

Motion of a Brick Wall Produced by Earthquakes.*

By

F. Omori, *Rigakushi, Rigakuhakushi,*

Member of the Imperial Earthquake Investigation Committee.

The present note contains the results of the measurement of the motion of a wall produced by earthquakes; the wall chosen for examination being the eastern end wall† of the Natural History Museum, which is a two-storied brick building situated in the higher part of the grounds of the University, Tokyo. Fig. 2 (Pl. XXIII) gives the exterior view of the building, while Fig. 3 (Pl. XXIV) gives the vertical section of the wall. As will be seen from the latter figure, the total height of the wall, that is to say, the distance between the coping stone and the ground, amounts to 53 *shaku* ‡; the height of the ceiling of the second story above the ground being 37 *shaku*.

The motion of the wall was measured by means of a small horizontal pendulum seismograph set up on a strong wooden support fixed to the wall at a height of 31 *shaku* from the ground, fig. 1 (Pl. XXIII); the pointer of the instrument, which has a magnification of 5, recording the motion normal to the wall, or that in the E W direction. The records obtained at the Natural History Museum

* See also the present Author's paper: "Earthquake Measurement in a brick building," the *Publications*, No. 4.

† The wall was originally intended to be a kind of partition wall separating the present building from its extension. The latter, however, never came into existence, the idea having since been abandoned.

‡ 1 *shaku* = 0.994 feet.

have been compared with the E W component diagrams given by a seismograph, also of 5-times magnification, in the Seismological Institute ; it being assumed that the motion at the latter is identical with that at the basement of the Museum.

The record-receiver, or drum, of the seismograph at the Natural History Museum has a circumference of 668mm and made one revolution in about 30 seconds, the rate of motion being accurately gauged by means of a time-marking pendulum, whose one complete oscillation was made in 0.75 sec. Again the recording drum of the seismograph in the Seismological Institute has a circumference of 960mm and made one revolution in about 40 seconds, the period of the time-marking pendulum being 0.99 sec. Each instrument is automatically started at the time of an earthquake by means of an electric contact-maker, whose sensibility was purposely made not very great in order to exclude very slight earthquakes.

It was soon found that the movements of the wall in question was always much greater than those at the ground surface ; consequently the seismograph in the Natural History Museum being much more sensitive than the other. Thus, during the five months between May 15th and Oct. 25th, 1892, twenty-three earthquakes were recorded at the Museum, of which only eleven were observed at the Seismological Institute. Tables I and II give respectively the date and the elements of motion of the 23 earthquakes ; some of the illustrative diagrams being given in Pls. XXV and XXVI.

In the analysis of the seismograms, 2a denotes the range of motion, or double amplitude, of the vibration.

TABLE I.
LIST OF THE EARTHQUAKES OBSERVED.

No. of earthquake.	Date.	Time of occurrence.	Intensity.
1.	May 15th 1902;	8.50. 0 p.m.	Slight.
2.	„ 25th „	8.30. 0 p.m.	Weak.
3.	June 13th „	5. 1.25 a.m.	Slight.
4.	„ 20th „	5.49.19 p.m.	Weak.
5.	„ 23rd „	7.42.20 a.m.	„
6.	„ 24th „	9. 7.40 p.m.	Slight.
7.	July 1st „	2. 0.54 a.m.	„
8. *	„ 8th „	11. 8.36 p.m.	„
9.	„ 14th „	10.40. 7 p.m.	„
10.	„ 23rd „	11.52.54 p.m.	„
11.	„ 26th „	7.51. 2 a.m.	„
12. *	Aug. 4th „	1.56. 2 a.m.	„
13.	„ 7th „	0.35.55 p.m.	Weak.
14.	„ 8th „	8.36.53 a.m.	Slight.
15.	„ 25th „	9. 8.48 a.m.	„
16.	Sept. 12th „	4. 7.54 a.m.	„
17. *	„ 14th „	6.20.41 p.m.	„
18. *	„ 22nd „	5.43.25 a.m.	„
19. *	„ „ „	10 52.29 a.m.	„
20. *	„ 27th „	7.19.17 a.m.	„
21.	Oct. 12th „	10.23. 0 a.m.	„
22. *	„ 16th „	1.57.24 a.m.	„
23.	„ 25th „	9. a.m.	„

* Those *slight* earthquakes marked with *asterisks* were very small *unfelt* ones.

