

mean value of the intervals between the successive maximum displacements was about 1m 12 s. The motion may be regarded as the resultant of two series of simple harmonic movements of nearly equal amplitudes, whose period were 8 and 9 seconds respectively.

XII. The Preliminary Tremors of the Earthquake Motion.

(A) DISTANT EARTHQUAKES.

§ 20. In the *Publications*, No. 5, p.p. 61-66, I have discussed the relation between the durations of the preliminary tremors at a given station and the distance of the latter from the origin of disturbance. I am here going to consider again the same problem, with additional material recently obtained.

The following table contains the list of the observations of 15 large earthquakes of known origin, whose *spherical* distance (x) from Tokyō varied between 2200 km and 14200 km. Of these earthquakes, which are arranged in order of the duration (y) of the *total* preliminary tremor, ten occurred in 1900-1902, while the other five took place in 1899 and have already been discussed in the *Publications*, No. 5. The relation between x and y is graphically illustrated in Fig. 4.

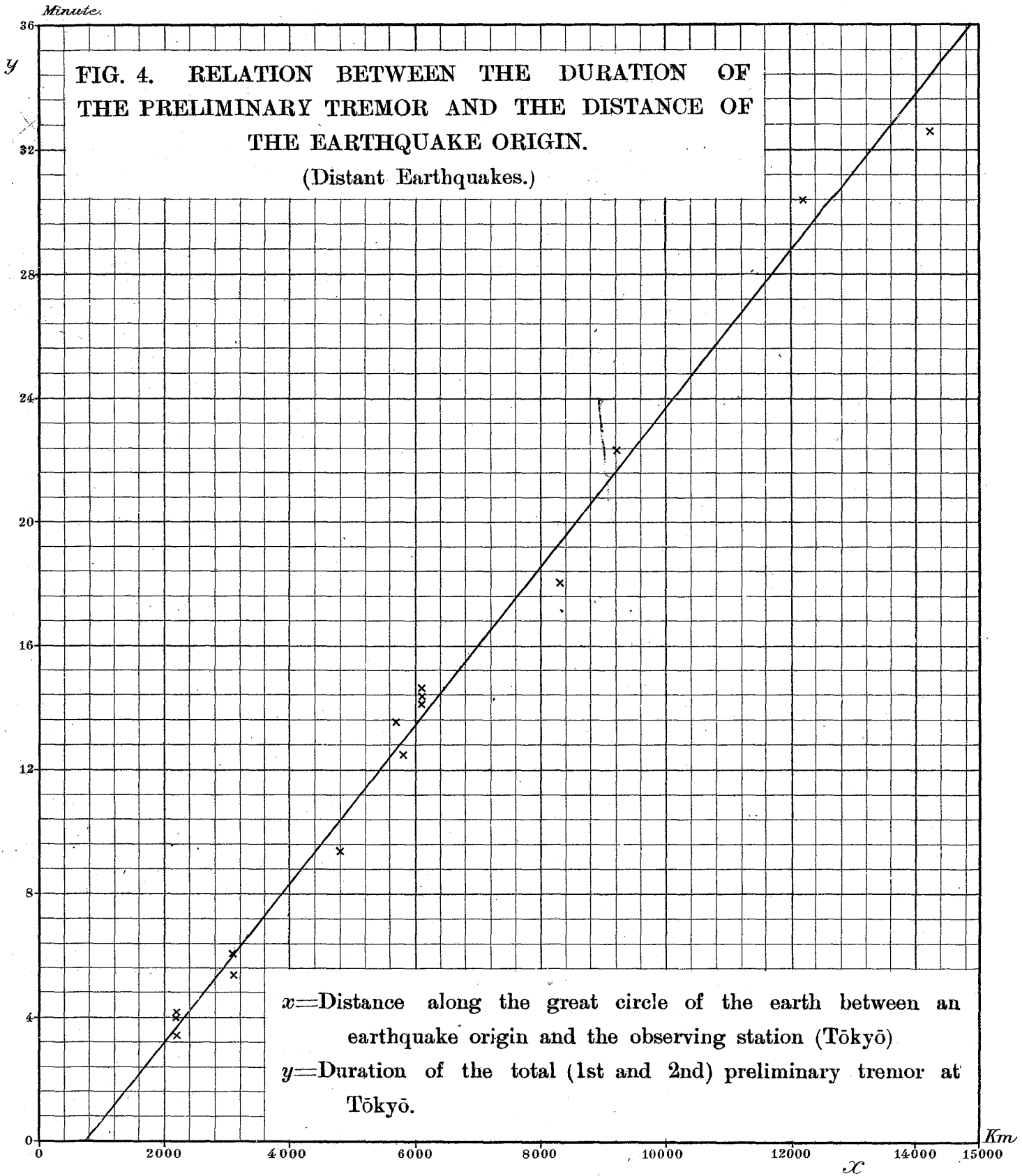


TABLE XXVIII.

