12. Direction of Earthquake Motion.

The following table gives, for Hitotsubashi and Hongo, the 2a and direction of the maximum horizontal motion in the 15 earthquakes, in which these two elements of motion were distinctly measured; the distance and direction of the seismic origins from Tokyo being also given for the sake of reference.

Place of observation.	Group.	No.	Max. 2a (mm.)	Direction of max. motion.	Distance and direction of earthquake origin from Tokyo.	
Hitotsubashi	II	50	0.25	N—S	60 km	N 54° E.
Hongo	,,	28	2.4	N 15° W	60	S 21° W.
,,	,,	65	1.4	NEN.	69	N 15° E.
,,	,,	123	0.54	SW	62	N 22° W.
Hitotsubashi	III	142	0.38	E	29	N 18° W.
Hongo	IV	154	7.2	S 48° E.	29	S 15° E.
Hitotsubashi	V	19	1.7	S 70° W	125	N 77° E.
,,	,,	23	0.64	SE	160	N 78° E.
,,	,,	42	0.38	E—W	90	S 62° E.
Hongo	,,	13	15.0	N 84° E	125	S 85° E.
,,	,,	23	0.6	S	160	N 78° E.
,,	,,	43	2.0	W 20° N	107	N 65° E.
,,	,,	122	0.6	S	150	N 61° E.

From the above table it seems that in the majority of cases, in which the 2a is large, the direction of motion points more or less approximately towards, or from, the origin of disturbance.

13. On the Amplitude of Vibration and the Duration of Earthquake Motion.

AMPLITUDE.

To find the relation, if any, respecting the maximum range of motion in the different earthquakes observed at a given station, let us assume the equation,

$$2a=j\times\frac{r}{d}, \qquad (1)$$

in which j is a constant, r the mean radius (in km) of the area of disturbance, d the distance (in km) between the earthquake origin and a given observing station, and $2a$ the maximum range of motion (in mm) at the latter. This equation may be deduced as follows: Let $2a_0$ be the *mean* range of motion at the boundary of the area of disturbance. If now the earth's crust be supposed to be a homogeneous medium, the amplitude varies inversely with the distance from the earthquake origin; we have therefore

$$\frac{2a}{2a_0}=\frac{r}{d}$$

$$\text{or} \quad 2a=2a_0\times\frac{r}{d}, \qquad (1')$$

Thus j in equation (1) corresponds to $2a_0$ in equation (1'), that is to say, j denotes the motion at a given station which is just large enough to be felt by people without instrumental aid.

DURATION

With respect to the duration of an earthquake at a given station, I assume, as already done in the case of the Miyako earthquake observations,* the relation

$$D=k\times\frac{r^2}{d}, \qquad (2)$$

in which k is a constant, r and d have the same signification as in equation (1), and D is the duration (in sec.) of an earthquake at a given station. This equation is based on the supposition that D is proportional to the magnitude of an earthquake, or the area of disturbance, and inversely proportional to the distance between the origin and the station.

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* Omori and Hirata: *Earthquake Measurement at Miyako*, Jorn. Sc Coll., Imp. Univ., Tokyo, Vol. XI.

Tables XVIII to XX give the values of r and d, as well as the elements of motion for the earthquakes of Groups II to VII observed at Hitotsubashi, Hongo and the Central Meteorological Observatory, of which the duration (D) and the range of motion (2a) were accurately measured. Similarly Table XXI, which is given for the sake of comparison, indicates the values of $2a$, D, d and r for the 45 earthquakes observed by the late Professor Sekiya between Sept. 1885 and Aug. 1887 at Hitotsubashi.*