TABLE II.

EARTHQUAKE OBSERVATION AT THE NATURAL HISTORY MUSEUM.
AND AT THE SEISMOLOGICAL INSTITUTE.

{ 2a = Range of motion or double amplitude.
{ T = Complete period of vibration.

No. of earthquake.	Motion of the Wall. [Nat. Hist. Museum]				Motion of the ground. [Seismological Institute]			
	Total duration. (sec.)	Duration of Principal portion. (sec.)	Max. 2a (mm.)	T (sec.)	Total duration. (sec.)	Duration of Principal portion. (sec.)	Max. 2a. (mm.)	T (sec.)
1	94	29	0.40	0.31	91	9	0.04	0.18
2	100	40	1.20	—	—	—	—	—
3	80	17	0.08	0.29	—	—	—	—
4	117	68	0.80	0.34	—	17	0.12	0.18
5	184	86	3.60	0.35	—	23	{ 0.70 1.20 1.50	{ 0.19 0.39 0.66
6	—	—	0.32	—	—	—	—	—
7	59	14	0.50	0.25	42	11	0.12	0.19
8	40	—	Small.	0.38	—	—	Very gentle.	—
9	61	17	0.36	0.32	18	—	0.06	0.23
10	73	22	0.40	0.31	27	—	0.08	0.20
11	124	40	0.80	0.34	—	14	0.14	0.19
12	105	19	0.40	0.31	—	—	—	—
13	84	28	1.80	—	—	15	1.30	0.34
14	84	31	0.46	0.31	—	—	—	—
15	122	17	0.20	0.40	9	—	0.04	0.19
16	40	—	0.10	0.33	—	—	—	—
17	90	30	0.34	—	—	—	—	—
18	—	—	Very small.	—	—	—	—	—
19	127	—	0.10	0.31	—	—	—	—
20	165	37	0.40	0.45	25	7	0.04	0.18
21	97	21	0.46	0.30	—	—	—	—
22	84	15	0.26	0.31	—	—	—	—
23	81	40	0.30	0.30	22	—	0.06	—
Mean*	94 sec. (96 sec.)	36 sec. (32 sec.)	0.78 mm (0.58 mm)	0.33 sec.	33 sec.	14 sec.	0.29	{ 0.19 0.37 0.66

* The mean values of the elements of motion of the wall have been obtained by taking only the 11 earthquakes also recorded in the Seismological Institute. The mean values deduced from all the 23 earthquakes are closed within brackets.

NOTES.

Eqke No. 2. (Nat. Hist. Mus.) At the commencement there were traces of small vibrations of an average period of about 0.11sec.

Eqke No. 4. This was a moderate earthquake.

(Nat. Hist. Mus.) In the *preliminary tremor*, the motion consisted of small vibrations of an average period of 0.12 sec. During the first 6.2 sec. of the *principal portion*, these quick vibrations were superposed on principal vibrations, whose average period was 0.34 sec. In the *end portion*, the average period was 0.35 sec.

(Seism. Inst.) In the *principal portion*, the vibrations of an average period of 0.18 sec. (max. $2a=0.12\text{mm}$) were superposed on larger ones of an average period of 0.63 sec. (max. $2a=0.4\text{mm}$).

Eqke No. 5. This was a moderately sharp shock.

(Nat. Hist. Mus.) In the *preliminary tremor*, the max. $2a$ was 0.6mm and the average period 0.35 sec.; there being also small vibrations of an average period of 0.11 sec. The *principal portion* began with a single slow undulation of $2a=7.6\text{mm}$, period=2.0 sec.; and the motion was most active for the first 10.5 seconds, during which the average period was 0.35 sec., the two maximum motions of $2a=3.6\text{mm}$ and $2a=3.4\text{mm}$ having occurred respectively at 1.5 sec. after the commencement, and at the end, of this epoch. In the succeeding part, where the motion was much smaller, the average period was 0.33 sec. In the *end portion*, the average period was also 0.33 sec. As is usually the case with the records from the Nat. Hist. Museum, the motion presented a series of alternations of maximum and minimum groups. Thus the maximum groups, each containing 4 or 5 well pronounced vibrations, occurred at a mean interval of 4.8 seconds.

