A Horizontal Tremor Recorder.

By

F. Omori, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates III and IV.

1. The Metropolitan Police had recently to consider several cases of complaints respecting the disturbances caused by steam engines, dynamos, etc. to neighbouring buildings; and the instrument which I am going to describe in the following pages has been constructed to measure the horizontal movement due to the above mentioned causes.

Fig. 1.
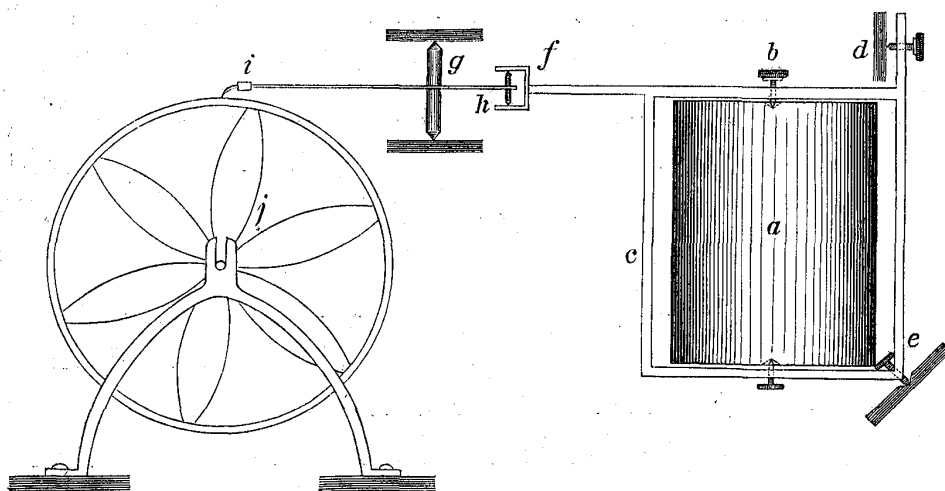
2. The essential part of the instrument, which is diagramatically shown in fig. 1, consists of a vertical brass cylinder, *a*, 16 cm in height and 10 cm in diameter, filled with lead, and about 15 kg in weight, pivoted in a strong iron frame *bc*, the latter being supported by means

of two screw points d and e from a strong brass stand, about 20 cm in height and furnished with three levelling screws exactly in the same way as in Prof. Ewing's horizontal pendulum. The distance between the pendulum axis and the centre of the heavy cylinder, or the steady point, is 6 cm; while there is attached to the iron frame in way of prolongation a stout aluminium rod bf, whose length is 15 cm. The horizontal motion, whose direction is normal to the pendulum plane, will thus be magnified $3\frac{1}{2}$ times at the end of the aluminium .prolongtion. There is, however, an independent multiplying pointer, consisting of a vertical axis, g, which is pivoted in an inverted bracket properly attached to an upright support, and which carries a horizontal light lever hgi. The shorter arm of the latter consist of a thin brass piece formed into a fork between whose two limbs fits exactly a highly polished axis of steel, h, pivoted in a small bracket attached to the end of the strong aluminium prologation before mentioned. The longer arm of the lever consists of a tapering tube of aluminium, 120 mm in length, at whose end, i, is hinged an index which writes on a smoked paper wrapped round a drum, j, driven by a clock work. In other instruments, the record is taken in ink on a white band of paper driven by means of rollers, as in the *vibration measurers* for bridges, railway carriages, etc. It will be observed that the multiplying arrangement here employed is perfectly similar to that in the horizontal pendulums for the observation of distant earthquakes. As the minimum effective length of the shorter arm of the multiplying lever is 6 mm, the writing index records the motion $20 \times 3\frac{1}{2} = 70$ times magnified; it being, however, also possible to reduce the magnification ratio down to 10, by suitably changing the effective distance of the shorter arm of the pointer. The mechanical details and the photograph* of the instrument are given in figs. 2, 3, 4 and 5, Pl. III.

For the complete observation of the horizontal motion, we require,

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* The photograph represents an instrument which is slightly different from that whose mechanical details are given in the Plate, the record being taken on a smoked paper.

of course, a pair of these instruments, with their pendulum planes at right angles to one another.

The horizontal tremor recorder has already been used in a few cases, of which the following are examples.

