On the Relation between the Duration of the Preliminary Tremor and the Epicentral Distance for Near Earthquakes.

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With Plates VIII and IX.

1. Introduction. The empirical formulæ formerly deduced by the present author for the calculation of the epicentral distance ($=x$ km) of a near earthquake from the duration ($=y$ sec.) of the preliminary tremor, was as follows:—

x km $= 6$ y sec. ..... for $x < 6$ km

x km $= 6.86$ y sec. $+ 8.1$ ..... 50 km $< x <$ 200 km

x km $= 7.27$ y sec. $+ 38$ ..... 100 km $< x <$ 1000 km

As it is inconvenient to have different formulæ for the various limits of the epicentral distance, it is here proposed to deduce one which covers the ranges in question and which is specially useful in the application to the cases of local earthquakes.

2. Earthquake observations. The earthquakes taken into consideration in the deduction of the formula are 41 in number and occurred recently in Japan, the origins having been accurately located from the tromometrical determination of the epicentral distance and the direction of the movements in the earlier portion of the preliminary tremor, or from some special studies. These

are: 27 explosions and strong earthquakes of the Asama-yama; 2 severe earthquakes of Ueda (1912) and of Ōzasa (1916), both in the vicinity of the same volcano; 2 strong earthquakes in 1917 of the Hakone-yama and of Odawara; 6 destructive earthquakes of Shizuoka (1917), Kobe (1916), Torahime (in Ōmi, 1909), Aki-Iyo (1905), Sakura-jima (1914), and Kagi (in Formosa, 1906); and 4 destructive earthquakes in 1916 and 1917 in the Nanto prefecture, Formosa. In the cases of the Asama-yama explosions, the source of the earthquake motion was of course at the crater itself; the epicentral distance being thus at the same time the actual distance between the origin and the place of observation. The seismic vibrations due to these disturbances have been observed with tromometers not only in Tokyo, Ōsaka, and Nagano, but also at Yuno-taira and Ashino-taira on the S.W. slope, and at the Asama Pasture Ground at the E.E.N. foot, of the mountain, at the radial distances of 2 to 6 km from the crater, thus giving the values of the duration ($=y$) of the preliminary tremor for the cases of extremely small lengths of the radial distance ($=x$). I feel much gratified that the majority of the numerous meteorological observatories in Japan have now been equipped with the mechanically registering tromometers, mostly of the 100 times magnification, which are simple in construction and yet furnish much valuable material for the investigation of such fundamental seismological problems as the location of the origin of the disturbance and the causes of earthquakes. The two following tables give for the different earthquakes the position of the origin, the epicentral distance (x), and the duration (y) of the preliminary tremor.

OBSERVATIONS OF EXPLOSION SHOCKS AND DESTRUCTIVE EARTHQUAKES. 1905—1917.

Earthquake and Date.	Position of Earthquake Origin.	Place of Observation.	Duration of Preliminary Tremor $=y$	Epicentral Distance $=x$.
			sec.	km.
12 strong Asama-yama Explosions, 1912–14.	Asama-yama Crater: $\varphi = 36°\ 24'13''$ N, $\lambda = 138°\ 31'15''$ E	Yuno-taira Seismological Qbservatory.	0.40	2.4
4 strong Asama-yama Explosions in 1913.	*Do.*	Ashino-taira Seismological Station.	0.63	5.0
3 strong Asama-yama Explosions in 1913.	*Do.*	Asama Pasture Ground.	1.40	6.8
6 strong Asama-yama Explosions, 1910–11.	*Do.*	Nagano Met. Observatory.	4.9	40.3
Asama-yama Eqke., Dec. 7th, 1909.	Close to Asama-yama Crater.	Nagano Met. Observatory. Tokyo, Seism. Institute. Osaka Met. Observatory.	4.5 18.8 47.0	40.3 135.4 341.3
Asama-yama Eqke., July 16th, 1912.	*Do.*	Tokyo, Seism. Institute. Osaka Met. Observatory.	18.3 49.3	135.4 341.3
Ueda (Shinano) Eqke., Aug. 17th, 1912.	26 km to the west of Asama-yama Crater: $\varphi = 36°\ 26'.9$ N, $\lambda = 138°\ 14'.8$ E	Yuno-taira Seism. Obs. Nagano Met. Observatory. Tokyo, Seism. Institute. Osaka Met. Observatory.	3.3 3.4 21.7 43.0	24.8 25.8 160.0 323.1
Ozasa (Asama-yama) Earthquake, Feb. 22nd, 1916.	8 km to the N.W. of Asama-yama Crater: $\varphi = 36°\ 28'.5$ N, $\lambda = 138°\ 28'.8$ E	Ueda, Sericultural College. Nagano Met. Observatory. Maebashi „ Tokyo, Seism. Institute. Osaka Met. Observatory.	2.2 4.6 6.1 20.3 48.0	21.7 36. 53. 143.5 343.
Odawara Eqke., Feb. 8th, 1917.	29 km to the S. of Odawara, under sea: $\varphi = 35°\ 00'.0$ N, $\lambda = 139°\ 13'.8$ E	Miyanoshita (Hakone). Tokyo, Seism. Institute.	4.7 12.1	33. 93.
Hakone-yama Eqke., Jan. 31st, 1917.	Vicinity of Komaga-take: $\varphi = 35°\ 13'.5$ N, $\lambda = 139°\ 1'.3$ E	Tokyo, Seism. Institute.	11.7	88.