THE DURATION OF THE TOTAL PRELIMINARY TREMOR
OF DISTANT EARTHQUAKES, OBSERVED IN
TOKYO. [$x > 2000$ km.]

No.	Date.	Time of occurrence. (1st. N. J. T.)	y = Total Duration of 1st and 2nd Prel. Tremors.	x = Spherical Distance between earthquake origin and Tokyo.	Origin.
		h m s	m s	km	
1	Nov. 21, 1902	4. 7. 46 p.m.	4. 00	2200	Formosa.
2	June 7, 1901	9. 14. 13 a.m.	3. 29	2200	"
3	Sept. 22, 1902	10. 52. 16 a.m.	4. 4	2200	Guam Island.
4	Dec. 15, 1901	8. 3. 16 a.m.	5. 20	3050	Manila (Mindanao).
5	Aug. 21, 1902	8. 21. 53 a.m.	6. 6	3050	"
6	Sept. 30, 1899	2. 11. 00 a.m.	9. 25	4800	Ceram.
7	Aug. 22, 1902	0. 9. 33 p.m.	13. 30	5700	Kashgar (Turkestan).
8	Jan. 6, 1900	4. 6. 24 a.m.	12. 30	5800	Sumatra.
9	Sept. 4, 1899	9. 31. 59 a.m.	14. 23	6100	Alasca.
10	" 11, "	3. 14. 16 a.m.	14. 31	6100	"
11	" " "	6. 50. 58 a.m.	14. 13	6100	"
12	Feb. 13, 1902	6. 59. 17 p.m.	18. 00	8330	Schemacha.
13	Sept. 20, 1899	11. 24. 27 a.m.	22. 19	9200	Aidin (Smyrna).
14	April 19, 1902	11. 38. 47 a.m.	30. 20	12200	Guatemala.
15	Oct. 29, 1900	6. 31. 52 p.m.	32. 31	14200	Caracas.

Assuming the linear relation $ay + b + x = 0$, and determining the values of the constants a and b by the Method of Least Squares from the observations contained in the above table, we obtain the following equation:—

$$x_{\text{km}} = 6,54y_{\text{sec.}} + 720_{\text{km}}, \quad (1)$$

where $2000_{\text{km}} < x < 14000_{\text{km}}$

This equation, which slightly differs from those formerly obtained, gives fairly satisfactory results, as will be seen from the following table; the actual and the calculated values of x being on the whole practically identical.

TABLE XXIX.

RELATION BETWEEN THE DURATION OF THE *TOTAL*
PRELIMINARY TREMOR AND THE DISTANCE
OF THE ORIGIN.
[DISTANT EARTHQUAKES.]

Eqke No.	Total Duration of the 1st and 2nd preliminary tremors.	Actual x.	Calculated x.
	sec.	km.	km.
1	209	2200	2090
2	240	2200	2290
3	244	2200	2320
4	320	3100	2820
5	366	3100	3120
6	565	4800	4420
7	810	5700	6020
8	750	5800	5630
9	863	6100	6370
10	871	6100	6420
11	853	6100	6310
12	1080	8300	7790
13	1339	9200	9480
14	1838	12200	12640
15	1951	14200	13500
<i>Mean</i>	sec. 820	km. 6090	km. 6080

(B) EARTHQUAKES OF NEAR ORIGIN.

§ 21. Let us next confine our attention to earthquakes of comparatively near origin. The following table contains a list of the 14 earthquakes,* the distances of whose origins from Tōkyō varied

* Of these, five earthquakes took place between Dec. 1898 and 1900, while the remaining nine occurred previous to Aug. 1898 and have already been discussed in the Jour. Sci. Coll., Tōkyō Imp. Univ., Vol. XI.

sec.

