THE MOVEMENT PRODUCED IN CERTAIN BUILDINGS BY EARTHQUAKES.

By John Milne.

[Read January 26th, 1887.]

The following experiments were made with the object of measuring the relative amounts of motion felt at the time of an earthquake in buildings of different construction and in different parts of the same building. The buildings chosen are situated upon the grounds of the Imperial College of Engineering in Tokyo, one of them being inhabited by myself and the other, which is situated on similar ground about 60 feet distant, by Professor Alexander. The relative position of these buildings is shown in a plan of the Imperial College of Engineering published in connection with a paper on a seismic survey in Vol. X. of the Society's publications. My house, which has an upper story and is built of brick with a heavy tile roof and an internal wooden framing, forms the western end of a row of three houses running from S. 35° E. to N. 35° W.

As it is the last house in a row the direction of which approximately coincides with a direction of considerable motion, its position is not a good one. This assumption is born out by the fact that it has recently been cracked from top to bottom and some of the stone work at the angles pushed forward. Professor Alexander's house, which has recently been pulled down, was built of wood, and covered externally with plaster. The roof, like mine, was tiled. Both houses had an upper story.

In each of these houses pendulum seismographs were placed, one upstairs and one downstairs, vertically above each other and as nearly as possible in similar positions. They stood upon the wooden floors, which measured vertically

were approximately 13 feet apart. The doors of the instruments (which are described on p. 91 of Vol. IV. of the Society's Transactions) in my house faced N. 60 E., and in Professor Alexander's house N. 30 W.

In looking at the following records, which were very kindly drawn up by Professor Sekiya and subsequently revised by myself, it must be remembered that the actual movement experienced is only one-eighth of that which is recorded. Several of the records obtained at Professor Alexander's house, especially those which were recorded for down stairs, are untrustworthy owing to the instrument having been in the vicinity of the front door and therefore subject to accidental disturbance. There is, however, little difficulty in distinguishing between the records obtained from an earthquake and those due to an accidental swinging of the pendulum.

Here and there a few records as given from an earthquake house resting on balls have been interpolated. Here a long, slow, surging motion was produced, and although the amplitude of motion was great its severity was mitigated by the increase in period. Subsequently the house was placed on layers of cast iron shot, and the aseismic character of the foundations greatly improved. (See Seismic Experiments. Trans. Seis. Soc., Vol. X.)

The earthquake house records were taken on the solid ground between my house and that of Professor Alexander.

January 2nd, 1884.

Milne's House upstairs.—1.6 mm. N. 15° E. There is a record of larger motion, but that is not perhaps the earthquake motion.

Earthquake House.—2 mm. W.E.

January 10th, 1884, 9 p.m.

Milne's House upstairs.—4.2 mm. N. 50° E. There is one stroke of 5.5 mm. which is perhaps an earthquake motion.

Milne's House downstairs.—3.5 mm. N. 70° E.

Earthquake House.—Very complicated diagram: 4.5 mm. in form of a circle.

January 19th, 1884, 12.55 p.m.

Milne's House upstairs.—3 mm. (?) very complicated diagram which is difficult to measure. Direction mostly N.E.

Milne's House downstairs.—2 mm. N. 20° E. (marked on the plate "evidently too small").

Earthquake House.—7 to 9 mm. mostly N.E.; very complicated diagram.

February 10th, 1884.

Milne's House upstairs.—2 mm.

February 22nd 1884, 5 a.m.

Earthquake House on Ground.—0·8 mm., the direction variable.

Milne's House upstairs.—1.1 mm., N. 45 E. very distinct.

Earthquake House on Balls.—Mostly 1.5 mm., the direction variable; there are also waves of 4 mm. although they might not have been produced by earthquake.

February 22nd 1884, 6 p.m.

Alexander's House upstairs.—7 mm. (maximum) in the direction of the door, but there were motions (5 to 4 mm.) in several directions—motion of rotation. The record is good.

Alexander's House downstairs.—Very indistinct, perhaps 2.5 mm. Record fairly good.

Milne's House downstairs.—1.1 mm. Direction uncertain.

February 10th, 1884.

Milne's House upstairs.—1.5 mm. N. 60 W.

March 3rd, 1884.

Milne's House upstairs.—2 mm. N. 30° E. distinct.

Milne's House downstairs.—0.5 mm.

Earthquake House.—1 mm. indistinct.

Alexander's House upstairs.—9 mm. (maximum) 30° left, and other motions 6.3 mm. of much variety. Good record.

Alexander's House downstairs.—Very indistinct. Say 5 mm.

Aseismic House.—19 mm. in the direction of the door and motion of 12 mm. in other directions. Probably the instrument (or house) moved with its own period of vibration.

March 7th, 1884.

Milne's House upstairs.—2.2 mm. N. 45° W. The pointer had been creeping.

Milne's House downstairs.—1.1 mm. N. 60° W.