(Seism. Inst.) In the *preliminary tremor*, the max. $2a$ was 0.06 mm, the average period being 0.14 sec. The *principal portion*, began with a slow undulation of $2a=10.4\text{mm}$, period=2.2 sec. The most active part of motion consisted of the vibrations of an average period of 0.19 sec., whose max. $2a$ of 0.7mm occurred at the 8th second

(after the commencement of the principal portion). From about the 9th second, there predominated the vibrations of an average period of 0.39 sec., of which the max. 2a of 1.2mm took place at the 10th second; these being mixed up with slower ones of an average period of 0.66 sec., whose max. 2a of 1.5mm occurred at the 15th second.

Eqke No. 9. (Nat. Hist. Mus.) The average period was 0.32 sec. in the *principal* and 0.31 sec. in the *end portion*. The maximum groups occurred at a mean interval of 4.3 seconds.

Eqke No. 10. (Nat. Hist. Mus.) The maximum groups occurred at a mean interval of 3.0 seconds.

Eqke No. 11. This was a moderate earthquake. (Nat. Hist. Mus.) The max. 2a of 0.8mm occurred at the commencement of the *principal portion*, the motion being most active and nearly uniform for the first 20.2 seconds. The average period was 0.32 sec. in the *principal portion* and 0.35 sec. in the *end portion*.

Eqke No. 12. (Nat. Hist. Mus.) The average period was 0.31 sec. in the *principal portion* and 0.35 sec. in the *end portion*. The maximum groups occurred at a mean interval of 4.8 seconds.

Eqke No. 13. (Nat. Hist. Mus.) The maximum groups occurred at a mean interval of 4.7 seconds.

(Seism. Inst.) The most active vibrations had a max. 2a of 1.3mm and an average period of 0.18 sec.

Eqke No. 21. (Nat. Hist. Mus.) The average period was 0.30 sec. in the *principal portion*, and 0.33 sec. in the *end portion*. The max. 2a of 0.46mm occurred 11.3 seconds after the commencement.

Eqke No. 23. (Nat. Hist. Mus.) The average period was 0.30 sec. in the *principal portion* and 0.32 sec. in the *end portion*.

SUMMARY OF THE RESULTS.

Comparison of the motion of the wall with that of the ground. Taking the 11 earthquakes recorded at the two stations (Table II), we obtain the following results:—

Elements of earthquake motion.	Nat. Hist. Museum.	Seism. Institute.	Ratio, $\left(\frac{\text{Nat. Hist. Mus.}}{\text{Seism. Inst.}}\right)$
Total duration.	94 sec.	33 sec.	2.8
Duration of princ. portion.	36 sec.	14 sec.	2.6
Max. 2a.	0.78mm.	0.29mm.	2.7
Period.	0.33 sec.	0.19; 0.37; 0.63 sec.	—

Thus the duration and the range of motion of the wall of the Natural History Museum are nearly three times larger than those at the ground surface, or the Seismological Institute. The motion at the apex of the wall, where the latter is joined to the roof, will probably be about twice as great as that at the point where the seismograph has been fixed.

Motion of the wall. From Table II, it will be seen that the period of vibration of the wall is practically constant, the mean value being 0.33 sec. This shows that the wall behaves in earthquakes like an elastic spring and executes vibrations with its own period, whatever the period and amplitude of the ground motion may be, excepting in cases of very slow waves, say, of periods longer than 2 seconds, which are felt equally on the ground and at the top of the wall.

The motion of the wall was in each case not a uniform one, but presented always a series of maximum groups at fairly regular intervals. The average value of the intervals between the successive maxima was 4.3 seconds, each including some 13 vibrations. The occurrence of the different maximum groups is probably due to the relation between the elasticity and the dissipation coefficient of the brick work of the wall. There was usually no very predominating

single large motion, the amplitude in the successive maximum groups being nearly equal to each other.