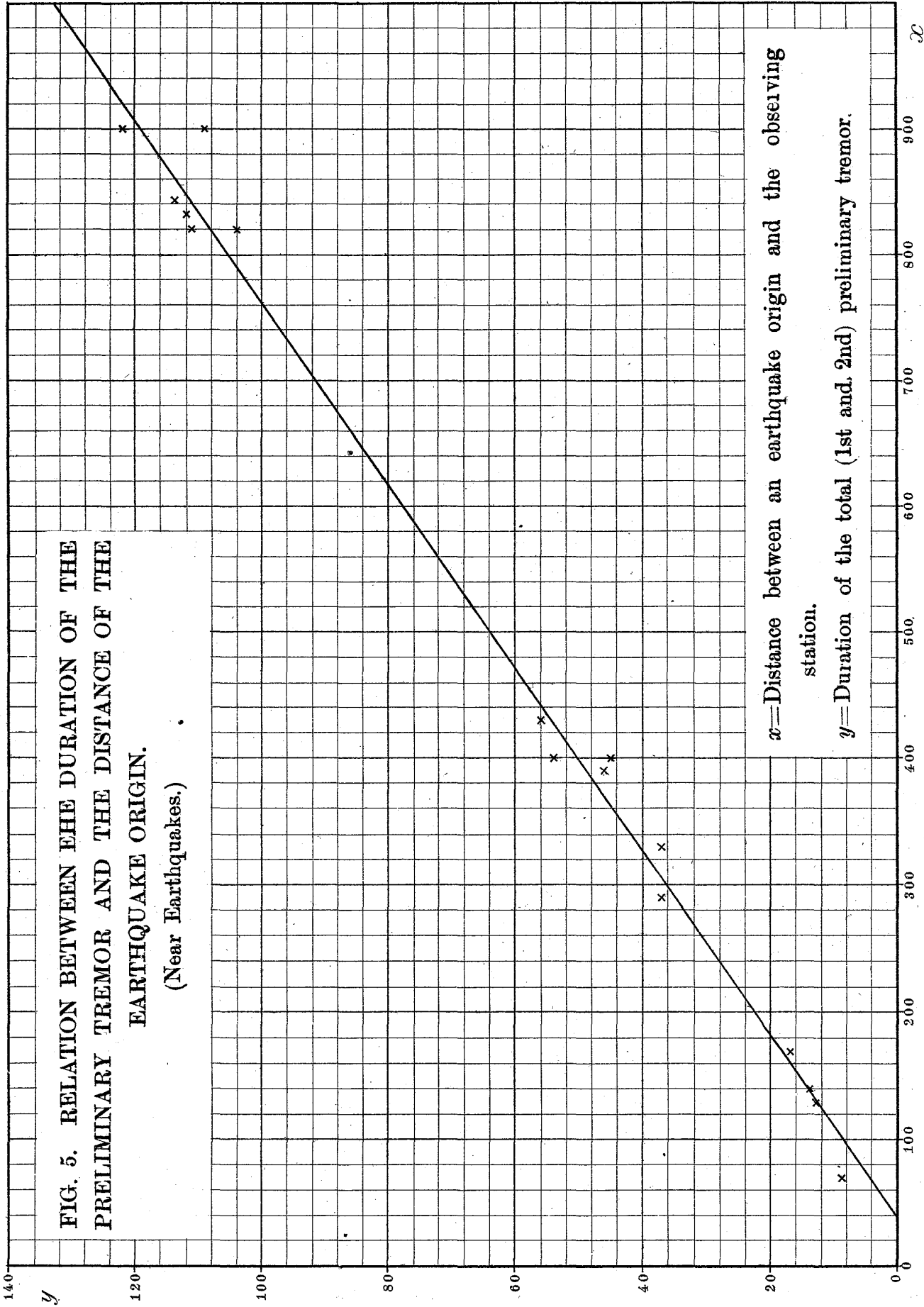


FIG. 5. RELATION BETWEEN THE DURATION OF THE PRELIMINARY TREMOR AND THE DISTANCE OF THE EARTHQUAKE ORIGIN.
(Near Earthquakes.)

(Near Earthquakes.)

x = Distance between an earthquake origin and the observing station.

y = Duration of the total (1st and 2nd) preliminary tremor.

Km

x

between 70 km and 900 km. Of the 17 observations on these earthquakes, nine were made by means of Ewing's or Gray-Milne's seismographs, while the rest were made by means of the continuous registering mechanical horizontal pendulum apparatus. The relation between the duration and the distance is illustrated in Fig. 5.

TABLE XXX.