Observing station.	r (km)	d (km)	D (sec.)	$2a$ (mm)	$j=\frac{2a\ d}{r}$	$k=\frac{d\ D}{r_2}$
Hitotsubashi, (Table XVIII)	61	41	66	0.38	0.26	0.73
	86	57	130	0.99	0.66	1.00
	110	71	105	0.70	0.45	0.62
	181	139	128	0.85	0.65	0.54
	348	384	95	0.52	0.52	0.25
	Mean				**0.51** ...	**0.63**
Hitotsubashi, (Table XXI)	62	23	78	0.43	0.16	0.47
	100	56	97	0.78	0.44	0.54
	124	108	105	0.62	0.54	0.74
	228	212	154	0.95	0.88	0.63
	Mean				**0.51** ...	**0.60**
	General Mean				**0.51** ...	**0.62**
Hongo. (Table XIX)	119	31	115	1.25	0.33	0.25
	99	67	64	0.46	0.31	0.44
	194	129	86	0.59	0.39	0.29
	250	169	142	0.54	0.37	0.38
	312	307	133	0.41	0.40	0.42
	Mean				**0.36** ...	**0.36**
Cent. Met. Observatory, (Table XX)	87	32	67	0.40	0.15	0.28
	87	63	90	0.64	0.46	0.75
	208	138	110	0.52	0.34	0.35
	341	319	123	0.47	0.44	0.34
	Mean				**0.35** ...	**0.43**

* The data in Table XXI are taken from Professor Sekiya's paper before referred to; the earthquakes chosen being those for which d and r are definitely known.

To determine the values of the constants j and k, which are to be regarded as *seismic coefficients* for a given locality with regard to the amplitude and the duration, I have divided the earthquakes contained in each of Tables XVIII to XXI arbitrarily to a convenient number of groups and calculated in each case the mean values of the different quantities. These latter and the corresponding values of j and k for Hitotsubashi, Hongo and the Central Meteorological Observatory are given in the above table.

Considering the nature of the question, the agreement of the values of each of the constants for the different places of observation must be regarded as being tolerably satisfactory. In these calculations I have not taken the focal depth into consideration. The result is in general slightly improved if we correct for this latter factor.

From the above it will be seen that the corresponding seismic coefficients for Hongo and the Central Meteorological Observatory are nearly identical to one another while the values for Hitotsubashi are larger than those for the two other places ; the mean values of the constants being as follows.

Hitotsubashi : $j=0.51$, $k=0.62$.
Hongo : $j=0.36$, $k=0.36$.
Cent. Met. Observatory : $j=0.35$, $k=0.43$.

TABLE XVIII.—EARTHQUAKES OBSERVED AT HITOTSUBASHI. (Groups II—VII.)