Earthquake and Date.	Position of Earthquake Origin.	Place of Observation.	Duration of Preliminary Tremor = y	Epicentral Distance = x.
Shizuoka Eqke., May 18th, 1917.	36 km to the N 65° W of Shizuoka: $\varphi = 35°\ 7'$ N, $\lambda = 138°\ 2'$ E	Miyanoshita (Hakone).	12.4 sec.	92. km.
		Yuno-taira (Asama).	23.2	150.
		Hikone Met. Observatory.	20.7	163.
		Tokyo, Seism. Institute.	23.3	173.
		Osaka Met. Observatory.	32.3	242.5
Kobe Eqke., Nov. 26th, 1916.	Northern part of the Island of Awaji; $\varphi = 34°\ 33'.0$ N, $\lambda = 134°\ 58'.5$ E	Kobe Met. Observatory.	3.5	23.
		Osaka „	6.4	43.5
		Tokyo, Seism. Institute.	58.0	455.
Omi-Mino Eqke., Aug. 14th, 1909.	$\varphi = 35°\ 28'$ N, $\lambda = 136°\ 20'$ E	Tokyo, Seism. Institute.	42.8	311.
Aki-Iyo Eqke., June 2nd, 1905.	$\varphi = 34°\ 8'$ N, $\lambda = 132°\ 24'$ E	Tokyo, Seism. Institute.	93.0	693.
Sakura-jima Eqke., Jan. 12th, 1914.	$\varphi = 31°\ 35'$ N, $\lambda = 130°\ 39'.4$E	Fukuoka Met. Observatory.	30.7	223.
		Osaka „	70.9	560.
		Tokyo, Seism. Institute.	130.7	958.
Kagi (Formosa) Eqke., March 17th, 1906.	$\varphi = 23°\ 35'$ N, $\lambda = 120°\ 32'$ E	Taichu Met. Observatory.	8.7	65.
		Tainan „	11.4	74.
		Taihoku „	27.2	189.
		Osaka „	273.0	1903.
		Tokyo, Seism. Institute.	299.0	2286.

OBSERVATION OF THE DESTRUCTIVE NANTO (FORMOSA) EARTHQUAKES IN 1916 AND 1917.

Met. Observatory. \ Date and Position of Origin.	Aug. 28th, 1916. $\varphi = 23°\ 48'.8$ N, $\lambda = 121°\ 02'.1$ E		Nov. 15th, 1916. $\varphi = 23°\ 56'.3$ N, $\lambda = 121°\ 05'$ E		Jan. 5th, 1917. $\varphi = 23°\ 54'.5$ N, $\lambda = 121°\ 07'.1$ E		Jan. 7th, 1917. $\varphi = 23°\ 58'.7$ N, $\lambda = 121°\ 07.7$ E	
	(y) sec.	(x) km	(y) sec.	(x) km	(y) sec.	(x) km	(y) sec.	(x) km
Taichū.	7.0	54	7.5	50	—	54	6.5	52
Karenkō.	7.9	56	—	48	—	45	—	42
Taihoku.	21.3	144	18.0	130	20.2	132	16.9	124

Met. Observatory. \ Date and Position of Origin.	Aug. 28th, 1919. $\varphi = 23°\ 48'.8$ N, $\lambda = 121°\ 02'.1$ E		Nov. 15th, 1916. $\varphi = 23°\ 56'.3$ N, $\lambda = 121°\ 05'$ E		Jan. 5th, 1917. $\varphi = 23°\ 54'.5$ N, $\lambda = 121°\ 07'.1$ E		Jan. 7th, 1917. $\varphi = 23°\ 58'.7$ N, $\lambda = 121°\ 07.7$ E	
	(y) sec.	(x) km	(y) sec.	(x) km	(y) sec.	(x) km	(y) sec.	(x) km
Hokoto.	—	154	20.7	162	—	164	—	168
Tainan.	16.1	125	17.0	138	20.1	138	17.3	145
Taitō.	—	116	—	130	18.7	126	20.2	134
Kōshun.	27.0	201	—	215	—	212	30.7	220

3. Relation between epicentral distance and duration of preliminary tremor. The results of the observations contained in the two preceding tables may conveniently be divided into 13 groups, a to m, according to the length of the epicentral distance; the mean values of $y=0.40$ to 286 sec. corresponding to those of $x=2.4$ to 2195 km. The letters $a, b, c \ldots . m$ in figs. 1 and 2 have the same signification as in the following table.