3. *Shakings in the Hospital of the Tōkyō Imperial University, Hongō.* Towads the end of 1903 and in the beginning of 1904, the Medical Laboratory in the Hospital of the Imperial University, Hongō, was subject from time to time to *unfelt shakings,* which caused windows to rattle and bottles placed on tables to rock. On inquiry, these effects were traced to be due to the working of a small oil engine of 10 horse power, temporarily set up in the University compound; the engine being about 87 metres to the NW of the Medical Laboratory, which is a low wooden structure. When observed on Jan. 8th, 1904, at 10 am., the movements of the windows and bottles were executed in a quite regular way at the rate of about 4 in a second and were sufficiently well pronounced as to constitute a source of disturbance to the people sitting in the room. The floor itself, however, indicated no *sensible* motion.

The movements on the date above mentioned, which were measured by a tremor recorder set up on the floor of the laboratory, consisted of a series of regular and nearly uniform vibrations, whose double amplitude was, in each of the EW and NS components, about 0·02 mm, and whose period was 0·24 sec., corresponding to 250 revolutions per minute of the engine. The absolutely greatest movements in the EW and NS components were respectively 0·028 and 0·034 mm.

The disturbances due to the same source were simultaneously measured in the brick Earthquake-proof House, which is situated at a distance of about 110 metres to the south-west of the oil-engine. The movements there measured, on the solid concrete basement, were much smaller than in the Medical Laboratory, and consisted of a series of maximum groups, the absolutely greatest double-amplitude in the NS direction being 0·026 mm. The period was 0·24 sec.

The positions of the oil engine, the Medical Laboratory, and

the Earthquake-proof House, are indicated in the accompanying plan of a part of the University compound.

Fig. 6. Plan of a part of the Tōkyō Imperial
University compound.

Scale of Ken   (1 Ken = about six feet)
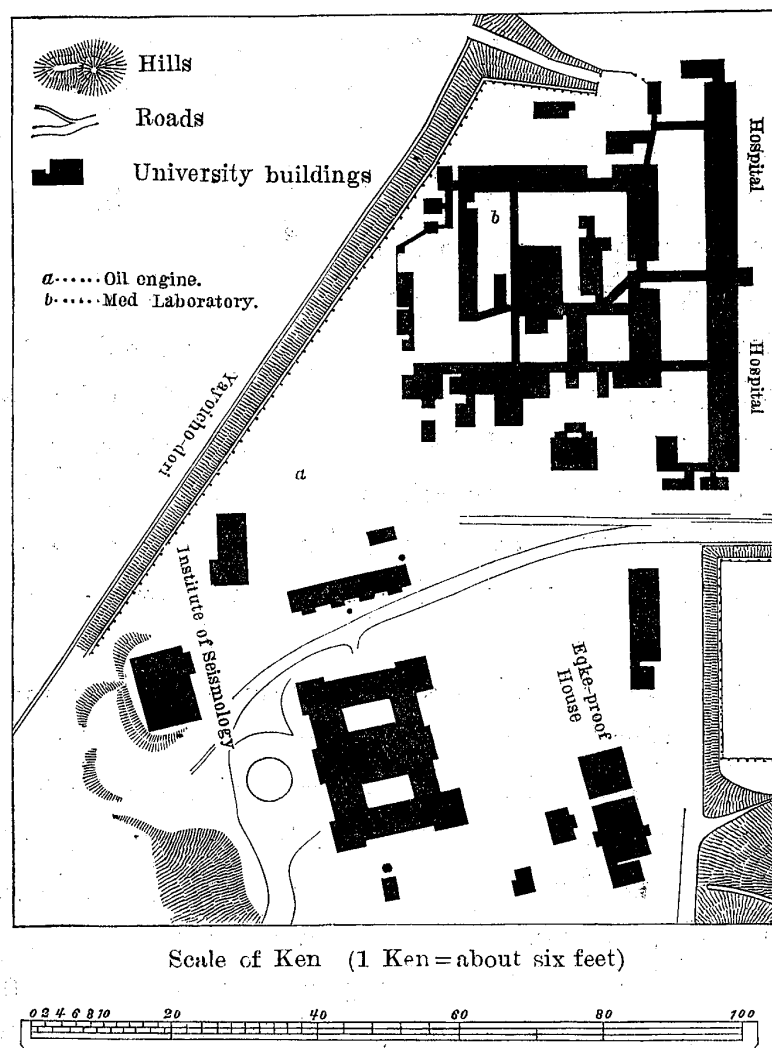
4. *Movement in the Seismological Institute.* On May 19th, 1904, the effects of the oil engine mentioned in the preceding § were very markedly indicated in the Seismological Institute, which is a one-storied wooden building. Fig. 7 is a part of the NS component diagram obtained on the above date by means of a horizontal tremor recorder set up on a solid brick column in one of the instruments rooms, whose

Fig. 7. Vibration caused by an Oil Engine.
NS component. Multiplication = 29.

sec.