Group.	No.	r (km)	d (km)	D (s)	$2a$(mm)	T_0 (s)	V $\left(\frac{mm}{s}\right)$	A $\left(\frac{mm}{s^2}\right)$	T (s)
IV	21	92	22	180	—	—	—	—	0.63
III	115	25	23	—	0.1	—	—	—	—
,,	142	82	29	70	0.38	0.87	1.4	9.9	0.83
,,	49	34	32	25	0.25	0.6	1.3	13.0	0.74
IV	161	38	35	25	0.13	0.51	0.8	9.9	0.62
,,	126	44	38	60	0.25	0.82	1.0	7.1	0.77
III	155	87	40	100	0.3	0.65	1.4	14.0	0.74
IV	137	32	41	120	0.63	0.79	2.5	20.0	0.77
II	76	59	44	60	0.35	0.75	1.6	14.0	0.76
IV	10	63	49	50	0.21	0.54	1.2	14.2	0.54
,,	92	53	51	30	0.25	0.57	1.4	16.0	—
,,	86	90	52	120	1.0	0.70	4.5	41.0	0.76
Mean		**61**	**41**	**66**	**0.38**				
II	59	65	53	100	0.4	0.7	1.8	16.0	0.71
,,	29	60	55	—	0.3	—	—	—	—
,,	78	65	56	240	2.2	0.97	7.1	46.1	0.83
IV	84	87	56	100	0.3	0.88	1.1	8.1	0.78
II	83	128	58	180	1.8	0.94	6.0	40.0	0.84
,,	50	84	60	30	0.25	0.62	1.3	12.9	0.70
,,	28	155	60	—	2.8	—	—	—	—
Mean		**86**	**57**	**130**	**0.99**				
II	123	105	62	160	1.2	0.77	4.9	40.0	0.71
IV	82	58	63	60	0.25	0.71	1.1	10.0	0.74
,,	62	115	63	100	0.4	0.74	1.7	15.0	0.85
II	65	240	69	150	2.0	0.77	8.2	67.0	0.76
,,	38	76	80	100	0.35	0.9	1.2	8.5	0.85
,,	61	93	89	—	0.32	0.86	1.2	9.0	—
V	42	57	90	60	0.38	0.91	1.3	9.1	0.89
Mean		**110**	**71**	**105**	**0.7**				
V	43	255	107	—	5.0	—	—	—	—
,,	19	185	125	180	1.7	0.84	6.3	47.6	0.77
,,	71	100	140	110	0.35	0.91	1.2	8.0	0.88
,,	97	—	144	50	0.43	0.73	1.9	16.0	0.71
,,	39	—	150	120	0.6	0.79	2.4	19.0	0.83
,,	122	185	150	120	0.7	0.66	3.3	31.0	0.78
,,	23	235	160	100	0.64	0.96	2.1	13.7	0.83
Mean		**181**	**139**	**128**	**0.85**				
VI	103	—	270	180	1.1	0.81	4.3	34.0	0.78
VII	94	164	280	60	0.45	0.83	1.7	13.0	0.85
VI	138	270	380	80	0.17	0.68	0.79	7.3	0.75
,,	56	390	390	120	0.45	0.78	1.8	14.0	0.67
,,	48	680	680	120	1.0	0.57	5.5	60.0	0.45
Mean		**384**	**384**	**95**	**0.52**				

TABLE XIX.—EARTHQUAKES OBSERVED AT HONGO.

Groups II—VII.

Group.	No.	r (km)	d (km)	D (s)	2a(mm)	T_0 (s)	V $\left(\frac{mm}{s}\right)$	A $\left(\frac{mm}{s^2}\right)$	T (s)
IV	171	160	0	80	0.7	0.25	9.0	221.0	1.2 0.75
,,	177	120	23	80	0.3	0.26	3.6	87.6	1.6 0.79
III	124	24	26	20	0.14	0.34	1.3	2.4	—
IV	154	360	29	480	7.2	1.3	17.4	84.1	1.07
,,	220	47	36	15	0.1	0.25	1.3	31.5	0.44
,,	10	63	49	—	0.2	0.45	1.4	19.5	0.44
II	60	62	51	16	0.1	0.23	1.4	37.3	0.23
Mean		**119**	**31**	**115**	**1.25**				
IV	86	90	52	70	0.2	0.6	0.52	2.7	2.1 1.3
II	29	60	55	40	0.2	0.7	0.9	8.1	—
,,	78	65	56	140	0.74	0.78	3.0	25.0	0.70
IV	84	87	56	60	0.16	0.22	2.3	66.0	2.0
II	179	90	58	25	0.26	0.49	1.7	21.4	2.6
,,	194	70	60	120	0.4	—	—	—	1.2
,,	50	84	60	35	0.15	0.5	0.94	12.0	—
,,	28	155	60	100	2.4	0.8	9.4	74.0	0.53
,,	219	79	60	30	0.1	0.20	1.6	49.3	—
,,	123	105	62	40	0.54	—	—	—	—
IV	62	115	63	70	—	—	—	—	—
II	65	240	69	110	1.4	0.71	6.2	55.0	0.68
,,	216	73	73	30	0.24	—	—	—	0.43
VII	184	120	74	60	0.1	—	—	—	0.58
III	17	89	80	65	0.05	0.6	0.3	2.7	1.4 0.5
II	20	96	85	70	0.16	0.6	0.8	8.8	—
,,	61	93	89	30	0.32	0.3	3.4	72.0	0.37 0.19
,,	208	70	100	50	—	—	—	—	—
Mean		**99**	**67**	**64**	**0.46**				

TABLE XIX.—(*Continued*).