MEAN RELATION OF THE DURATION OF THE PRELIMINARY TREMOR TO THE EPICENTRAL DISTANCE.

Division.	Group.	Number of Observations.	Duration of Preliminary Tremor $=y$.	Epicentral Distance $=x$.	Ratio : $\frac{x}{y}$.
I.	a	12	0.40 sec.	2.4 km.	6.00
	b	7	0.96	5.8	6.04
II.	c	4	3.1 sec.	23.8 km.	7.68
	d	10	6.1	47.3	7.72
	e	4	11.9	87.	7.31
	f	8	17.6	132.	7.52
	g	10	21.2	150.	7.08
	h	5	29.6	215.	7.26
	i	2	42.9	317.	7.39
	j	5	54.6	408.	7.47
	k	1	93.0	693.	7.45
	l	1	130.7	958.	7.33
	m	2	286.0	2095.	7.33
Mean.	——	——	——	——	(I) 6.02 (II) **7.42**

The value of x/y is 6.02 for a and b, (I), namely, for the cases of the duration of preliminary tremor under 1.0 sec. For c, d,....m, (II), namely, for the cases of the y of 1.0 to nearly 300 sec., the ratio in question is included between 7.08 and 7.72, giving the mean of 7.42. As illustrated in figs. 1 and 2, the mean relation between the x and the y is represented by a straight line passing through the coordinate origin, the formula thus becoming:—

$$x \text{ km.} = 7.42\ y \text{ sec.} \quad \cdots\cdots \begin{cases} 0 \text{ sec.} < y < 130 \text{ sec.} \\ 0 \text{ km.} < x < 1000 \text{ km.} \end{cases}$$

The applicability of this equation is here limited to less than 1000 km, although it may possibly be extended to $x=2000$ km. When y is less than 1.0 sec., the coefficient is in reality a little smaller and becomes 6.0, but this does not produce any material difference in the result. The epicentral distance (x) corresponding to a given duration (y) of the preliminary tremor may be taken from the table at the end of the paper, or may be read off from figs. 1 and 2, respectively for the ranges of y under 30 sec. and under 130 sec. As the cases of the small radial distance utilized in the deduction of the ratio x/y, relate mostly to the Asama-yama explosions, whose centre was superficial, the new formula may be assumed to give, for earthquakes of short duration (y) of the preliminary tremor, the actual distance between the observing place and the centre of disturbance, enabling us thence to deduce an approximate value of the focal depth.

TABLE FOR THE CALCULATION OF THE EPICENTRAL DISTANCE FROM THE DURATION OF THE PRELIMINARY TREMOR, FOR NEAR EARTHQUAKES.

$$x \text{ km.} = 7.42\ y \text{ sec.} \ldots\ldots\ldots \begin{cases} 0<x<1000 \text{ km.} \\ 0<y<130 \text{ sec.} \end{cases}$$

sec. y	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	km.	km.	km.	km.	km.	km.	km.	km.	km.	km.
0.0	0.0	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4
1.0	6.0	6.9	7.8	8.6	9.4	10.2	11.0	11.8	12.7	13.5
2.0	14.3	15.1	15.9	16.7	17.5	18.3	19.1	19.9	20.7	21.6

sec. y	0	1	2	3	4	5	6	7	8	9
	km.	km.	km.	km.	km.	km.	km.	km.	km.	km.
0	0.0	6.0	14.3	22.3	29.7	37.1	44.5	51.9	59.4	66.8
10	74.2	81.6	89.0	96.5	103.9	111.3	118.7	126.1	133.6	141.0
20	148.4	155.8	163.2	170.7	178.1	185.5	192.9	200.3	207.8	215.2
30	222.6	230.0	237.4	244.9	252.3	259.7	267.1	274.5	282.0	289.4
40	296.8	304.2	311.6	319.1	326.5	333.9	341.3	348.7	356.2	363.6
50	371.0	378.4	385.8	393.3	400.7	408.1	415.5	422.9	430.4	437.8
60	445.2	452.6	460.0	467.5	474.9	482.3	489.7	497.1	504.6	512.0
70	519.4	526.8	534.2	541.7	549.1	556.5	563.9	571.3	578.8	586.2
80	593.6	601.0	608.4	615.9	623.3	630.7	638.1	645.5	653.0	660·4
90	667.8	675.2	682.6	690.1	697.5	704.9	712.3	719.7	727.2	734.6
100	742.0	749.4	756.8	764.3	771.7	779.1	786.5	793.9	801.4	808.8
110	816.2	823.6	831.0	838.5	845.9	853.3	860.7	868.1	875.6	883.0
120	890.4	897.8	905.2	912.7	920.1	927.5	934.9	942.3	949.8	957.2
130	964.6	972.0	979.4	986.9	994.3	1001.7	1009.1	1016.5	1024.0	1031.4

7.42

1	0.7
2	1.5
3	2.2
4	3.0
5	3.7
6	4.5
7	5.2
8	5.9
9	6.7

Fig. 1. Diagram showing the Relation between the Duration (=y sec.) of the Preliminary Tremor and the Central Distance (=x km) for Near Earthquakes. y=0 to 30 sec.