The wall, which was evidently a very weak one, can be caused to move slightly by pushing with hand at regular intervals ; the max. $2a$ of the vibrations thus produced was, in a trial, 0.08mm, the average period being about 0.36 sec., that is to say, practically equal to that of the movements caused by actual earthquakes.

Effect of wind. On Sept. 28th, 1902, the weather was stormy. In consequence of the trembling of the wall of the Natural History Museum caused by the impact of the winds, the contact-maker was brought into action, and the seismograph recorded movements, whose max. $2a$ was 0.06mm and whose average period was 0.32 sec.

Tokyo. Nov. 1902.

LIST OF PLATES.

Pl. XXIII. *Fig. 1.* The seismograph set up on a support fixed to the eastern outer wall of the Natural History Museum.

Fig. 2. The Natural History Museum. *a* indicates the position where the seismograph has been mounted.

Pl. XXIV. *Fig. 3.* The eastern outer wall of the Natural History Museum. Vertical section through the coping stone.

[*Seismograms ; EW component, multiplication = 5.*]

Pl. XXV. *Fig. 4.* The earthquake of June 23rd, 1902, at 7h 42 m 20 s. a.m. ; *intensity = weak.*

(a) Record at the Seismological Institute.

(b) „ „ „ Nat. Hist. Museum.

Pl. XXVI. *Fig. 5.* Earthquake of July 23rd, 1902, at 11h 52m 54s p.m. ; *intensity = slight.*

(a) Record at the Seismological Institute.

(b) „ „ „ Nat. Hist. Museum.

Fig. 6. Earthquake of July 26th, 1902, at 7h 51m 2s a.m. ; *intensity = slight.*

Record at the Nat. Hist. Museum.

Time marks. The values of the complete oscillations of the time-marking pendulums, each corresponding to two consecutive tick intervals, are 0.99 sec. and 0.75 sec. respectively for the seismographs at the Seismological Institute and at the Natural History Museum.

Fig. 1. Seismograph.

