Note on the Direction and Magnitude of the Vibrations in the Different Phases of the Earthquake Motion

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Note on the Direction and Magnitude of the Vibrations in the Different Phases of the Earthquake Motion.*

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1. The present note contains the result of study on the observations at Tokyo concerning the magnitude and direction of seismic movements originating from distant centres. The direction of movements is examined with reference to the path of the wave transit, which is assumed to coincide with the great circle passing through the observing station and epicentre; the calculation being made according to the formula

$$\cos\frac{\Delta}{2}=\sqrt{\frac{\sin\frac{-\varphi+\varphi'+\delta}{2}\cos\frac{\varphi+\varphi'-\delta}{2}}{\sin\delta\cos\varphi}}$$

where Δ represents the angle between the great circle and the meridian of the observing station, δ the angular epicentral distance at the latter, and φ and φ' the latitudes of the station and the epicentre respectively.† The direction of the seismic motion has been obtained by composing the two horizontal movements of a few well-defined vibrations at the beginning of the different phases in the seismograms, which were given by Omori H. P. Seismographs registering EW and NS motions.

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* Abstract of a paper read before the meeting of the Imp. Earthq. Inv. Comm. on Dec. 5, 1906, with addition of the discussion of earthquakes Nos. 4 and 9.

† The formula for the calculation of δ is $\cos\delta=\sin\varphi\sin\varphi'+\cos\varphi\cos\varphi'\cos(\lambda-\lambda')$, where λ and λ' represent the longitudes of the observing station and the epicentre respectively.

2. The earthquakes taken into consideration are as follows:—

TABLE I.

Group.	No.	Date.	Epicentre:	λ'	φ'	δ	Δ
I	1	Sept. 29, 1899	Ceram.	129°E	6°S	42° 54′.6	S 15°.8 W
	2	July 29, 1900	New Hebrides.	170°E	17°S	59° 58′.6	S 33°.8 E
	3	June 1, 1906	N. Australia.	139°E	13°S	48° 42′.4	S 1°.1 W
	4	Nov. 19, 1906	W. Australia.	104°50′E	21°27′S	66° 1′.8	S 35°.7 W
II	5	Aug. 22, 1902	Turkestan.	75°E	39°.5N	50° 20′.1	N 65°.1 W
	6	April 4, 1905	India.	77°E	31°.8N	51° 26′.4	N 75°.1 W
III	7	Oct. 9, 1900	Alasca.	140°W	60°N	54° 57′.2	N 37°.0 E
	8	April 18, 1906	San Francisco.	123°W	38°.3N	73° 29′.3	N 54°.2 E
	9	Jan. 31, 1906	Columbia.	79°W	5°N	125° 26′.7	N 50.°0 E

Of these, the first four originated in Javan district, the next two in the Himalayan district, and the last three in the Pacific side of America. Thus the earthquakes in Groups I, II and III were propagated to Tokyo nearly from south, west, and north-east, respectively.

3. The positions of the epicentres given in the table were obtained as centres of the most disturbed areas, except for the suboceanic earthquakes Nos. 2–4, whose origins were determined by means of the following observations concerning the time of commencement.*

No. 2:—7^h 8.7^m at Tokyo, 7^h 9.7^m at Batavia, 7^h 11.7^m at Calcutta, 7^h 12.0^m at Victoria, 7^h 15.2^m at Mauritius, 7^h 17.8^m at Cape of Good Hope.

No. 3:—4^h 38.2^m at Tokyo (dur. of p. t.$=8^m$ 25^s), 4^h 38.2^m at

* Time is given in Greenwich mean time.

Osaka (dur. of p. t.=8^m 25^s), 4^h 35.8^m at Perth, 4^h 37.1^m at Batavia, 4^h 41.9^m at Bombay, 4^h 39.8^m at Calcutta.

No. 4:—7^h 28.9^m at Tokyo (dur. of p. t.=16^m 13^s), 7^h 20.5^m at Perth.

The most important datum for the determination of the epicentre in No. 4 is the observation of the sea-quake on board the steamer Omrah at a point *long.* 104°50′E, *lat.* 21°27′S.