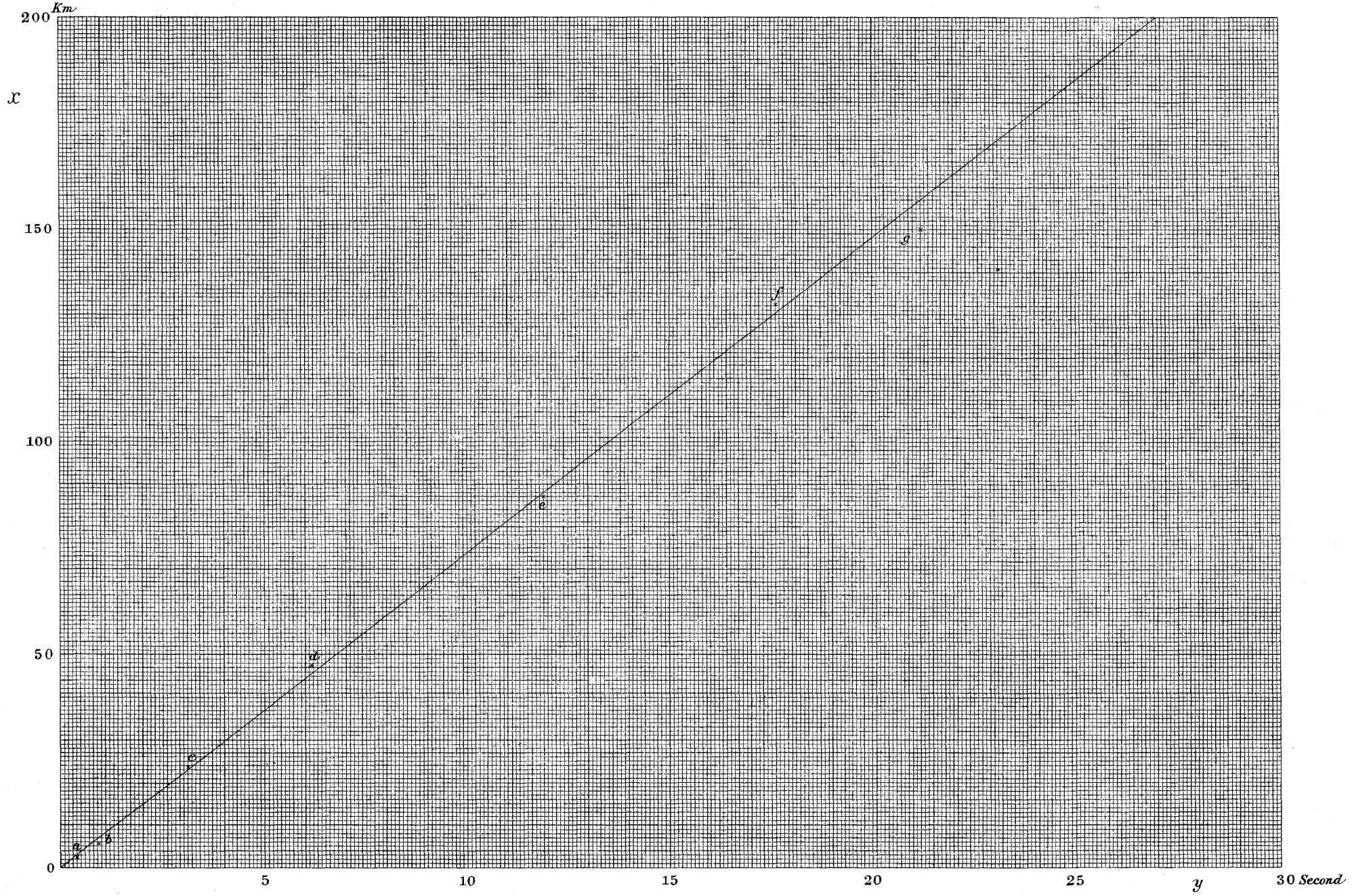

Fig. 2. Diagram showing the Relation between the Duration (=y sec.) of the Preliminary Tremor and the Central Distance (=x km) for Near Earthquakes. y=0 to 130 sec.