Group.	No.	r (km)	d (km)	D (s)	2a(mm)	T_0 (s)	V $\left(\frac{mm}{s}\right)$	A $\left(\frac{mm}{s^2}\right)$	T (s)
V	212	—	107	30	0.14	0.84	0.5	3.9	0.88
,,	43	255	107	130	2.0	1.3	4.8	23.0	0.67
,,	172	225	115	100	0.8	0.69	—	—	0.88
,,	13	380	125	270	15.0	—	—	—	1.3 0.57
,,	19	185	125	116	0.5	0.5	3.1	39.5	0.48 0.93
,,	46	225	130	115	0.5	0.57	2.8	31.0	0.65
,,	192	150	137	60	0.2	0.67	0.9	8.8	—
,,	44	135	140	—	0.2	—	—	—	—
,,	39	—	150	65	0.32	0.48	2.1	28.0	0.60
,,	122	185	150	70	0.6	—	—	—	0.52
Mean.		**194**	**129**	**86**	**0.59**				
V	23	235	160	90	0.6	1.3	1.4	7.0	0.69
,,	174	300	160	200	1.2	1.13	3.3	18.5	1.18
VII	215	190	160	90	0.2	1.14	0.6	3.0	1.32
V	214	200	170	90	0.1	0.56	0.6	8.8	0.55
,,	176	315	195	240	0.6	1.43	1.3	5.8	1.2 2.3
Mean.		**250**	**169**	**142**	**0.54**				
VII	197	234	260	120	0.5	1.16	1.4	7.3	1.19
VI	103	—	270	180	0.5	—	—	—	—
,,	56	390	390	100	0.24	0.79	0.95	7.5	0.74
Mean.		**312**	**307**	**133**	**0.41**				

TABLE XX.—EARTHQUAKES OBSERVED AT THE CENTRAL METEOROLOGICAL OBSERVATORY.

Groups II–VII.

Group.	No.	r (km).	d (km).	D (s).	2a (mm).	T_0 (s).
IV	171	160	0	90	4.1	0.6
,,	114	23	21	25	0.4	0.4
,,	89	24	21	20	0.2	0.8
III	156	80	21	120	Small.	—
IV	21	92	22	45	0.2	0.5
,,	177	120	23	90	1.5	0.7
III	115	25	23	30	Small.	—
,,	124	24	26	90	0.3	0.5
IV	154	360	29	372	—	—
III	70	305	29	—	Small.	—
,,	142	82	29	12	0.5	0.3
,,	49	34	32	10	Small.	—
II	152	45	34	10	,,	—
IV	161	38	35	15	,,	—
,,	220	47	36	10	,,	—
,,	18	40	37	180	0.2	0.3
III	195	60	37	30	Small.	—
,,	155	87	40	120	0.2	—
II	143	200	38	120	1.1	1.0
IV	137	32	41	120	0.2	1.8
,,	163	41	41	30	Small.	—
II	53	52	44	30	,,	—
,,	76	59	44	10	0.2	0.5
III	158	80	44	30	Small.	—
IV	10	63	49	10	0.4	0.7
Mean.		**87**	**32**	**67**	**0.4**	

TABLE XX.—(*Continued.*)