4. That the different phases of seismic movements have different directions may probably be best understood from the diagram of the earthquake No. 3. (see Pl. XXX.) In the seismogram, not only the commencement of the 1st prel. tremor (I), but also that of the 2nd one (II) and its successive waves (a-d) are larger in the NS than in the EW component, while this relation is quite contrary in the 1st princ. portion (III-D). It will also be seen that the 3rd phase of the princ. portion (V-γ) is enlarged in the NS component only. I have hardly any reason to assume such peculiarities as errors due to the instruments which are most reliable ones in our Institute, the pendulums of EW and NS components having 61.5 and 48.5 sec. as the periods of free vibration, and 15 and 20 times as the magnifications of their writing indices respectively. The same instruments registered both components in Nos. 4, 6 and 9, and NS component in No. 8. The other component in the last named earthquake is taken from the illustration given by Prof. Omori in the Publ. of the Imp. Earthq. Inv. Comm., No. 21, Appendix II. With respect to the diagrams of the four other earthquakes, the EW component in Nos. 1 and 5 was recorded by the instrument A, that in Nos. 2 and 7 by D and C respectively, while the NS component in Nos.

TABLE

Earth-quake No.	Compo-nent.	1st preliminary tremor.		2nd preliminary tremor.	
		I-a′ a′-b′ b′-c′ aver. mm.	Resultant dir. amp.	II-a a-b b-c c-d d-e aver. mm.	Resultant dir. amp.
1	E-W W-E	Began gradually.	— —	·15 ·10 ·10 ·20 ·14	S27°·4W ·30
	N-S S-N	Bagan abruptly.		·24 ·17 ·17 ·49 ·27	
2	E-W W-E	Began gradually.	— —	·65 1·54 1·07 ·48 ·95	S41°·8E 1·42
	N-S S-N	Began very abruptly.		·75 1·20 1·50 ·80 1·06	
3	E-W W-E	Began gradually.	— —	·07 ·07 ·07 ·07 ·07	Due S ·67
	N-S S-N	Began abruptly.		·24 ·75 1·05 ·65 ·67	
4	E-W W-E	Began gradually.	— —	·17 ·33 ·33 ·20 ·26	S33°·7W ·47
	N-S S-N	Began gradually.		·20 ·40 ·56 ·40 ·39	
5	E-W W-E	Began gradually.	— —	·40 ·55 ·48	N42°·0W ·72
	N-S S-N	Began gradually.		·40 ·65 ·53	
6	E-W W-E	·39 ·54 ·37 ·43	N64°W .48	·78 2·40 4·73 5·78 5·12 3·76	N53°·6W 4·68
	N-S S-N	·16 ·25 ·23 ·21		·53 2·30 3·90 3·78 3·40 2·78	
7	E-W W-E	Began gradually.	— —	·78 ·78 ·25 ·78 ·65	N36°·8E 1·08
	N-S S-N	Beginning large.			
8	E-W W-E	Began gradually.	— —	1·31 3·33 3·33 2·32 2·57	N46°·2E 3·57
	N-S S-N	Began gradually.		1·70 3·05 2·97 2·20 2·48	
9	E-W W-E	Began very gradually.	— —	·67 2·60 4·66 2·64	N59°·9E 3·05
	N-S S-N	Began very gradually.		·65 1·75 2·16 1·53	

II.

1st principal portion.								3rd principal portion.						
III-A	A-B	B-C	C-D	D-E	aver.	Resultant dir.	Resultant amp.	V-α	α-β	β-γ	γ-δ	aver.	Resultant dir.	Resultant amp.
mm.								mm.						
3·2	5·4	5·0	2·7		4·1	N79°·4W	4·2							
·85	·68	·73	·79		·77									
1·78	3·3	2·9			2·6	N77·0°·E	2·7	·18	·71	·65	·36	·48	S25°·5E	1·12
·45	·84	·50			·60									
·53	1·80	2·73	1·33		1·60	N99°·2W	1·62	·28	·73	1·30		·77	N11°·2E	4·0
·08	·20	·35	·39		·26			3·1	4·9	3·7		3·9		
·22	·37	·37			·32	N64°·8W	·35	·13	·23	·15	·10	·15	S15°·0W	·58
·11	·13	·20			·15			·38	·51	·62	·73	·56		
·50	·60	·90	1·15	·93	·83	N19°·3E	2·44	8·2	10·2	8·05	8·5	8·74	N58°·5W	10·2
1·63	2·17	2·53	2·58	2·60	2·30			5·75	6·4	4·7	4·6	5·36		
1·25	1·00	·73	1·78		1·19	N17°·7E	3·93							
2·61	3·15	3·75	5·45		3·74									
1·70	2·20	1·66			1·85	N63°·1W	2·38							
·62	·98	1·22			·94									
·40	·33	·33	·36	·33	·35	N27°·5W	·76							
·70	·33	·20	·58	1·55	·67									
1·73	1·13				1·43	N35°·1W	2·48							
1·70	2·35				2·03									

1 and 7 was given by B, and in Nos. 2 and 5 by one whose magnification was 10 times, and whose period of free vibration was 30 sec.*

5. Table II shows the range of motion (double amplitudes) of the different phases together with the resultant directions and magnitudes. The numbers in the row E-W show the ranges of motion from *east to west*, and those in W-E the magnitudes in the opposite direction.