Earthquake House.—1.3 mm. N. 25° E. Indistinct.

Alexander's House downstairs.—6 mm. N. 25° E.; marked on the plate "very doubtful."

Alexander's House upstairs.—4 mm. N. 25 E.; marked on the plate "very doubtful."

March 7th, 1884, 1.15 p.m.

Aseismic House.—6 mm. N. 20 W.; marked on the plate "this is doubtful." Complicated diagram.

March 13th, 1884, p.m.

Alexander's House downstairs.—(3) mm. ? direction N. 30° W.

Alexander's House upstairs.—7 mm. N. 20° W. motion of long duration.

March 14th 1884, a.m.

Milne's House upstairs.—1 mm. N. 35° E.

Milne's House downstairs.—The diagram incomplete; it is difficult to judge how far the house moved; perhaps much friction in the instrument.

Earthquake House.—0·9 mm. in variable direction.

Alexander's House downstairs.—15 mm., motion of very long duration. Probably the instrument moved.

March 14th, 1884, 9 p.m.

Milne's House upstairs.—0.8 mm.; small dot.

Milne's House downstairs.—1.5 mm. in single stroke, but very incomplete diagram; too much friction or instrument moved.

Earthquake House.—1 mm. in a few strokes.

Alexander's House upstairs.—Described a circle whose diametre is 1.8 mm.

Alexander's House downstairs.—2 mm. in the direction of the door. Rather difficult to measure.

NOTE.—This earthquake was undoubtedly a short one as seen from all diagrams.

Aseimic House.—17 mm.; complicated motion of long duration; instrument moved by some outside disturbance.

March 15th, 1884, 8.24.0 p.m.

Milne's House downstairs.—2 mm. N. 20° E. in one stroke, but rather doubtful whether this is an earthquake motion.

Milne's House upstairs.—1.7 mm. N. 60° E. in a few strokes.

Earthquake House.—2 mm. in several directions.

Alexander's House downstairs.—3 mm. N. 30° E.

Alexander's House upstairs.—10 mm. N. 60° E. elliptical figures of various magnitudes in the same direction; good diagram.

Aseismic House.—20 mm. 70° right. Very complicated figure, and motion of very long duration. Apparently the house and instrument moved considerably.

Aseismic House.—17 mm. 45° Right. The same remarks apply in this figure as stated for the above diagram.

March 17th, 1884, 9.30.0 p.m.

Milne's House (?)—1.5 mm. N. 25 E.

Upstairs (?)—2 mm. in the direction of the door in a few strokes.

Earthquake House.—1.5 mm. in several directions.

Alexander's House downstairs.—3 mm. mostly N.E., not very clear; good record.

Alexander's House upstairs.—6 or 7 mm., mostly N.E. also large motion in other directions; good record.

March 26th, 1884, 12.50 p.m.

Milne's House upstairs.—5 mm. N.E. direction very distinct.

Milne's House downstairs.—2.5 mm. N.S.

Earthquake House.—3 or 4 mm. in several directions. Pointers had been creeping.

Alexander's House upstairs.—10 mm. N.E. and large motion in other directions; good record.

Alexander's House downstairs.—5 mm. N. 25° E.

April 6th, 1884.

Milne's House downstairs.—2 mm. to 3.5 mm. in various directions.

Milne's House upstairs.—4 mm. N.E.

Earthquake House.—5 mm. S. 25° W.

Alexander's House upstairs.—9 mm. in several directions.

Alexander's House downstairs.—Very indistinct, probably 2.5 mm. (Rather too small for Alexander's House, apparently the instrument was *not* in good order.)

May 6th, 1884.

Milne's House upstairs.—4.5 mm. N. 32° E.

Milne's House downstairs.—3 mm. 25° left.

Earthquake House.—6 mm.—8 mm. in several directions.

Alexander's House upstairs.—4.5 mm. N. 45° W.; doubtful record.

Alexander's House downstairs.—18 mm. N. 10° W.; doubtful record.

May 11th, 1884, 8 p.m.

Milne's House upstairs.—5.5 mm. N. 40° E.

Milne's House downstairs.—3 mm. in several directions.

Earthquake House.—2.2 mm. in various directions.

Alexander's House upstairs.—7 mm. N. 50° W.

Alexander's House downstairs.—5 mm. in several directions.

May 12th, 1884.

Milne's House upstairs.—1 or 2 mm.

Milne's House downstairs.—1 or 2 mm.

May 19th, 1884.

Milne's House upstairs.—2.2 N. 25° E.

Milne's House downstairs.—2.2 mm. in several directions.

Earthquake House.—1.8 in various directions.

Alexander's House upstairs.—1.7 N. 60° W.

Alexander's House upstairs.—Large but indistinct diagram. About 3 mm.

May 20th.

Milne's House upstairs.—2.8 mm. N.

Milne's House downstairs.—0.5 mm.; a small mark.

May 23rd.