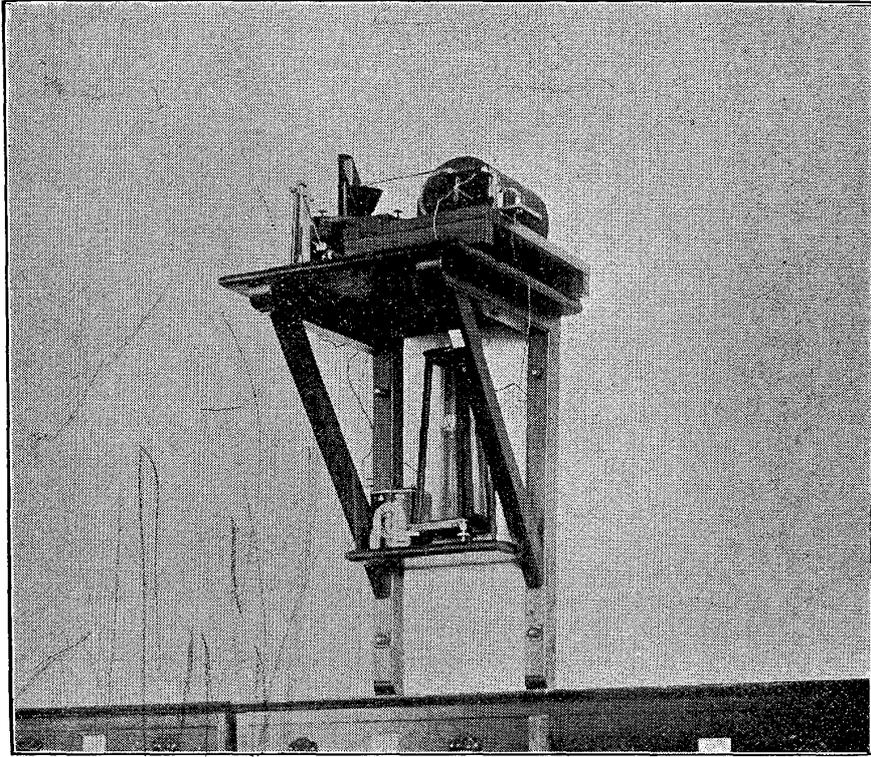
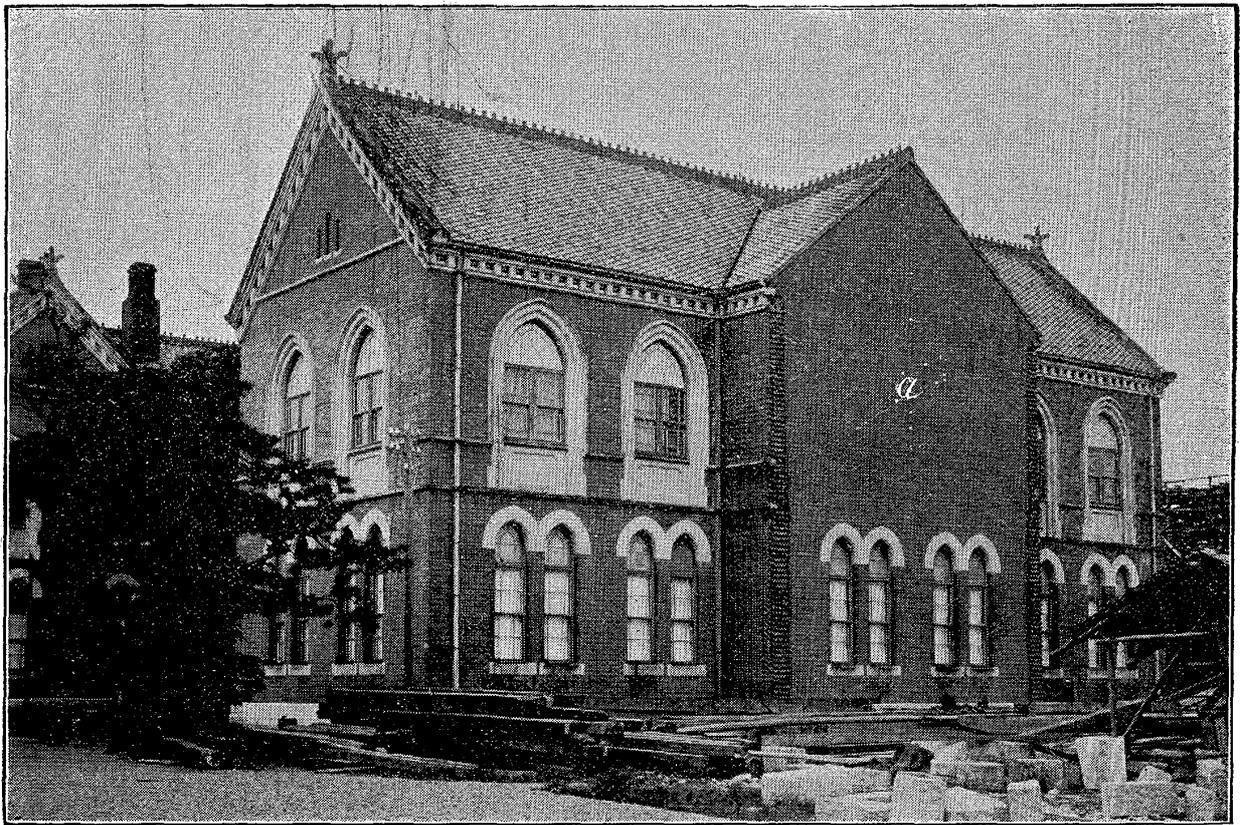


Fig. 2. Natural History Museum.