0   5   10   20   25

Time Scale.
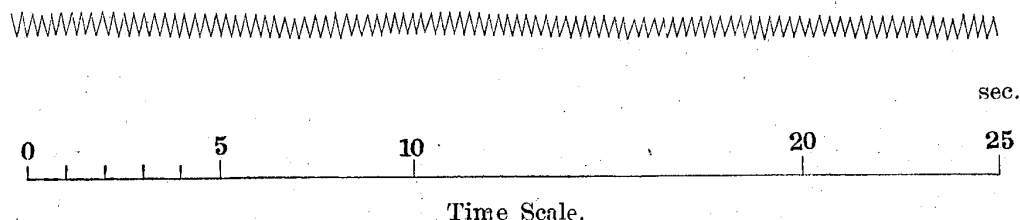
distance from the engine was about 70 metres: the positions of the Institute being shown in the map (fig. 6). The max. double amplitude was 0·09 mm and the period was 0·227 sec., corresponding to 265 revolutions per minute ot the engine. The movements were perceptible and sufficiently intense to produce considerable amount of the rattling of the windows.

5. *Miscellaneous experiments.* (Pl. IV.) Fig. 8 and 9 are parts of the diagrams of the longitudinal motion of the ground at the distances respectively of about 17 and 60 feet from a small oil engine of the workshop of the Physical Institute. Again, figs. 10 and 11 represent the normal vibrations respectively of the eastern and southern up-stair walls of the workshop of the Mechanical Institute of the Engineering College due to the working of a small steam engine which is situated close to the southern wall.

The following table gives the results of the measurements made in 1903.

Place of observation.	Cause of disturbance.	Direction of the motion measured.	Distance between the origin of disturbance and the place of observation.	Max. double-amplitude.	Period of vibration.
			Feet.	mm	sec.
Upper-story floor of the Workshop of the Mech. Inst., Tokyo Imp. Univ.	A steam engine in the Workshop of the Mech. Inst., Tokyo Imp. Univ.	Normal to the E. end wall.	(Near to the E. end wall.)	0.018	0.09
		,,	,,	0.016	0.17
		Parallel to the S. nd wall.	(Near to the S. end wall.)	0.050	0.043
		,,	,,	0.016	0.097
Ground floor of the same Workshop.		Parallel to the piston of the engine.	18	0.015	0.071
Ground surface.	An oil-engine in the Workshop of the Physical Inst., Tokyo Imp. Univ.	45° to the direction of the piston.	90	0.02	0.10
		At right angles to the direction of the piston.	60	0.03	0.12
		45° to the direction of the piston.	9	0.17	0.25
Ground surface.	An engine in a crucible factory, at Shiba, Tokyo.	Parallel to the direction of the piston.	18	{0.02 {0.007 ···	{0.23 {0.058
		At right angles to the direction of the piston.	,,	0.012	0.20
,,		——	48	0.007	0.087
,,		Parallel to the direction of the piston.	170	Very slight.	—
,,		Parallel to the direction.	78	0.018	0.12
,,		Normal to the direction of the piston.	,,	0.01	0.18
On the floor of a one-storied wooden house.		Normal to the direction of the piston.	60	{0.018 {0.022 ···	{0.24 {0.086
		Parallel to the direction of the piston.	,,	0.02	0.23

From the above table, it will be seen that the movements measured were usually very small and amounted, at a distance of a few dozen metres from the origin of disturbance, to only a few hundredths of a mm; it being extremely rare that the double amplitude reaches some tenths of a mm. The period varied between 0·058 and 0·25 sec.

It is to be remarked that the motion of a wall (or house) is, for evident reasons, generally much greater than that of the ground on which it stands. Thus in the case of the Workshop of the Mechanical Institute of Tokyo Imperial University, the normal motion of one of the upper story walls amounted to 0·05 mm (period = 0·043 sec.), while that on the ground at a distance of 18 feet from the engine was 0·015 mm (period = 0·071 sec.). Similarly in cases of actual earthquakes, buildings generally act more or less as a kind of seismoscope, being sometimes thrown into vibrations many times larger than the motion of the ground.[1] ·

6. *Sensible limit of small motion.* For practical purposes, it is desirable to fix the sensible limit of small motion in the disturbances of artificial origins. This is, however, a difficult problem, since the limit in question would be widely different for different persons. The following result is to be regarded only as a provisionary one.

