EARTHQUAKE MEASUREMENTS OF RECENT YEARS ESPECIALLY RELATING TO VERTICAL MOTION.

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[Read February 23rd, 1888.]

This paper contains the records of earthquake observations made during the two years from September, 1885, to September, 1887. Severe shocks as well as feeble tremors are arranged in the accompanying table, and in some shocks separate notes are added by way of fuller description. The measurements were made at two places in Tōkyō; one set at Hitotsubashi, where the ground is soft and marshy, and the other set at Hongō, where the soil is hardened alluvial mud.

Vertical motion, which forms the principal subject in this paper, has not hitherto been so much studied as horizontal motion. This is on account of its comparatively rare occurrence, and when it occurs its smallness makes it of secondary importance to the more prominent horizontal movement. Reference will be made to Plates IX., XI., and XXVI., Vol. I. of the Journal of the Science College, Imperial University, Japan, and Transactions of this Society Vol. XI., p. 176, Plate I., in which the characteristic features of vertical motion occurring in conjunction with horizontal motion can be seen.

In this country absolute vertical motion[1] was first measured by Mr. E. Knipping between 1878 and 1880. During that period eight observations were made; in four cases the vertical motion reached 0.02 mm. The largest value, 0.56 mm., was

[1] Mittheilungen der Deutschen Gesellschaft, etc. Ostasiens Vol. 17, May, 1879, and Transactions of the Seismological Society of Japan, Vol. I. p. 72.

observed in the severe earthquake of February 22nd, 1880. In 1883, Professor J. Milne, in conjunction with Professor T. Gray, made experiments on artificial earthquakes.[2] Vibrations then were caused by letting fall a heavy weight from various heights or exploding dynamite in holes made in the ground. His results were principally as follows:—(1) In the soft ground vertical motion appears to be a free surface wave which outraces the horizontal components of motion. (2) Vertical motion commences with small rapid vibrations and ends with vibrations which are long and slow. (3) High velocities of transit of seismic waves may be obtained by the observation of this component of motion. It is possibly an explanation of the preliminary tremors of an earthquake and the sound phenomena.

In the table are given the following quantities:—

1. Maximum Motion ($2r$) or the largest range of the displacement of the ground in each shock.

2. Complete Period (t) of the maximum motion or the time taken to make a complete to-and-fro motion of the ground.

3. Maximum Velocity (v) of the ground, or $v=\frac{2r\pi}{t}$.

4. Maximum Acceleration $=\frac{v^2}{r}$.

The last two quantities were calculated by assuming for convenience sake the motion of the ground to be harmonic, though it is not exactly so in actual cases.

5. Direction of the maximum horizontal motion of the ground.

6. Duration of the earthquake, *i.e.*, the interval of time from the commencement to the end of the disturbance. It is almost impossible to measure the absolute duration of earthquakes, as they usually begin with exceedingly feeble tremors and end with very slow undulations.

7. The distance and direction of the origin of each earthquake from Tōkyō and its area. These were kindly supplied

[2] Transactions of the Seismological Society, Vol. VIII.

by the Imperial Meteorological Observatory. Existence of vertical motion, the range and the direction of horizontal motion, etc., may be examined in reference to the position of the origin of shocks and their area.

By *Tremors* are meant feeble shocks whose range of motion is less than one-tenth of a millimeter.

Local shocks, marked *Local*, are small earthquakes, shaking only limited regions of the country, usually from five to fifteen miles around.

Professor J. A. Ewing's Horizontal Pendulum and Vertical-motion Seismographs were mainly used in making these measurements. They are automatically started by the earthquake motion when it attains one-fifteenth part of a millimeter. By increasing the sensitiveness of the instruments the number of records may be proportionally increased.

The records, unless otherwise stated, are those obtained at Hitotsubashi.

1885.