Group.	No.	r (km).	d (km).	D (s).	2a (mm).	T_0 (s).
II	60	62	51	30	Small.	—
IV	86	90	52	100	0.3	0.8
II	69	60	52	480	5.6	0.8
,,	59	65	53	88	Small.	—
III	125	92	53	270	1.9	0.4
II	188	48	55	50	0.2	0.6
,,	29	60	55	10	Small	—
,,	78	65	56	270	—	—
IV	84	87	56	20	0.4	1.2
,,	79	55	57	60	Small.	—
II	179	90	58	50	0.3	0.5
,,	83	128	58	180	1.5	1.3
,,	194	70	60	60	0.4	0.5
,,	50	84	60	12	Small.	—
,,	28	155	60	120	2.5	1.5
,,	219	79	60	35	Small.	—
,,	123	105	62	60	0.3	0.8
III	118	54	68	30	Small.	—
II	65	240	69	120	1.2	0.7
,,	216	73	73	40	0.3	0.5
VII	184	120	74	—	0.3	0.9
III	17	89	80	12	0.2	1.2
II	20	96	85	120	—	—
,,	61	93	89	25	0.4	0.2
V	42	57	90	10	Small.	—
,,	54	62	95	50	,,	—
II	208	70	100	25	0.2	0.5
Mean.		**87**	**63**	**90**	**0.64**	
V	212	—	107	50	Small.	—
,,	43	255	107	228	—	—

TABLE XX.—(*Continued.*)

Group.	No.	*r* (km).	*d* (km).	D (s).	2a (mm).	T_0 (s).
V	172	225	115	75	0.5	0.5
IV	182	160	120	—	0.8	1.0
V	13	380	125	360	—	—
,,	19	185	125	120	1.0	1.8
,,	144	—	126	120	0.8	1.5
,,	104	200	130	70	0.2	1.0
,,	46	225	130	45	—	—
,,	55	—	130	15	Small.	—
,,	192	150	137	30	,,	—
,,	71	100	140	120	0.2	1.5
,,	44	135	140	109	0.7	1.4
,,	97	—	144	180	—	—
,,	39	—	150	60	0.4	1.8
,,	122	185	150	120	1.2	0.5
,,	23	235	160	90	1.3	1.2
,,	174	300	160	240	—	—
VII	215	190	160	60	—	—
V	173	—	162	20	0.2	0.2
,,	214	200	170	90	0.5	0.6
Mean.		**208**	**138**	**110**	**0.52**	
V	131	—	190	150	0.2	0.9
,,	176	315	195	120	1.2	0.7
VII	197	234	260	120	—	—
V	189	—	260	90	0.2	0.6
VI	103	—	270	180	0.4	1.2
VII	94	164	280	60	Small.	—
VI	56	390	390	90	—	—
,,	134	—	430	240	0.4	1.4
,,	48	600	600	60	—	—
Mean.		**341**	**319**	**123**	**0.47**	