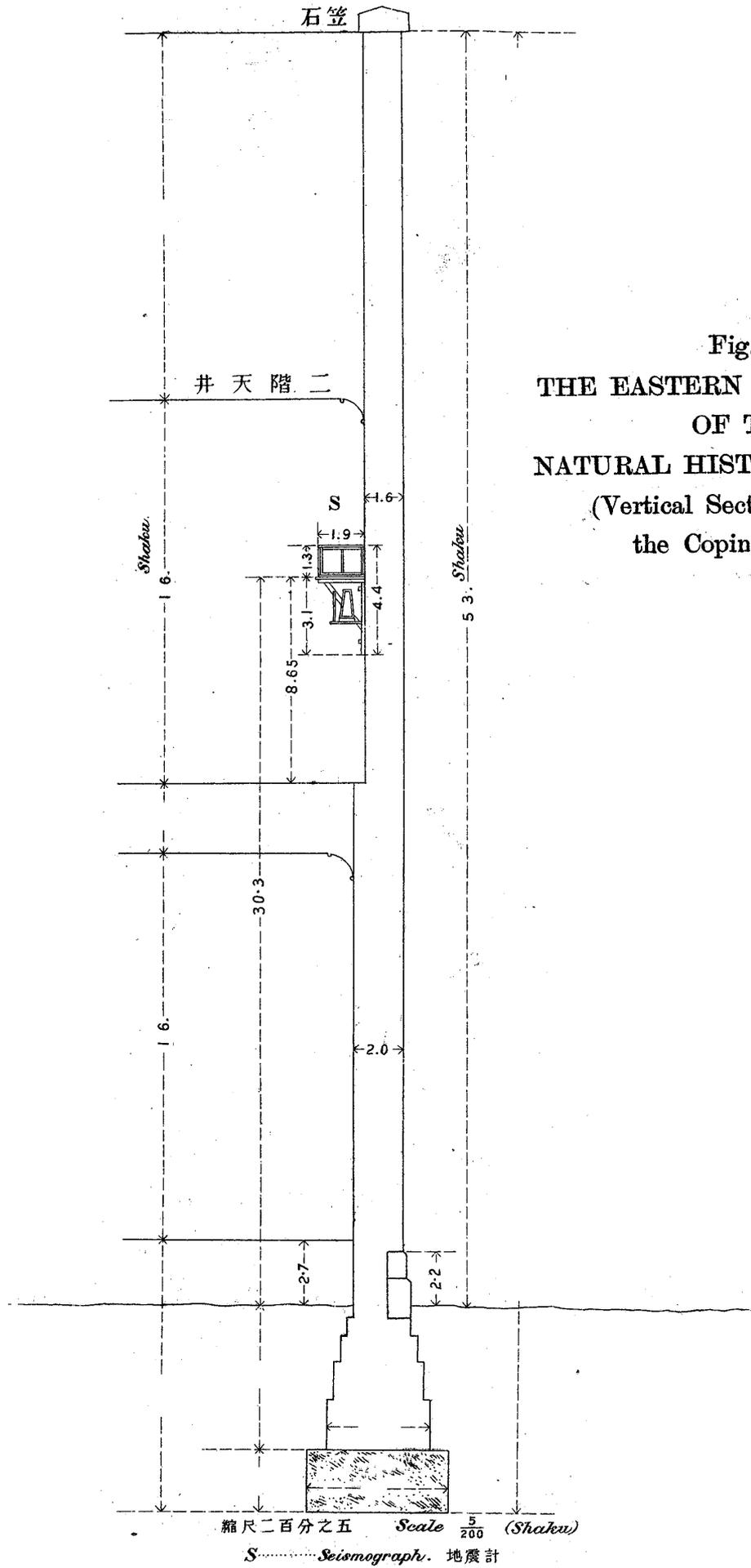
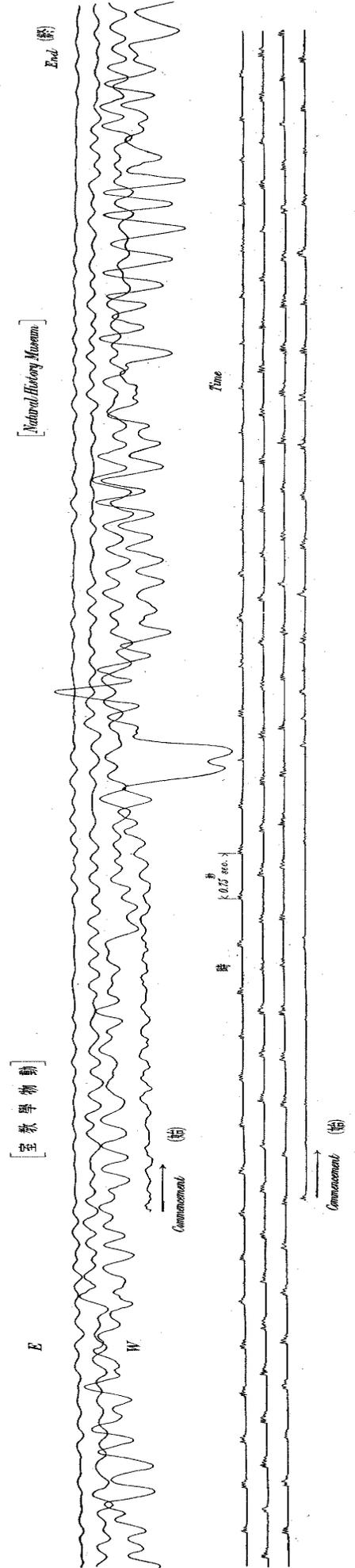
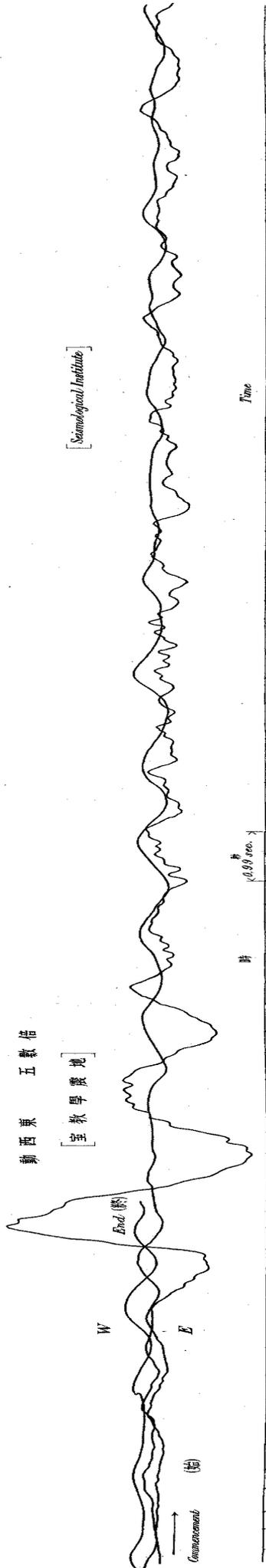