No.	Date.	Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity in mm. per Sec.	Accel. in mm. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion.	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
							min.sec.			min.scc.		
1	Sept. 2, 8.36. 0. p.m.	0.3	0.8	1.2	9.6	NNE	2.30	0.05	0.70	0.46	46 miles due North inland.	54 m.
2	Sept. 26, 0.30. 0. p.m.	6.5	2.2	9.3	26.6	N76°W	3.35	0.14	0.56	1.42	110 miles S 30 W in the ocean.	146 m.
3	Sept. 28, 5.28. 0. a.m.	3.8	1.7	7	25.8	EW	3.00	Trace			The same in general features as No. 2.	
4	Sept. 29, 8.36.16. a.m.	0.1	1	0.3	2.	SN	1.45				Local.	
5	Oct. 1, 1. 9. 0. p.m.	1	0.7	4.5	40.5	SN	2.00	0.10	0.40	0.09	59 miles N 35 E on the sea shore.	90 m.
6	Oct. 3.	0.1	1	0.3	2.	SN	0.50				Local.	
7	Oct. 7, 7.34.45. a.m.	0.4	0.7	1.8	16.2	N15°E	0.18				Local.	
8	Oct. 9, 7.54. 0. p.m.	0.1	0.8	0.4	3.2	EW	2.00				Local.	
9	Oct. 11, 5.28.18. a.m.	1.1	1	3.5	22.3	WNW	4.03	0.02		0.06	71 Miles N 60 E in the sea.	83 m.
10	Oct. 15, 9. 2.29. a.m.	0.3	0.8	1.2	9.6	W15°N	1.10				178 miles WSW.	14,333 sq. m.
11	Oct. 15, 8.18.43. p.m.	1.0	0.7	4.5	40.5	ESE	2.28	0.03		0.07	15 miles SSE in Tokyo Bay.	33 m.

12	Oct. 18, a.m.	Tremors				EW	0.20				Local.	
13	Oct. 18, 0.15. 0. p.m.	0.3	0.9	1.6	17.1	NS	1.00				N60°E 59 miles.	61 m.
14	Oct. 21, 1.15. 0. a.m.	0.4	0.9	1.4	9.8	NW	2.02				98 miles N 73° W	19,500 sq. m.
15	Oct. 24, 5.12.18. p.m.	0.7	0.9	2.4	16.0	S60°W	1.15				81 miles nearly E in the sea.	93 m.
16	Oct. 26, 10.41.11. p.m.	2.2	1.4	4.9	21.8	EW	3.20				112 miles S in the sea.	139 m.
17	Oct. 30, 8.31.16. p.m.	0.3	1.0	0.9	5.4	WNW	2.30	Trace			415 miles NW in the ocean.	34,700 sq. m.
18	Nov. 16, 1.53.36. p.m.	Tremors					0.30				15 miles SSE.	22 m.
19	Nov. 18.	Tremors				NS					Local.	
20	Dec. 3, 6. 1.42. a.m.	0.2	0.6	1.0	10.	NS	1.00				20 miles NNE inland.	29 m.
21	Dec. 7, 1. 2. 0. a.m.	2.1	1.6	4.1	16.0	NNW	5.02				98 miles E 13° N in the sea.	17,120 sq. m.
22	Dec. 19, 2.12. 0. a.m.	Tremors				NS	0.43				Local.	
23	Dec. 19, 6.28. 0. p.m.	2.8	1.7	5.2	19.4	S55°W and then to N 30° W	1.46	0.22	0.50	0.45	37 miles E 35° N inland.	160 m.
24	Dec. 25, 1.13.30. p.m.	0.2	0.7	0.9	8.1	EW		Trace		0.10	Local.	
25	Dec. 28, 10. 6.30. p.m.	3.5	1.4	7.9	35.7	EW	3.30	1.00	0.60	1.62	29 miles NNE inland.	98 m.

1886.

No.	Date.	Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity, in mm. per Sec.	Accel. in mm. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion.	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
							min.sec.			min.sec.		
26	Jan. 4, 8.31.30. p.m.	0.4	0.7	1.8	16.2	EW	0.54				59 miles N 60° E in the sea.	61 m.
27	Jan. 5, 4.26.42. p.m.	0.8	1	2.5	15.8	EW	0.75	Trace			66 miles due E on the sea shore.	73 m.
28	Jan. 9, 6.48.0. a.m.	0.1	1.2	0.3	1.8	SN	2.00				Local	
29	Jan. 18, 9.15.0 p.m.	0.3	0.8	1.2	9.6	NS	0.65				Local	
30	Feb. 18, 3.0.0. a.m.	0.2	0.7	0.9	8.1	EW	0.22				Local	
31	Feb. 19, 9.51.11. a.m.	0.1	1	0.3	1.8	EW	0.15				Local	
32	Feb. 22.	0.1	0.7	0.4	3.2	EW	0.40				Local	
33	Feb. 24, 7.34.0. a.m.	0.5	0.6	2.6	27.0	NW	1.45	0.08	0.3	0.56	29 miles due N inland.	73 m.
34	Feb. 24, 3.36.25. p.m.	0.3	1	0.9	5.0	EW	1.20				Local	
35	March 2, 5.3.49. a.m.	0.6	0.8	2.4	19.2	NNE	2.10				73 miles due E in the sea shore.	78 m.