THE DURATION OF THE TOTAL PRELIMINARY
TREMOR OF THE EARTHQUAKES. [$x < 1000$ km.]

No.	Date.	Time of occurrence in Tokyo (1st N. J. T.)	Duration of preliminary tremor.	Distance between earthquake origin and place of observation.	Place of observation.	Crigin.
		h m s	sec.	km.		
1*	Oct. 23, 1891	6. 39. 11 a.m.	37	288	Tōkyō.	{ Mino, Owari, Echizen.
2*	(Same eqke)	"	14	140	Osaka.	Do.
3*	March 23, 1894	7. 27. 49 p.m.	109	900	Tōkyō.	{ Off SE coast of Hokkaido.
4*	Nov. 30, 1894	8. 30. 57 p.m.	9	70	"	In Tokyo Bay.
5*	Aug. 31, 1896	5. 9. 33 p.m.	56	430	"	{ Rikuchu and Ugo.
6*	Jan. 17, 1897	0. 49. 28 a.m.	17	170	"	Nagano.
7*	Aug. 5, 1897	9. 12. 23 a.m.	45	400	"	{ Off the NE coast of Main Island.
8	April 23, 1898	8. 37. 00 a.m.	54	400	"	Do.
9	May. 26, 1898	2. 57. 57 a.m.	17	170	"	Echigo.
10	Aug. 12, 1898	9. 35. 34 a.m.	122	900	"	Fukuoka.
11	Dec. 4, 1898	1. 45. 32 a.m.	112	833	"	Kyushu.
12	March 7, 1899	9. 55. 29 a.m.	43	390	"	{ Off E coase of Kii.
13*	(Same eqke)	"	13	130	Wakayama.	Do.
14*	(")	"	104	820	Miyako.	Do.
15	March 24, 1899	1. 2. 35 p.m.	111	821	Tōkyō.	Kyushu.
16	Nov. 24, 1899	3. 45. 24 a.m.	114	844	"	Kyushu.
17	March 22, 1900	0. 56. 7 a.m.	37	330	"	Echizen.

* Those marked with *asterisks* have been observed in Tōkyō by means of Ewing's or Gray-Milne's seismographs.

Assuming again the linear relation $ay + b + x = 0$, and determining the values of the constants a and b by the Method of Least Squares from the observations contained in the above table, we obtain the following equation :—

$$x^{\text{km}} = 7,27y^{\text{sec.}} + 38\text{km.} \quad (2)$$

This equation, which is nearly identical with that formerly obtained, gives fairly satisfactory results, except for a case of $x < 100$ km, as will be seen from the following table.

TABLE XXXI.

RELATION BETWEEN THE DURATION OF THE
PRELIMINARY TREMORS AND THE
DISTANCE OF THE ORIGIN.
[Near Earthquakes.]

No.	Duration of the total preliminary tremor.	Actual x .	Calculated x .
4	9 ^{sec.}	70 ^{km} ‡	102 ^{km} ‡
2	14	140	140
6	17	170	162
9	17	170	162
1	37	288	307
17	37	330	307
7	45	400	365
8	54	400	431
5	56	430	445
15	111	821	846
14	104	820	793
11	112	833	852
16	114	844	867
12	46	390	373
13	13	130	133
3	109	900	830
10	122	900	926
<i>Mean.</i>	63 ^{sec.}	498 ^{km}	496 ^{km}

(‡ Excepted in the deduction of the mean values.)

In the above table, the *actual x* is, except in earthquake observation No. 4, the distance between the epicentrum and an

observing station, the focal depth being supposed not to be very great. This would produce no considerable error for x greater than 100 or 150 km. Thus, to take, as an example, earthquake observation No. 2, the distance (x) between the observing station and the origin of disturbance would be 149 km, instead of the value of the surface distance of 140 km, if we assume the focal depth to be 50 km. In the case of earthquake observation No. 4, x denotes the radial distance between the seismic origin and the place of observation. Equation (2) is to be understood as being valid for the values of x between about 100 km and 900 km, or for the values of y between some 10 sec. and 2 minutes.

The two equations (1) and (2) give practically identical result for large values of x and y . Thus, for $y=1000$ sec.=16m 40s, we obtain:—

from equation (1),..... $x=7300$ km,

„ „ (2),..... $x=7300$ „ .