6. Table III gives the relation between the directions of the 2nd preliminary tremor (II), the 1st (III) and 3rd principal portions (V) and that of propagation. The deviation of directions with positive or negative sign means the angle through which the direction of movement deviated from that of the path in the counterclockwise or clockwise sense. As it will be seen from the average values, the directions of the 2nd preliminary tremor and the 3rd principal portion are almost coincident with the path, while that of the 1st principal portion is nearly normal to the latter.

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* For the details of the instruments, the reader is referred to Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. in Foreign Languages, No. 21.

TABLE III.

No.	δ		Direction.				Deviation of direction.			Range of motion.				
			Δ	II	III	V	II	III	V	II	III	V	$\frac{III}{II}$	$\frac{V}{II}$
										mm.	mm.	mm		
1	42°	54′·6	S15°·3W	S27°·4W	N79°·4W	—	−11°·6	+95°·2	—	·30	4·2	—	14·0	—
2	59°	58′·6	S33°·8E	S41°·8E	N77°·0E	S25°·5E	+ 8°·0	+69°·2	− 8°·3	1·42	2·7	1·12	1·90	·79
3	48°	42′·4	S 1°·1W	S-N	N99°·2W	N11°·2E	+ 1°·1	+100°·3	−10°·1	·67	1·62	4·0	2·42	6·0
4	66°	1′·8	S35°·7W	S33°·7W	N64°·8W	S15°·0W	− 2°·0	+100°·5	−20°·7	·47	·35	·58	·74	1·23
5	50°	20′·1	N65°·1W	N42°·0W	N19°·8E	N58°·5W	−23°·1	+95°·1	− 6°·6	·72	2·44	10·2	3·40	14·2
6	51°	26′·4	N75°·1W	N53°·6W	N17°·7E	—	−21°·5	+87°·2	—	4·68	3·93	—	·84	—
7	54°	57′·2	N37° 0E	N36°·8E	N63°·1W	—	+ 0°·2	+100°·1	—	1·08	2·38	—	2·21	—
8	73°	39′·3	N54°·2E	N46°·2E	N27°·5W	—	+ 8°·0	+81°·7	—	3·57	·76	—	·21	—
9	125°	26′·7	N50°·0E	N59°·9E	N35°·1W	—	− 9°·9	+85°·1	—	3·05	2·48	—	·81	—
Average.							− 5°·6	+90°·5	−11°.4	1·77	2·32	3·98	2·95	5.56

7. The result contained in the foregoing § § may be summarized as follows:—

(*a*) The direction of the 1st prel. tremor, when it is distinct, tends to coincide with that of the path.

(*b*) The 2nd prel. tremor, whose direction coincides with the path, may possibly consist of longitudinal waves.

(*c*) The 1st princ. portion, whose direction is normal to the path, may possibly consist of transverse waves.

(*d*) The paths of the two last mentioned phases are probably common, as there are rocks of older geological formation giving as much transit velocities for the seismic waves of longitudinal and transverse types as the 2nd prel. tremor and the 1st princ. portion.

(*e*) Of the magnitude of the different phases, the 3rd princ. portion is the largest, but no definite relation could be found for the two other phases. In fact, the 2nd prel. tremor was larger than the 1st princ. portion in the earthquakes nos. 4, 6, 8 and 9 which had more distant origins, while this relation was quite contrary in the case of the nearer earthquakes.

(*f*) Similarity of the seismic motion originating at neighboring centres* is probably due to the existence of definite directions for the different phases and similarity of the path. With respect to the latter statement, the earthquakes of Group I, which were propagated along suboceanic paths, had the principal portion slightly developed in magnitude and duration when compared to the preliminary tremor, while those of Group II, mostly propagated along the free surface layer had well developed principal portion. This property, however, requires further investigation.

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* See Prof. Omori: Publ. of the Imp. Earthq. Inv. Comm. No. 21.

Earthquake of June 1st, 1906.