36	March 3, 3.36.0. p.m.	Tremors				EW	0.15				Local	
37	March 13, 6.25.0. p.m.	0.7	0.9	2.4	16.2	WNW	2.00				68 miles nearly E on the sea shore.	73 m.
38	March 26, 6.6.0. p.m.	0.1	0.8	0.4	3.2	SSE	0.65				17 miles SSE in the bay.	24 m.
39	April 1.	0.1	1	0.3	1.8	EW	0.65	Trace		0.04	Local	
40	April 4, 1.0.0. a.m.	0.4	1	1.3	8.0	EW	2.10	Trace		0.15	134 miles NNE away in the sea.	146 m.
41	April 13, 4.45.0. a.m.	1.2	0.9	4.2	29.2	S54E	4.02	0.05	0.4	0.10	342 miles SE in the ocean.	33,000 sq. m.
42	April 14, a.m.	0.8	0.9	2.8	19.6	EW	0.40				Local	
43	April 23, 4.22.22. a.m.	0.7	0.8	2.7	20.8	ENE	1.26				171 miles NW on the other side of the island.	16,400 sq. m.
44	May 2, p.m.	0.1	0.9	0.4	3.2	WE	0.40				Local	
45	May 3, 0.0.0. p.m.	0.2	0.7	0.9	8.1	ESE	2.00				Local	
46	May 5.	0.2	0.9	0.7	4.9	EW	0.54				29 miles NNE inland.	32 m.
47	May 8, 10.14.0. p.m.	2.1	0.8	8.2	64.0	N47°E	2.24	0.33	0.5	0.44	32 miles WNW inland.	85 m.
48	May 9, 3.0.0. p.m.	0.5	1.2	1.3	6.8	E30°N	2.50				Local	

1886.

No.	Date.		Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity, in mm. per Sec.	Accel. in mm. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
								min.sec			min.sec.		
49	May 11, 2.31.58. p.m.		0.5	0.9	1.7	11.6	E10°S	1.25				Local	
50	May 16, 9.7.16. a.m.		3.3	1.2	8.6	44.8	N50°W	3.05	0.4	0.8	1.25	56 miles nearly NW inland.	18,530 sq. m.
51	May 18, 8.12.51. p.m.		0.5	0.9	1.7	11.6	S50E	2.15	0.1	0.3	0.36	29 miles NNE inland.	85 m.
52	May 30, 8.38.18. p.m.		0.4	0.9	1.4	9.8	EW (mainly)	1.30				57 miles NNE inland.	57 m.
53	June 3, 3.6.37. p.m.		0.4	1.1	1.1	6.1	EW	1.31	Trace			NE 76 miles in sea shore.	76 m.
54	June 6, 6.0.0. p.m.		0.5	0.7	2.2	19.4	EW	1.06	Trace			25 miles.	
55	June 11, 1.45.44 a.m.	Hongo.	0.1	0.7	0.4	3.2	NW	1.02				ESE in Tokyo Bay 15 miles.	35 m.
		Hitotsu-bashi	0.4	0.6	2.1	22.1	EW	1.15					
56	June 12.		0.5	0.7	2.2	19.4	WE	1.15				Local	
57	June 13.		0.3	0.9	1.0	6.7	EW	0.36				Local	

58	June 14, 6.25.19. p.m.		0.6	0.8	2.4	19.2	ESW	1.10	0.1	0.5	0.30	In or near Tokyo.	35 m.
59	June 22.		0.3	0.8	1.2	9.6	EW	0.52				Local	
60	June 28.		0.2	0.8	0.8	6.4	EW	0.31				Local	
61	July 2, 0.33.6. p.m.	Hongo.	0.7	1.0	2.2	13.8	ESE WNW	1.27	0.3	1.3	1.30	NE in the Pacific ocean.	Extensive earthquake shaking the whole of North Japan, Tokyo on its edge.
		Hitotsu-bashi.	1.8	0.9	6.2	42.7	ESE WNW	2.24	0.3	0.8	1.22		
62	July 23, 0.57.0. a.m.		0.6	0.9	2.1	14.7	NS	1.24				NW 110 miles on shore line.	Extensive shock, Tokyo on its edge.
63	August 3, 2.11.40 a.m.	Tremors					EW	0.20				N 30 miles inland.	30 m.
64	August 9, 11.24.0. a.m.	Hongo.	0.5	0.9	1.7	11.6	NE SW	1.44				The same as No. 62 in general features.	
		Hitotsu-bashi.	0.5	0.8	2.0	16.0	NE	1.10					
65	August 29, 8.34.54 p.m.		0.6	0.8	2.4	19.2	ESE	1.10					
66	Sept. 6, 0.38.53. p.m.		0.2	0.7	0.9	8.1	EW	0.35				Local	
67	Sept. 12, 8.43.22. p.m.		0.8	1.2	2.1	11.0	S30°W	0.50	0.1	0.4	0.16	In or near Tokyo.	65 m.