TABLE XXI.—EARTHQUAKES OBSERVED AT HITOTSUBASHI.*

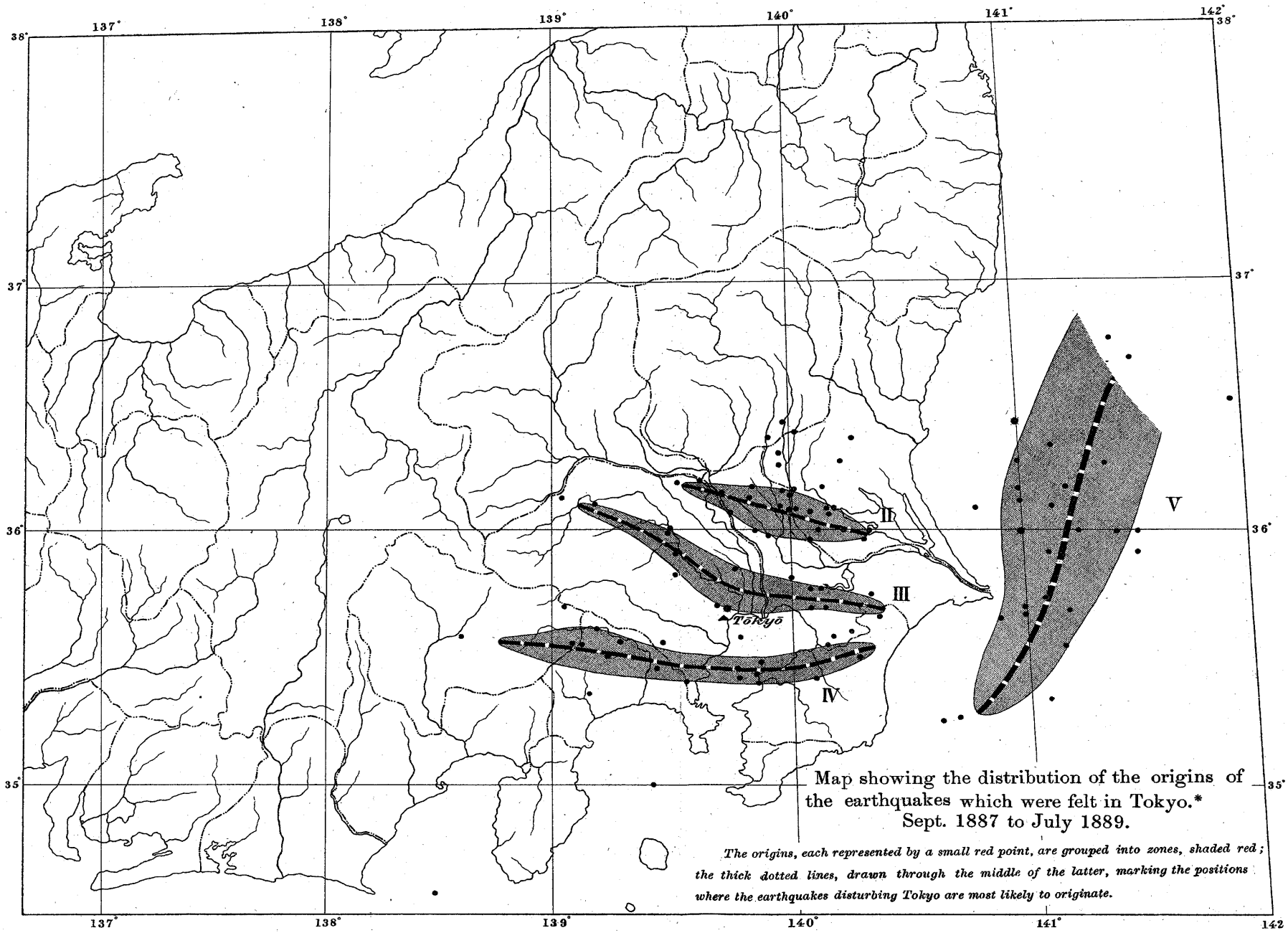
Sept. 1885–Aug. 1887.

Date.	Time of occurrence.	Max. hor. 2a (mm).	D (s).	d (km).	γ (km).
1886. VI. 14	6. 25. 19 p.m.	0.6	70	0	56
„ IX. 12	8. 43. 22 p.m.	0.8	50	0	105
„ XII 26	5. 48. 5 p.m.	0.8	51	0	105
1885. X 15	8. 18. 43 p.m.	1.0	148	24	53
„ XI. 16	1. 53. 36 p.m.	Small.	30	24	35
1886. VI. 11	1. 45. 44 p.m.	0.4	75	24	56
„ III 26	6. 6. 0 p.m.	0.1	65	27	39
1887. IV. 27	9. 30. 38 p.m.	—	140	27	53
1885. XII. 3	6. 1. 42 a.m.	0.2	60	32	47
1886. „ 29	11. 5. 43 a.m.	0.5	60	35	69
„ X. 4	2. 35. 25 p.m.	0.3	85	40	64
„ „ 25	10. 11. 18 p.m.	0.4	100	40	64
Mean.		**0.43**	**78**	**23**	**62**
1885. XII. 28	10. 6. 30 p.m.	3.5	210	47	158
1886. II 24	7. 34. 0 a.m.	0.5	105	47	118
„ V 5	——	0.2	54	47	52
„ „ 18	8. 12. 51 p.m.	0.5	135	47	137
„ VIII. 3	2. 11. 40 a.m.	Small.	20	48	48
„ XI. 2	8. 21. 46 p.m.	0.2	100	48	56
„ XII. 8	11. 58. 16 a.m.	0.3	122	48	56
1887. V. 17	4. 19. 44 p.m.	0.2	20	48	64
1886. „ 8	10. 14. 0 p.m.	2.1	144	52	137
„ X. 22	3. 49. 14 a.m.	0.5	65	55	113
1887. IV. 16	3. 35. 0 a.m.	0.4	112	56	60
1885. XII. 19	6. 28. 0 p.m.	2.8	106	60	258
1886. IX. 16	1. 2. 57 p.m.	0.1	50	64	80