From the study of the macro-seismographic diagrams obtained in Tokyo, the least value of the intensity, or maximum acceleration ($= a$), of the sensible earthquake motion seems to be about 17 mm per sec. per sec. Denoting by T and $2a$ respectively the period and the double amplitude of a motion of sensible limit, we have

$$a = \frac{2\pi^2 \times 2a}{T^2}, \quad \text{or} \quad 2a = \left(\frac{a}{2\pi^2}\right) \times T^2 = 0·86 \times T^2,$$

which latter equation gives the range of motion corresponding to a specified value of the period T. The figures contained in the following table have been calculated according to the above formula.

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1) See Prof. Milne: "Seismic Survey," Trans. Seism. Soc., Vol. X; and F. Omori: "Earthquake Measurement in a brick building," and "Motion of a Brick Wall produced by earthquakes," the Publ. of the Earthq. Inv. Com., Nos. 4 and 12.

T	$2a$	T	$2a$
sec.	mm.	sec.	mm.
0.10	0.009	0.043	0.0016
0.11		:	:
0.12	0.012	:	:
:	:	0.07	0.004
:	:	0.08	0.006
0.20	0.034	0.09	0.007
0.21	0.038		
0.22	0.042		
0.23	0,046		
0.24	0.050		
0.25	0.054		

Thus it will be observed that, with periods of 0·10 and 0·20 sec., the motion will become sensible respectively at ranges of about 0·01 and 0·03 mm. It is hereby to be noted that the quantities a, $2a$ and T relate all to the motion of the *ground*, which will be 'just strong enough to be felt by people sitting in wooden houses.

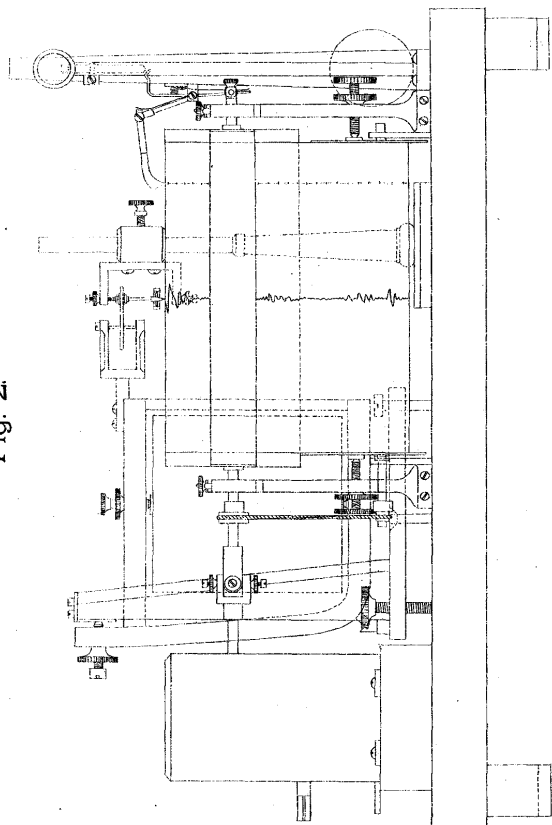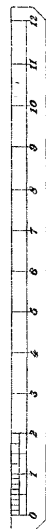Tokyo.   June, 1904.

Pl. III.

A Horizontal Tremor Recorder.

Fig. 2.

Fig. 4.

Fig. 3.