1886.

No.	Date.		Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity in mm. per Sec.	Accel. in mm. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion.	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
								min. sec.			min. sec.		
68	Sept. 15, 3.9.23 a.m.		0.2	1.1	0.6	3.6	S 30° W	1.13	Trace			Local	
69	Sept. 16, 1.2.57 p.m.		0.1	0.4	0.8	12.8	SW	0.50	Trace			NNW 40 miles inland. Tokyo on edge.	50 m.
70	Sept. 21, 8.17.0. p.m.	Hongo.	0.2	0.9	0.7	4.9	EW	0.53					
		Hitotsu-bashi.	0.4	0.8	1.6	12.8	NS	1.31					
71	Sept. 30.		0.8	0.8	3.1	24.0	SN	0.58				Local	
72	Oct. 4, 2.35.25. p.m.	Hongō.	0.2	0.6	1.0	10.0	SW	0.24	0.1	0.4	0.15	NNE 25 miles inland.	40 m.
		Hitotsu-bashi.	0.3	0.9	1.0	6.7	WNW	1.25	0.1	0.5	0.24		
73	Oct. 22, 3.49.14. a.m.		0.5	0.8	2.0	16.0	NS	1.05				ENE 34 miles inland.	70 m.

74	Oct. 25, 10.11.18. p.m.		0.4	1.2	1.1	6.1	SE	1.40	0.1	0.5	0.34	The same in general features as No. 72.	
75	Nov. 1, 5.13.5. a.m.	Hongō.	0.3	1.9	0.9	5.4	NS	1.15	Trace				
		Hitotsu-bashi.	0.5	0.8	2.0	16.0	NS	0.59	0.1	0.5	0.16		
76	Nov. 2, 8.21.46. p.m.		0.2	1.1	0.6	3.6	WNW	1.40	0.1	0.6	0.33	N30 miles inland. NE in the Pacific ocean.	35 m.
77	Dec. 4, 2. 0.39. p.m.	Hongō.	0.3	0.8	1.2	9.6	SW	1.50	0.1	0.3	1.12	NE 120 miles in the Pacific ocean.	140 m.
78	Dec. 6, 0.40. 0. p.m.		Tremors					0.29				Local.	
79	Dec. 8, 11.58.16. a.m.		0.3	0.9	1.0	6.7	SN	2.02				N 30 miles inland.	35 m.
80	Dec. 11, 10.16.25. p.m.		0.4	0.9	1.3	8.5	SN	1.16	Trace			SE 150 miles in ocean near the shore.	120 m.
81	Dec. 12. 10.11.55. p.m.		Lost.										
82	Dec. 21, 3. 7. 2. a.m.		Tremors										
83	Dec. 26, 5.48. 5. p.m.	Hongō.	0.3	0.5	1.9	24.1	S 50°W	0.37	0.1	0.4	0.26	In or very near Tokyo.	65 m.
		Hitotsu-bashi.	0.8	0.6	4.2	44.1	NNW	0.51	0.3	0.6	0.21		

1886-1887.

No.	Date.		Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity in mm. per Sec.	Accel. in m.m. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion.	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
								min.sec.			min. sec.		
84	Dec. 29, 11. 5.43. a.m.		0.5	0.6	2.6	27.0	SE	1.0	0.2	0.5	0.18	N 22 miles inland.	43 m.
85	Jan. 15, 6.52. 0. p.m.	Hongō.	7.3	2.0	11.5	36.2	SSW	6.24 (Principal motion 2 min.)	1.3	1.0	1.12	35 miles.	200 m.
		Hitotsu-bashi.	21	2.5	26	66	S65°W	6.35 (do.)	1.8	0.9	1.38		
86	Jan. 16, 10.16.19. p.m.		0.6	0.7	2.7	24.3	Variable	1.55				The same in general features as No. 85.	
87	Jan. 24, 10.40.50. p.m.		0.4	0.7	1.8	16.2	EW	2.06				Local.	
88	Jan. 28, 3.54. 8. p.m.		0.4	0.8	1.6	12.8	ENE	1.05				NW in the Pacific ocean.	Extended along the coasts of North-Japan.
89	Feb. 2, 2. 8.14. p.m.		0.8	0.9	2.8	22.1	S 30° W	1.58				178 miles WSW.	180 m.
90	March 2, 5.33.21. p.m.		Tremors									Origin inland.	Small earthquake.
91	March 20, 11.32.56. p.m.		Tremors									Local.	
92	March 23.		0.3	0.8	1.2	9.6	WE	0.45				Local.	