Again, for $y=2000$ sec.=33m 20s, we find:—

from equation (1),..... $x=13800$ km,

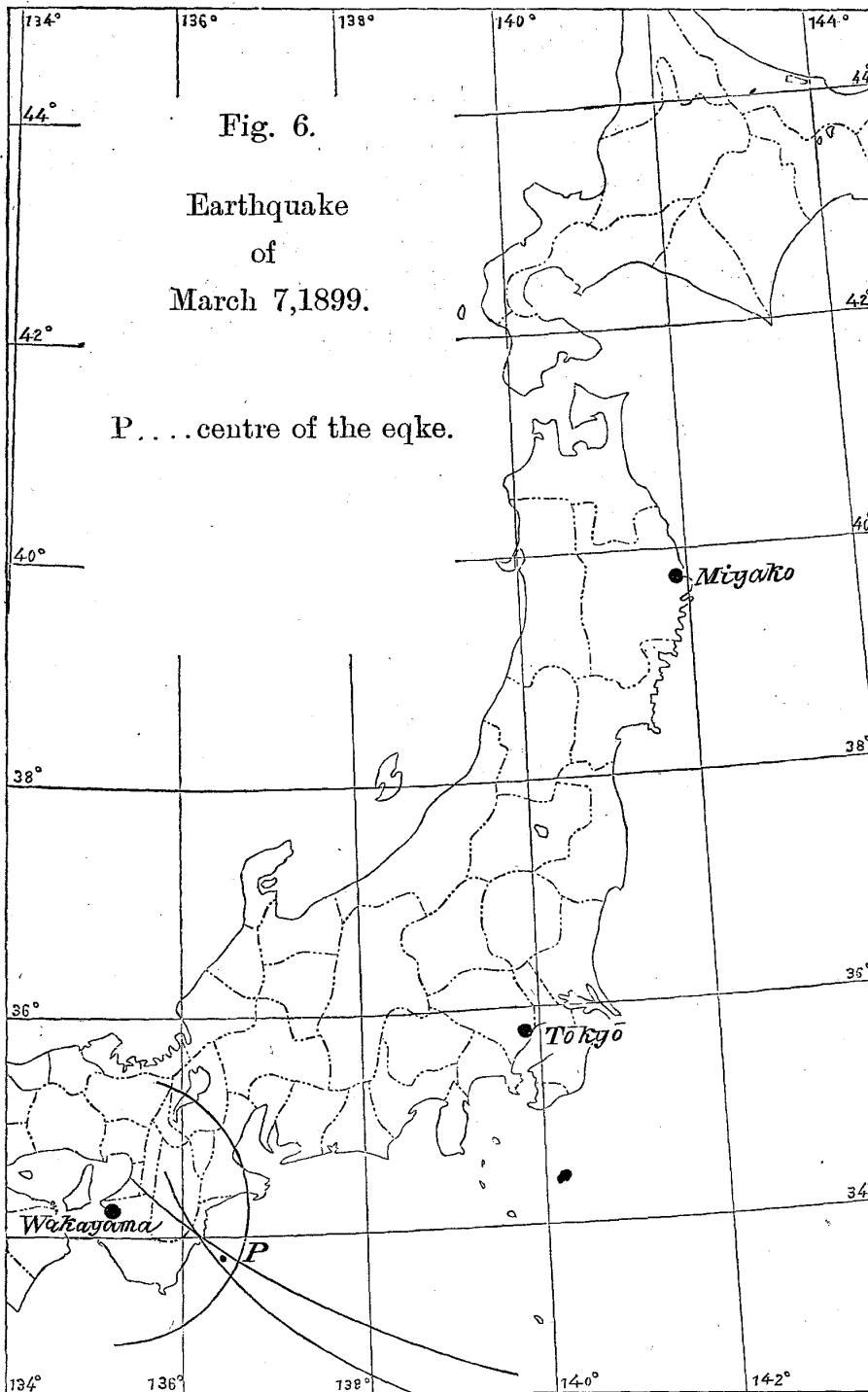
„ „ (2),..... $x=14600$ „ .

§ 22. Equation (2) is very useful in determining the position of the epicentrum of a submarine earthquake.* As an example, let us take the earthquake of march 7, 1899 (Eqke observations Nos. 12, 13 and 14), which caused considerable amount of landslips among the mountains of the provinces of Kii and Yamato, and caused in Ōsaka some damage, such as fracturing of chimneys, etc. The duration of the total preliminary tremor indicated by the Gray-Milne type seismograph at the Meteorological Observatory of Wakayama (province of Kii) was $13\frac{1}{2}$ sec.; while the durations of the same epoch observed by means of continuously recording horizontal pendulum apparatus at Tokyo and Miyako (province of Rikuchu) were respectively 47 and 104 sec. The distances of the seismic origin from these three places are found, by equation (2), to be as follows:—

* See the Jour. Sci. Coll., Tōkyō Imp. Univ., Vol. XI.