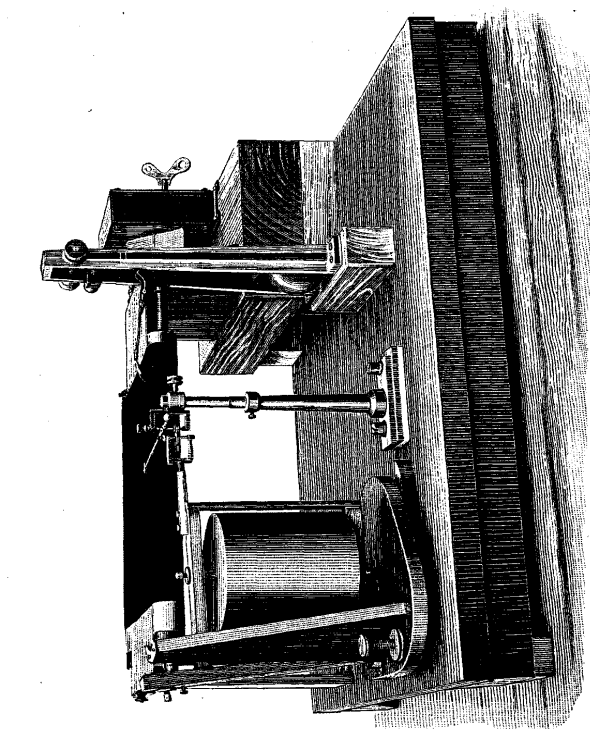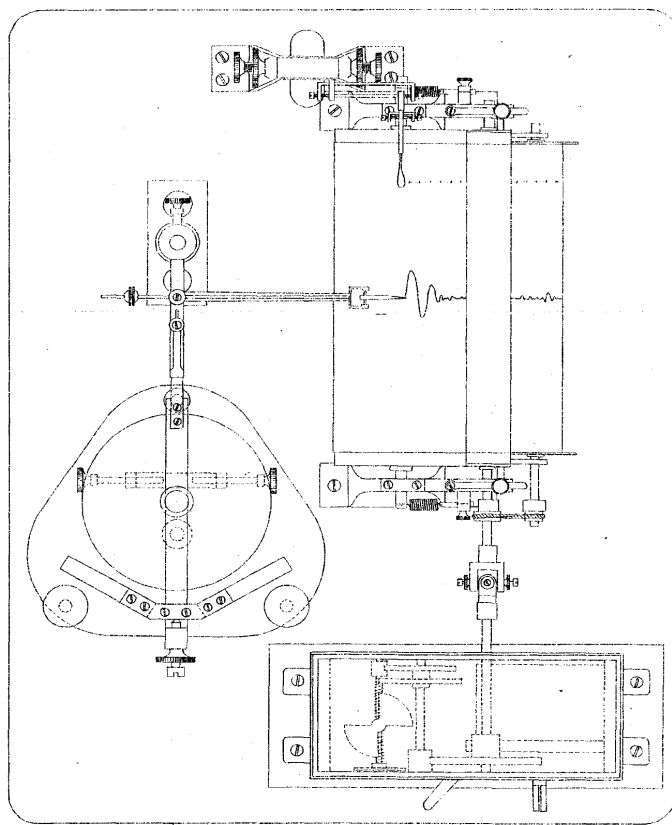Fig. 5.
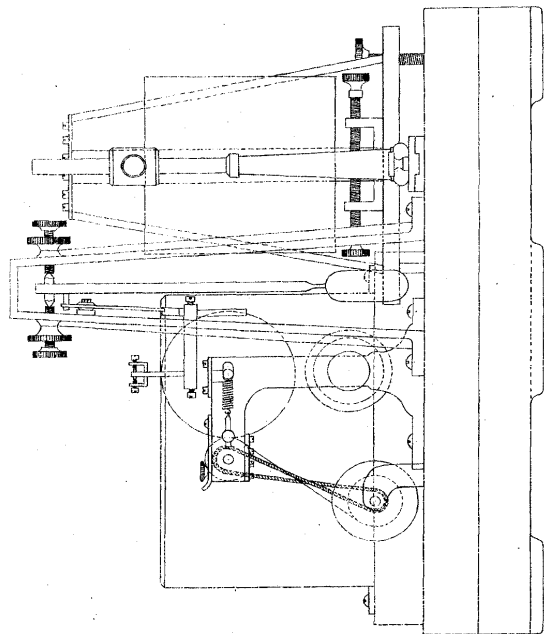
Scale for Figs. 2, 3 and 4.

INCHES.

Pl. IV.

Vibration of the ground caused by an Oil Engine.

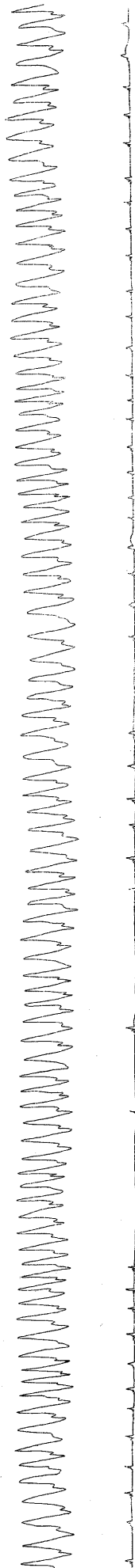**Fig. 8.** NS Component. Multiplication=70. Distance between the Engine and the place of observation=17 feet.

Fig. 9. NS Component. Multiplication=70. Distance between the Engine and the place of observation=30 feet.

Vibration of the walls of the Workshop of the Engineering College, caused by a Steam Engine.

Fig. 10. Normal motion of the eastern up-stair wall. Multiplication=30.

Fig. 11. Normal motion of the southern up-stair wall. Multiplication=30.

Time scale : 2 successive tick intervals=0.71 sec.