93	April 4, 8.46. 0. a.m.	Tremors									N58 miles inland, Tokyo on edge.	65 m.
94	April 9, 11.49.54. a.m.	Tremors									The same as No. 93.	
95	April 16, 3.35. 0. a.m.	Hongō.	0.2	0.7	0.9	8.1	variable	0.40	Trace			ENE 35 miles.	37 m.
		Hitotsu-bashi.	0.4	0.8	1.6	12.8	SW NE	1.52	0.1	0.8	0.28	
96	April 20, 2.35. 0. a.m.		0.3	1	0.9	5.4	EW	0.40				Local.
97	April 23, 6.30. 0. p.m.	Tremors										Local.
98	April 27, 9.30.38. p.m.		0.5	2.7	0.6	1.4	SN	2.20				SSE in Tokyo Bay, 17 miles.	33 m.
99	April 29, 11.12.10. a.m.		1.4	Lost					(occurred)				
100	May 2, 11.25.40. a.m.	Hongō.	0.4	0.6	2.1	22.1	NE	0.57	0.1	0.5	0.17	In or near Tokyo.	
101	May 4.		0.8	1	2.5	15.6	ENE	1.12				Local.	
102	May 5, 2.35.10. a.m.		0.1	0.9	0.3	1.8	EW	0.35				Local.	
103	May 6, 3.49.50. p.m.	Tremors										Local.	
104	May 7, 7.13.12. a.m.		0.2	0.7	0.9	8.1	NS	1.27				The same in general features as No. 88, but smaller in extent.	

1887.

No.	Date.		Max. Horiz. Motion in mm.	Complete Period of Max. Horiz. Motion in Sec.	Max. Velocity in mm. per Sec.	Accel. in mm. per Sec. per Sec.	Direction of Max. Horiz. Motion.	Duration of Horiz. Motion.	Max. Vertical Motion in mm.	Complete Period of Vertical Motion in Sec.	Duration of Vertical Motion.	Distance and direction of origin from the observatory in miles.	Radius of propagation of seismic waves in miles, or area of disturbance in sq. miles.
								min.sec.			min.sec.		
105	May 9, 0. 9.14. a.m.		0.8	0.7	3.6	31.9	S65°W	2.11				Local.	
106	May 17, 4.19.44. p.m.		0.2	0.3	2.1	44.1	NS	0.20				N30 miles inland, Tokyo on the edge of the disturbance.	40 m.
107	May 21, 9.46.20. p.m.	Hongo.	0.4	0.6	2.1	22.1	NS	0.35				N 20 miles.	50 m.
108	May 29, 0.50.52. a.m.	Hongo.	0.6	1.8	1.0	3.3	NS	4.02	0.2	1.1	2.22	NNE 100 miles on shore-line, Tokyo in the middle of disturbed area.	Extensive shock.
		Hitotsu-bashi.	2.1	1.1	6.0	34.3	W10°N	4.30	Lost				
109	June 1.		0.1	0.7	0.4	3.2	EW	0.51				Local.	
110	June 17, 1.41.41. a.m.		Tremors									Local.	
		Hongo.	0.2	0.8	0.8	6.4	EW	1.20					
111	June 20, 8.38.30. a.m.	Hitotsu-bashi.	0.4	0.9	1.4	9.8	Variable	1.35				NE 70 miles on shore-line, Tokyo on the edge of d. a.	100 miles. Moderately extensive earthquake.

112	June 21, 2. 2.35. p.m.		Tremors					1.05				Local.	
113	June 22, 7.42.39. a.m.	Hongō.	0.2	0.6	1.0	10.0	SN	0.46				E 48 miles on shore-line, Tokyo on edge.	53 m.
		Hitotsu-bashi.	0.3	0.7	1.3	11.2	NW	1.38					
114	June 30, 8. 0.35. a.m.		Tremors										
115	July 2, 3.16.24. p.m.	Hongō.	0.6	0.6	3.1	32.0	S20°E	1.30	Trace			W 45 miles, Tokyo on edge.	55 m.
		Hitotsu-bashi.	0.6	0.9	2.1	14.7	NNE	1.01	Trace				
116	July 4.		0.2	0.9	0.7	4.9	EW	0.32				Local.	
117	July 11, 3. 7.42. p.m.	Hongō.	0.2	0.5	3.1	9.61	SN	0.24					
118	July 22, 8.27. 0. p.m.	Hongō.	1.0	1.4	2.3	10.6	EW	1.38				The same in general features as No. 62 and No. 64. Extensive earthquake.	
		Hitotsu-bashi.	1.9	1.8	3.3	12.1	N30W	3.37					
119	August 15, 0.59.15. a.m.		1.9	2.0	3.0	9.5	SN	3.05	0.1	0.6	1.01	NE 105 miles on shore-line, Tokyo on the edge.	120 m.

Notes.