Distance from Wakayama,.....	136 km
" " Tokyo,	380 "
" " Miyako,	794 "

The circles described about the three places as centres and with the radii respectively equal to the values given above, are found to intersect approximately near a point P off the eastern coast of the province of Kii, which denotes the position of the epicentre. (See Fig. 6.)



(Boundary of provinces.)

§ 23. *Explanation of the phenomena of the preliminary tremors.*
 In a former paper,* I tried to explain the proportionality of the

* Jour. Sci. Coll., Tōkyō Imp. Univ., Vol. XI.

duration of the preliminary tremor with the distance by supposing two (or more) sets of waves, which, originating simultaneously at the centre of disturbance, are propagated with different velocities. This explanation, which assumes the paths of the different sets of waves to be identical, must, however, now be modified somewhat. Thus, the different kinds of waves would not differ much in their transit velocities, if propagated along one and the same path; the difference of the velocity to be modified by the length of the wave, the viscosity of the material of the earth's crust, etc., being anyhow not considerable. (For a discussion on the longitudinal and the transverse components in the earthquake motion, the reader is referred to §§ 47-49.) On the other hand, it is clear from §§ 43 and 55 that the waves in the *1st preliminary tremor*, whose transit velocity is v_1 , must be transmitted along a layer at some depth below the surface; while the waves in the *3rd phase of the principal portion*, whose transit velocity is v_3 , are propagated along the surface. From these considerations, I conclude that the relation of the duration of the preliminary tremors and the distance of earthquake origin is due to the transmission of the disturbances along different routes, and consequently with different velocities; it being only for large values of x , say, greater than 100 km, that the relation between the duration (y) and the distance (x) becomes practically identical as on the supposition of a common path.

§ 24. *On the application of the law of the preliminary tremors to the estimation of the depth of a seismic focus.* If the different sets of waves composing the earthquake motion were propagated along one and the same path, we can at once apply equation (1) or equation (2), properly modified, to the estimation of the focal depth of a local earthquake. But the depth obtained in this way is always found to be much greater than what we might otherwise infer, which is probably due to the transmission of the different kinds of waves along different paths, as stated in the preceding §. The discussion on this important problem must be postponed to a future occasion;

it being necessary, amongst other things, to obtain an accurate knowledge of the transit velocity v_1 for earthquakes of a very near origin.

XIII. Description of the EW component Seismograms of some of the distant great Earthquakes.

§ 25. As illustrations of the characteristics of the motion of distant great earthquakes, I shall here give the analysis of the EW component seismograms, obtained at Hongō (Tōkyō), of the following eleven earthquakes.

TABLE XXXII.

LIST OF GREAT DISTANT EARTHQUAKES.

No.	Date.	Time of occurrence. (1st Normal Japan Time.)			Origin.
		h	m	s	
a	Sept. 4, 1899	9	31	59 a.m.	Off the SW coast of Alasca.
b	" 11, "	6	50	58 a.m.	" "
c	" 20, "	11	24	27 a.m.	Aidin (Smyrna).
d	Jan. 6, 1900	4	6	24 a.m.	Sumatra.
e	" 20, "	3	52	39 p.m.	Mexico.
f	Sept. 18, "	7	1	41 a.m.	—
g	Oct. 9, "	9	37	14 p.m.	—
h	" 29, "	6	29	22 p.m.	Caracas.
i	April 19, 1902	11	38	47 a.m.	Guatemala.
j	Aug. 22, "	0	9	33 p.m.	Kashgar (Turkestan).
k	Sept. 22, "	10	52	16 a.m.	Guam Island.

The description of the first three earthquakes, (a), (b) and (c), are the same as those already given in the *Publications*, No. 6, with some modifications. The five earthquakes in 1900, namely, (d), (e), (f), (g) and (h), correspond respectively to Nos. 2, 13, 259, 277 and 291 in the list of the Hitotsubashi observations (Table I).

§ 26. (a). *Earthquake of Sept. 4, 1899; 9 31 59 a.m.* Total duration = 3h.