m, 6階建,床面積 1460m² の鉄筋コンクリート造の建物が 1953年に取こわされた. こわす前に起振機を6階又は3階にすえて振動実験をした. その実験につかつた計器については表に示し，測定結果は図によつて表わした. そして振動周期については計算値と比較し，振動に伴つて建物が傾斜してロッキングを起したかを調べた.