For reference see corresponding numbers in the Table and in Notes.

No 1.—This earthquake was moderate in its size, being enclosed within the radius of 47 miles. It affords a good example of both horizontal and vertical motions. The maximum horizontal motion occurred at the third second from the commencement of the shock; at this time the vertical motion was still exceedingly feeble although it was recognizible from the beginning. It reached its maximum 3 seconds later than the horizontal motion which had been then much reduced in its amplitude. The vertical motion was smaller than the horizontal motion in the ratio of 1 to 6; its period was quicker in the ratio of 7 to 8 and its duration of motion was shorter in the ratio of 1 to 3·3. The direction of the maximum horizontal motion was N.N.E. and S.S.W., while the origin of the earthquake lay in due N. from the observing station.

No. 2.—This shock gave the second largest motion recorded in the Table. The horizontal motion was comparatively feeble during the first 20 seconds, but gradually augmented and remained active during 80 seconds. The vertical motion appeared from the beginning, but was very small, notwithstanding the large horizontal movement that accompanied it. The ratio of the former to the latter was 1 to 46 in amplitude, 1 to 4 in period, and 1 to 3·8 in duration.

In this and in the following shocks it will be observed that the direction of the local movement of the ground at the observing station and the direction of the origin of the shock from the city did not generally coincide.

No. 3.—This earthquake disturbed the same portion of the country as No. 2, but with less force. The ground moved almost equally in all directions. More than 120 complete waves, whose periods varied from 0.7 second to 3 seconds, were registered. Notwithstanding the existence of considerable horizontal motion no vertical motion appeared.

No. 4.—This was one of the local shocks which frequently occur in this and in other parts of the country. Its area of disturbance is often not more than a few square miles. The motion is generally feeble in these local shocks.

No. 5.—The ratio of the vertical motion to the horizontal motion was 1 to 10 in amplitude and 1 to 13 in duration.

No. 13.—More than 50 distinct waves of small amplitudes were counted.

No. 14.—This extensive earthquake originated among the mountain districts of Shinano, which is one of the highest portions of the country, 2,000 ft. above the sea level. There is one active and many extinct volcanoes. The seismic waves were not propagated much beyond Tōkyō.

No. 21.—Tōkyō was in the middle of the shaken district.

No. 23.—Both horizontal and vertical tremors were visible from the beginning; but at the fifth second there suddenly appeared a large horizontal motion (maximum). Distinct vertical waves came a few seconds later.[1]

No. 25.—The motion commenced slowly and was not preceeded by quick tremors as is usually the case. The Observatory was comparatively near the origin of disturbance.

No. 33.—This was a middle-sized earthquake in which the observing station was near its origin. The maximum horizontal motion occurred 6 seconds from the commencement, and the maximum vertical motion 2 seconds later. Several distinct vertical waves of the average period of 0·3 second were registered.

No. 39.—Trace of the vertical motion was visible, though the shock was only local and the motion small.

No. 41.—The whole of North Japan was disturbed by this shock, the observing station being near the southern extremity of the disturbed district.

[1] The Jour. Scien. Coll. Vol. I., Plate XI.

No. 47.—The origin, which was inland, was comparatively near the city. There were hardly any vertical tremors during the first few seconds, while there were considerable horizontal tremors. A decided horizontal motion occurred at the beginning of the sixth second; more pronounced vertical motion began one and a half seconds later, and its maximum ocurred several seconds after.[1]

No. 50.—This was another large earthquake, in which the seismic waves were propagated from the origin some 120 miles both north and south, and 61 miles toward the west, where they were stopped by the mountains. On the east they reached the Pacific Ocean. The observing station was comparatively near the origin.

This shock was preceded by tremors of quick period during the first eight seconds, then there suddenly appeared the maximum horizontal motion; at this time the vertical motion, which was visible from the beginning, was yet very small—0·08 mm. with a period of 0.4 second; after 6 seconds it reached the maximum, and continued for eighty-five seconds with decreasing amplitudes and with lengthening periods. The ratio of the vertical motion to that of horizontal motion was 1 to 8·3 in amplitude, 1 to 1·5 in period, and 1 to 2·2 in duration.

No. 51.—This earthquake, although it was quite extensive, and its origin was comparatively near the observing station, produced small motions. The vertical motion was visible from the commencement, and exhibited its maximum at the seventh second when the horizontal motion was also largest.

No. 61.—This extensive shock disturbed the whole of North Japan, Tōkyō being near the edge of the disturbed area. The peculiarity in this shock was the unusually large vertical motion with its slow period.