Milne's House upstairs.—1.1 mm. ?
Milne's House downstairs.—1 mm. ?
Earthquake House.—1.8 or 2.5 mm.
Alexander's House upstairs.—2.2 mm. N.W.
Alexander's House downstairs.—3 mm. NW.

May 27th, 1884.

Milne's House upstairs.—2·5 mm. ?, very indistinct.
Milne's House downstairs.—2 mm.
Earthquake House.—2 mm. N. 25° E.
Alexander's House upstairs.—7 mm. Mostly N.W., good record.
Alexander's House downstairs.—Diagram of large motion, but difficult to give measurement, and record not good.

May 30th, 1884.

Milne's House upstairs.—5 mm. N.E.
Milne's House downstairs.—2.5 mm.
Earthquake House.—1.5 mm. N.E.
Alexander's House upstairs.—4 mm. W. N.W., good record.
Alexander's House downstairs.—6 mm. W. N.W., not good. Evidently due to accidental shaking.

May 31st, 1884.

Milne's House upstairs.—1.5 mm. N.
Milne's House downstairs.—1.5 mm. 30° Right.
Earthquake House.—2 mm.

June 8th, 1884.

Milne's House upstairs.—2.5 mm. ? N. 32° E.
Milne's House downstairs.—1—1.8 mm. N.
Earthquake House.—2 mm.

June 11th, 1884.

Milne's House upstairs.—3.5 mm.
Milne's House downstairs.—Creeping and indistinct diagram.
Earthquake House.—2.8 mm.

December 22nd, 1883, 6.45 a.m.

Milne's House upstairs.—5 mm. chiefly E.W.

Earthquake House.—3.5 mm. N.E. to S.W.

November 30th, 1883, 4 a.m.

Milne's House upstairs.—5 mm. N.E. to S.W.

Milne's House downstairs.—1 or 2 mm.

The above observations have been tabulated as follows :—

MOTION RECORDED IN DIFFERENT PARTS OF DIFFERENT BUILDINGS.

NUMBER.	DATE.	BRICK UPSTAIRS.	BRICK DOWNSTAIRS.	WOOD UPSTAIRS.	WOOD DOWNSTAIRS.	OUTSIDE ON GROUND.	ASEISMIC HOUSE ON BALLS.
	1883.						
	Nov. 30	5	1.5	—	—	—	—
	Dec. 22	5	3.5	—	—	—	—
	1884.						
	Jan. 2	1.6	—	—	—	2	—
	Jan. 10	4.2	3.5	—	—	4.5	—
	Jan. 19	3	2	—	—	7	—
	Feb. 10	2	—	—	—	—	—
	Feb. 10	1.5	—	—	—	—	—
	Feb. 22	1.1	—	—	—	.8	1.5
	Feb. 22	—	1.1	7	2.5	—	—
	Mar. 3	2	.5	9	5	1	—
	Mar. 7	2.2	1.1	?	—	1.3	6
	Mar. 14	.8	1.5	1.8	2	1	17 & 19
	Mar. 15	1.7	?	10	3	2	20 & 17
	Mar. 17	2	—	7	3	1.5	—
	Mar. 26	5	2.5	10	5	3	—
	April 6	4	2	9	2.5	5	—
	May 6	4.5	3	?	?	6	—
	May 11	5.5	3	7	5	2.2	—
	May 12	1	1	—	—	—	—
	May 19	2.2	2.2	3	—	1.8	—
	May 20	2.8	.5	—	—	—	—
	May 23	1.1	1	2.2	3	1.8	—
	May 27	2.5	2	7	—	2	—
	May 30	5	2.5	4	—	1.5	—
	May 31	1.5	1.5	—	—	2	—
	June 8	2.5	1.8	—	—	2	—
	June 11	3.5	—	—	—	2.8	—
General Average.	—	2.8	1.8	6.1	3.5	2.5	11.1

CONCLUSION.

In the last line of the preceding table a general average is given for the amount of motion felt in different houses and in different parts of the same honse, from which it appears that the least motion is felt downstairs in the brick house, more

upstairs, rather more downstairs in the wooden house, and the greatest motion upstairs in the wooden house.

Calling the motion experienced downstairs in the brick house 1, then the motion respectively experienced upstairs in the same house and downstairs and upstairs in the wooden house becomes 1.6, 2, and 3.4. Why the motion outside, that is in the earthquake house, should be greater than that felt downstairs in the brick house, it is difficult to explain. Perhaps it may be due to the relative position of the two places, or perhaps to the fact that the brick house has tolerably deep foundations (see Seismic Survey. Trans. Seis. Soc., Vol. X.).

The large motion in the aseismic building has already been explained. With the new foundations this no longer exists.

It will be observed that a fairer method of obtaining an average would have been only to consider those earthquakes which were recorded upstairs and downstairs in both buildings; such a set of averages have, however, been found to be practically the same as the general average.