* Compiled from the late Prof. S. Sekiya's paper : *Earthquake Measurement, etc.*, Jour. Sc. Coll. Imp. Univ. Tokio, II.

TABLE XXI.—(*Continued*).

Date.	Time of occurrence.	Max. hor. 2a (mm).	D (s).	d (km).	γ (km).
1887. VII. 2	3. 16. 24 p.m.	0.6	61	73	89
1885. IX. 2	8. 36. 0 p.m.	0.3	150	74	87
1887. VI. 22	7. 42. 39 a.m.	0.3	98	77	85
Mean.		**0.78**	**97**	**56**	**100**
1886. V. 30	8. 38. 18 p.m.	0.4	90	92	92
1885. X. 1	1. 9. 0 p.m.	1.0	120	95	145
„ „ 18	0. 15. 0 p.m.	0.3	60	95	98
1886. I. 4	8. 31. 30 p.m.	0.4	54	95	98
„ „ 5	4. 26. 42 p.m.	0.8	75	106	118
„ III. 13	6. 25. 0 p.m.	0.7	120	110	118
1887. VI. 20	8. 38. 30 a.m.	0.4	95	113	161
1885. X. 11	5. 28. 18 a.m.	1.1	243	114	134
1886. III. 2	5. 3. 49 a.m.	0.6	130	118	126
„ VI. 3	3. 6. 37 p.m.	0.4	91	122	122
1885. X. 24	5. 12. 18 p.m.	0.7	75	130	150
Mean.		**0.62**	**105**	**108**	**124**
1887. VIII. 15	0. 59. 15 a.m.	—	185	169	193
1885. IX. 26	0. 30. 0 p.m.	—	215	177	235
„ X. 26	10. 41. 11 p.m.	2.2	200	180	224
1886. IV. 4	1. 0. 0 a.m.	0.4	130	216	235
„ XII. 11	10. 16. 25 p.m.	0.4	76	242	193
1887. II. 2	2. 8. 14 p.m.	0.8	118	287	290
Mean.		**0.95**	**154**	**212**	**228**