The ratio of vertical motion to horizontal motion in Hongō 1:2.5
The ratio of vertical motion to horizontal motion, Hitotsubashi 1:6
The ratio of horizontal motion in Hongō to that of Hitotsubashi 1:2.5
The ratio of vertical motion in Hongō to that of Hitotsubashi 1:2

[1] The Jour. Scien. Coll. Vol. I., pl. IX.

No. 62.—Originating on the shores of the Japan Sea, the shock crossed the whole breadth of the main island. Nearer the origin the motions were very violent and somewhat destructive; it stopped the flow of springs and shattered houses.

No. 64.—In general features this shock resembled that of No. 62. It disturbed the same parts of the country and likewise caused considerable damage, though in less degree.

No. 67.—Vertical and horizontal motions began at the same moment, but the maximum of the latter preceded that of the former by several seconds.

No. 72.—Tōkyō was comparatively near the origin.

No. 75.—Tōkyō was near the edge of the disturbed area. The maximum horizontal and vertical motions were simultaneous.

No. 76.—Tōkyō was near the outskirts of the affected district.

No. 77.—It was quite a strong shock nearer its origin, which was in the sea not far from the shore. The maximum vertical motion arrived several seconds before the maximum horizontal motion.

No. 83.—Vertical motion was comparatively large considering the smallness of the horizontal motion; moreover it was clearly pronounced, exhibiting eight distinct waves. Its maximum appeared a few seconds after the horizontal maximum.

No. 85.—This is one of the two largest earthquakes in 1887. The origin of the shock was in S.W. about 35 miles from the Observatory. The seismic waves extended nearly 200 miles to the west and north-east along the Pacific sea-board. On the north-west they approached to the shores of the Japan Sea. They shook, in all, about 32,000 square miles of land area.

At Hitotsubashi, after a few seconds from the commencement of the shock the ground moved suddenly 3 mm. toward the west. At the thirtieth second the maximum horizontal motion recorded in the Table was observed, which apparently cor-

responded with the maximum horizontal motion in Hongō. More than sixty distinct shocks were recorded.

At Hongō, the earthquake commenced with quick tremors. During the third second there appeared for the first time a vigorous horizontal motion in N.W. and S.E. (*i.e.* at right angles to the line joining the origin of the disturbance and the Observatory) accompanied by a considerable vertical displacement. The maximum vertical motion occurred at the ninth second. The maximum horizontal motion occurred at the thirty-third second.

Decided vertical and horizontal motions simultaneously occurred at the second second.[1]

The ratio of the max. h. m. in Hongō to that of Hitotsubashi	1:3
The ratio of the max. v. m. in Hongō to that of Hitotsubashi	13:18
The ratio of the max. v. m. to max. h. m. in Hitotsubashi ...	1:12
The ratio of the max. v. m. to max. h. m. in Hongō	1:6

No. 95.—Tōkyō was on the edge of the disturbed area. There were a few distinct vertical waves at Hitotsubashi.

SUMMARY OF RESULTS.

The results obtained from a study of the preceding table may be summarised as follows :—

In most of the earthquakes vertical motion did not appear, that is, the ground moved entirely in a horizontal plane. This was on account of the origin of the disturbance being far away from the observing station. In the above table, if we reject the slight shocks marked *tremor*, and the doubtful cases, we see that out of 100 earthquakes vertical motion occurred in 28 only, *i.e.*, once in 3.6 shocks.

Taking averages of all the quantities involved in these 28 cases, we find :—

Maximum horizontal motion.....	1.2 mm.
Complete period of maximum horizontal motion	1 sec.
Duration of horizontal motion	124 sec.
Maximum vertical motion	0.18 mm.
Complete period of maximum vertical motion	0.56 sec.
Duration of vertical motion	42 sec.

[1] Trans. Seis. Soc. Vol. XI., p. 176, pl. I.

Treating similarly the horizontal motion in 95 earthquakes recorded at Hitotsubashi (soft soil), we find :—

Maximum horizontal motion	0.73 mm.
Complete period of maximum horizontal motion	0.96 sec.
Duration of horizontal motion	117 sec.

Also from a like treatment of the horizontal motions in 18 earthquakes recorded at Hongō (hard ground), we get :—

Maximum horizontal motion	0.37 mm.
Complete period of maximum horizontal motion	0.76 sec.
Duration of horizontal motion	74 sec.

The values of the horizontal motion given in the first tabulated set of averages are larger than those in the second and third. The reason is, clearly, that shocks containing vertical motion are generally larger than those without, so that the second and third sets, which include shocks both with and without vertical motion, naturally give smaller averages.

Although the second and the third sets, referring as they do to different shocks, are not strictly comparable, they nevertheless show in a general way that in hard ground the motion is smaller, the period quicker, and the duration shorter, than in soft soil. Their ratios are 1 to 2, 1 to 1.3, and 1 to 1.5 respectively.