Fig. 3.
 THE EASTERN OUTER WALL
 OF THE
 NATURAL HISTORY MUSEUM.
 (Vertical Section through
 the Coping Stone).

震弱秒十二分二十四時七前午日三二月六年五十三治明 圖四第

Fig. 4. EARTHQUAKE OF JUNE 23RD 1923: 7.42.20 A.M.

ZW COMPONENT; MULTIPLICATION = 5.



震微秒四十五分一十秒午日三十二月七年五十三治明 圖五第
 動西東 五數倍
 [室教學 震地]

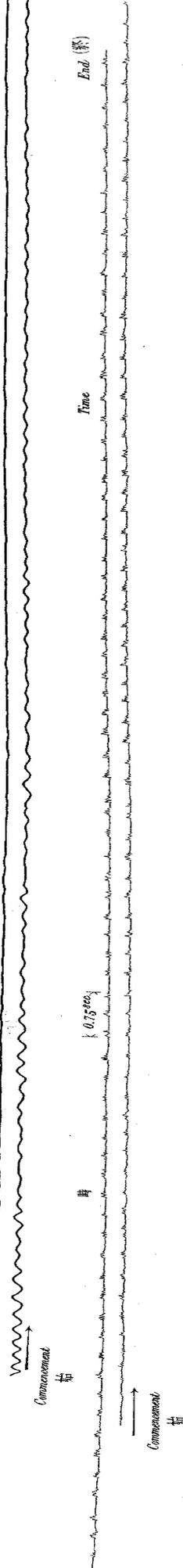
Fig. 5. EARTHQUAKE OF JUNE 23RD 1902: 11.53.54 P.M.
 ZW COMPONENT; MULTIPLICATION=5.
 [Seismological Institute]



[室教學 物動]

[Natural History Museum]

End (終)



震微秒二分一十五秒七前午日六十二月七年五十三治明 圖六第
 動西東 五數倍
 [室教學 物動]

Fig. 6. EARTHQUAKE OF JULY 24TH 1902: 7.51.2 A.M.
 ZW COMPONENT; MULTIPLICATION=5.
 [Natural History Museum]