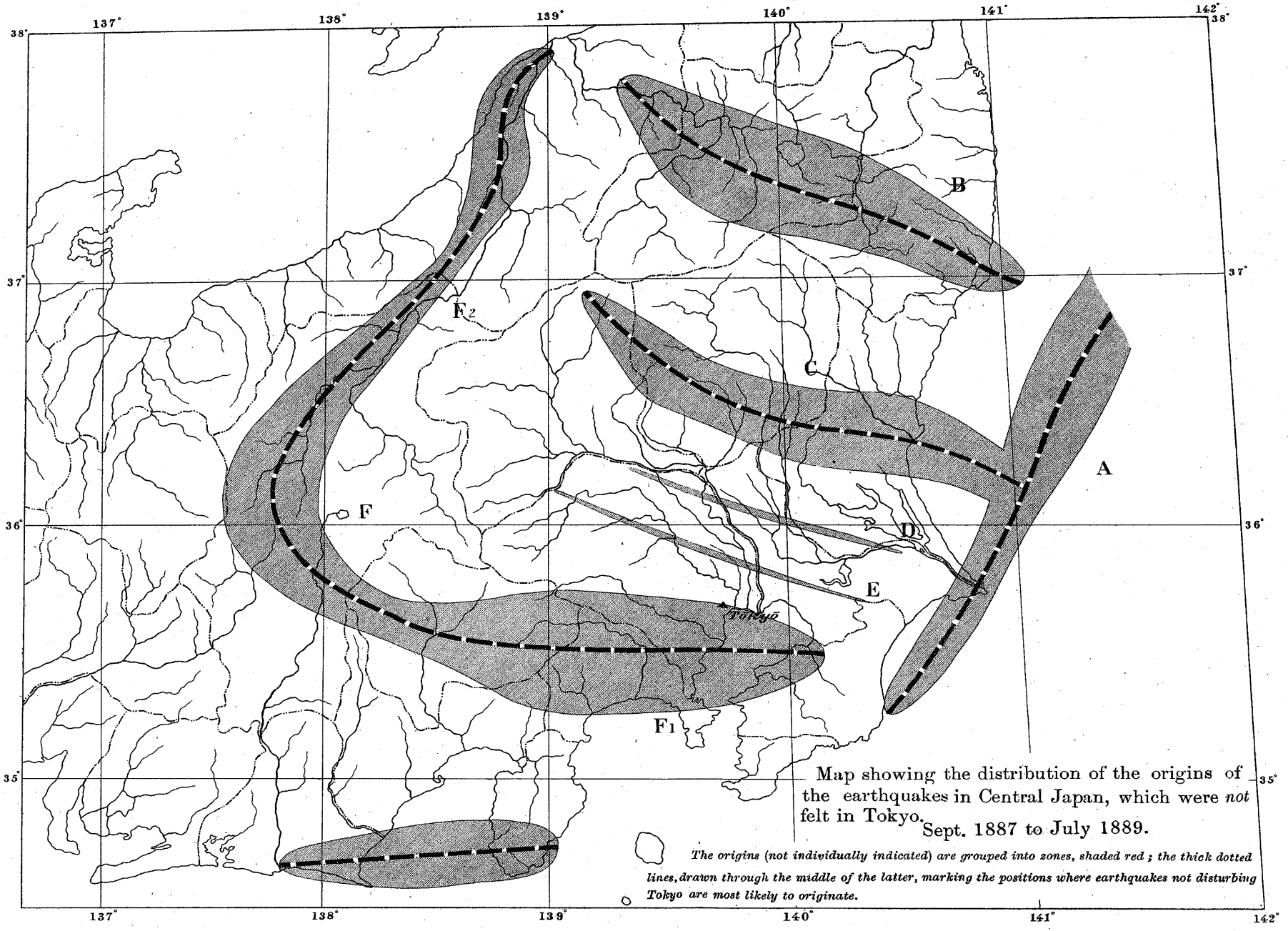


Map showing the distribution of the origins of the earthquakes which were felt in Tokyo.*
Sept. 1887 to July 1889.

The origins, each represented by a small red point, are grouped into zones, shaded red; the thick dotted lines, drawn through the middle of the latter, marking the positions where the earthquakes disturbing Tokyo are most likely to originate.

*Excepting the earthquakes of Groups VI and VII. The earthquakes of Group I are those observed only in Tokyo.

Boundary of Provinces.



Map showing the distribution of the origins of the earthquakes in Central Japan, which were *not* felt in Tokyo.
Sept. 1887 to July 1889.

The origins (not individually indicated) are grouped into zones, shaded red; the thick dotted lines, drawn through the middle of the latter, marking the positions where earthquakes not disturbing Tokyo are most likely to originate.

Boundary of Provinces.