In the above sets of averages the records of the somewhat destructive earthquake of January 15th, 1887, were not included, as that was much larger than the ordinary shocks we are dealing with. For the sake of comparison the characteristics of that shock as registered at Hitotsubashi are now given :—

Maximum horizontal motion	21 mm.
Complete period of maximum horizontal motion	2.5 sec.
Duration of horizontal motion	6 min. 34 sec. (Principal motion 2 min.)
Maximum vertical motion	1.8 mm.
Complete period of maximum vertical motion	0.9 sec.
Duration of vertical motion	98 sec.

For details see No. 85. In the earthquake of October 15th, 1884, a maximum horizontal motion of 42 mm., with a complete period of two seconds, was recorded at the above-named place.

When vertical motion occurred it was invariably smaller than the horizontal motion as is obvious from the first set of averages. The average ratio of the two components of the motion was 1 to 6, or the former was only one-sixth of the latter.

The period of the vertical motion was shorter than that of the horizontal motion their average ratio being 1 to 1·8. That is when the ground made one to-and-fro motion it so performed during the same time nearly two complete up-and-down oscillations. In all the preceding tables the periods of the *maximum* vertical motion are given, but the periods in the other parts of the disturbances were much shorter. They varied from 0·2 second to 0·5 second. Exceedingly feeble tremors of a few seconds' duration generally preceded the principal motions as in the case of the horizontal motions.

The duration of the vertical motion was much shorter than that of the horizontal motion. It occurred invariably during the early stages of the earthquake, and generally ended before the horizontal components. The average ratio of the two durations was 1 to 3, or the horizontal motion continued three times longer than the vertical.

The vertical motion almost invariably appeared when the horizontal motion had reached 1 mm. which was more than the average amplitude in ordinary earthquakes. Out of 100 shocks there were 18 cases in which the ground moved more than 1 mm. Out of these 18 earthquakes vertical motion occurred in 14 cases or 78 per cent., and did not appear in the remaining 4 cases.

But, on the other hand, vertical motion also appeared in certain cases when the horizontal motion was less than 1 mm. Out of the 28 shocks already specified as showing vertical motion, 14 showed a horizontal motion of more than 1 mm. while in the other 14 cases the horizontal motion was less than 1 mm.

Again, when we analyze the 14 cases which had vertical motion with less than 1 mm., we see that in 9 shocks the observing station was in, or comparatively near to, the centre of the disturbed districts, and in the remaining 5 cases it was at a considerable distance from the origin. In other words, vertical motion generally appeared when the origin of the disturbance was near the observing station. In such a case the vertical motion might have come directly through the earth-crust from the origin, and not in the form of free surface waves. It must be, however, noted that there were 4 cases in which the observing station was comparatively near the centre of disturbance, but in which vertical motion did not occur. They were all small shocks, with maxmium motions less than 1 mm.

In earthquakes showing both horizontal and vertical motions, feeble but quick-period tremors of both types simultaneously preceded the principal movements. The more decided and pronounced motion usually appeared first in the horizontal component, and then came the large vertical movements.

Tremors, or quick-period minor waves, generally precede earthquakes proper, and their probable connection with sound phenomena has been discussed in this country by Professors Ewing,[1] Milne,[2] and Knott.[3] The vertical motions which have just been considered possess in great measure the characteristics of these minor tremors.

It is a well-known fact that the movement of the ground at the time of earthquakes is very complex, and that the ground moves in all azimuths during prolonged shaking. In the earthquakes discussed in the present paper the direction and the distance of the origin of disturbance from the observing station were known, as also the direction of the maximum movement of the ground. No definite relation between these directions can be established. Seismic waves indeed must suffer much reflec-

[1] Memoirs on Earthquake Measurements, p. 11.
[2] Earthquake Notes—Sound Phenomena, Trans. Seis. Soc. Vol. XII.
[3] Earthquakes and Earthquake Sound, etc., Trans. Seis. Soc. Vol. XII.

tion, refraction, and diffusion as they progress, and the co-existence of normal and transverse waves is a distinct element of confusion.

Out of 119 earthquakes recorded in the tables, 42 were local shocks, which extended only over a small tract of land from a few miles to 10 or 15 miles around. They caused the ground only slightly to tremble, and the horizontal motion of the ground was from 0·1 mm., to 0·3 mm., or even less. There were 4 cases in which the motion reached 0.8 mm. No verctical motion occurred in these local shocks.

There were 119 shocks during the two years, which means more than one shaking per week.

As the continuation of these observations will be published in the coming volumes of this Societys's Transactions, further generalizations or conclusions, that might be deduced from the facts now given, will be reserved for a future paper.