The After-shocks of the Zenkoji (1847) and the Tenpo (1830) Earthquakes.

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With Pls. XL and XLI.

CONTENTS.

1. ***Introduction.*** The present note gives an account of the frequency of the after-shocks of the two great Japan earthquakes of Zenkoji and Tenpo, based on the old records given in the *Dai-Nippon Jishin Shiryo* ("Material for the Earthquake History of Japan," No. 46 of the Report [Japanese] of the Imperial Earthquake Investigation Committee, 2 Vols.)

2. ***After-shocks of the Zenkoji earthquake.**** The daily number of the after-shocks of the great Zenkoji earthquake of May 8, 1847, recorded at Matsushiro by an official in the service of the feudal lord of that place are given in Tables I and II, respectively for the first 31 days and for an interval of the 42 days between Nov. 29, 1847 and Jan. 9, 1848. There were also many *jinari*, their numbers not being included in the figures of Table I. The city of Matsushiro is about 10 km to the south of the middle point of the epifocal zone.

* A short account of the Zenkoji earthquake has been given in p.p. 136–143, of this Number.

TABLE I.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. MAY 8—JUNE 7, 1847. MATSUSHIRO.

Date.	Number of Earthquakes.	Date.	Number of Earthquakes.
May 8	31	May 24	16
9	69	25	11
10	56	26	25
11	80	27	7
12	82	28	10
13	86	29	12
14	52	30	17
15	39	31	3
16	57	June 1	13
17	43	2	20
18	29	3	5
19	20	4	8
20	37	5	14
21	16	6	13
22	31	7	7
23	21	*Sum.*	**930**

TABLE II.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE ZENKOJI EARTHQUAKE OF MAY 8, 1847. NOV. 29, 1847—JAN. 9, 1848.

Date.	Earthquakes.			*Jinari.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Nov. 29	2	2	—	—	4
30	—	1	—	—	1
Dec. 1	—	3	—	—	3
2	—	4	5	—	9
3	—	3	3	1	7
4	—	2	2	—	4
5	—	2	—	—	2

TABLE II. *(Cont.)*

Date.	Earthquakes.			*Jinari.*	Total Number.
	Strong.	Moderate.	Small.		
1847					
Dec. 6	—	2	—	—	2
7	—	1	—	2	3
8	2	1	3	—	6
9	—	1	1	—	2
10	—	2	—	—	2
11	—	1	—	—	1
12	—	—	1	1	2
13	—	2	—	—	2
14	1	1	1	2	5
15	—	1	—	—	1
16	—	2	—	—	2
17	—	1	1	3	5
18	—	1	—	—	1
19	—	2	—	1	3
20	—	—	—	—	—
21	—	—	—	—	—
22	2	6	1	2	11
23	—	1	3	—	4
24	—	1	—	—	1
25	—	1	—	—	1
26	—	1	—	—	1
27	—	4	—	—	4
28	—	—	—	—	—
29	—	—	—	—	—
30	—	1	—	—	1
31	—	2	5	2	9
1848					
Jan. 1	—	2	1	—	3
2	—	—	—	—	—
3	—	1	1	—	2
4	—	1	—	2	3
5	1	4	5	(Frequent)	10
6	—	1	3	—	4
7	—	1	1	—	2
8	3	5	2	—	10
9	1	—	—	—	1
Sum.	**12**	**67**	**39**	**16**	**134**

TABLE III.—MONTHLY NUMBERS OF THE SENSIBLE EARTHQUAKES RECORDED AT THE METEOROLOGICAL OBSERVATORY OF NAGANO. 1889—1907.

Month. / Year.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	*Sum.*
1889	0	1	1	0	1	0	0	0	0	1	0	0	4
1890	2	0	0	1	0	1	0	0	0	0	0	0	4
1891	0	0	0	0	1	0	1	0	0	2	1	2	7
1892	1	1	0	0	0	0	0	0	0	0	1	3	6
1893	0	1	1	0	0	0	0	0	0	0	2	0	4
1894	0	0	0	0	0	0	0	0	0	1	0	0	1
1895	2	0	0	1	0	0	0	0	0	0	0	0	3
1896	2	2	1	1	0	1	2	2	1	0	0	0	12
1897	4	2	0	5	5	2	1	1	0	0	2	1	23
1898	0	0	4	0	1	1	1	1	0	10	2	1	21
1899	1	0	4	3	1	0	1	0	0	0	2	0	12
1900	1	0	3	1	1	0	1	1	0	0	0	0	8
1901	1	0	0	0	0	1	2	2	1	0	2	3	12
1902	2	0	0	0	1	1	0	0	0	0	0	0	4
1903	1	1	1	0	0	0	2	2	0	0	0	0	7
1904	0	0	2	0	1	1	0	0	0	1	1	3	9
1905	1	1	1	1	1	2	6	2	0	3	1	0	19
1906	1	2	2	4	2	2	3	1	2	1	0	2	22
1907	0	1	1	5	4	4	2	2	0	2	1	2	24

The numbers of the after-shocks of the Zenkoji earthquake for the first 6 intervals of 5-days each commencing with May 9, the day after the great catastrophe, were, according to Table I, as follows:—

x	5-day Interval. (1847)	Observed Number of After-shocks $=y$	Calculated Number of After-shocks.
0	May 9—May 13	373	438
1	„ 14— „ 18	220	177
2	„ 19— „ 23	125	111
3	„ 24— „ 28	69	81
4	„ 29—June 2	65	63
5	June 3— „ 7	47	52

Denoting the 5-day interval and its corresponding after-shock frequency respectively by x and y, and calculating the constants of my equation for the frequency of after-shocks, we obtain from the foregoing table the following formula :—

$$y=\frac{296.4}{x+0.675} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

The values of y calculated by this equation for the different x's, given in the last columun of the above table, may be regarded on the whole to be approximately equal to the actual after-shock frequencies.

Calculating by means of Equation (1) the seismic frequency for $x=\frac{365}{5}=73$, we find :—$y=4.0$. Hence, $6y=24$ gives the probable number of the after-shocks during the one month exactly one year after the initial great earthquake, namely, during the 30 days between April 27 and May 26, 1848. The actual number of the shock during this interval was 27.

Again, calculating as a trial the seismic frequency for $x=50$ years, we find :—

$$y=0.081\,;\quad \frac{365}{5}\times y=5.9.$$

Thus, according to Equation (1), the annual frequency (of the after-shocks only) at Matsushiro 50 years after the Zenkoji earthquake, should be approximately 6; indicating a possibility of the continuance of after-shocks of a violent and great catastrophe for over half a century. For the sake of reference, I give in Table III the yearly numbers of the sensible earthquakes recorded at the meteorological observatory of Nagano (Zenkoji) during the 19 years between 1889 and 1907. The mean of the two last named years is 1898, which is 51 years after the date of the earthquake in question, and the average annual seismic frequency during the 19 years was 10.6, which is equivalent to the sum of the yearly number of the ordinary earthquakes and that of the after-shocks, if any.

3. ***Frequency of after-shocks of the Zenkoji earthquake compared with that of the Mino-Owari earthquake.*** The after-shocks of the Zenkoji earthquake were more numerous than those of the Ansei earthquake of Dec. 24, 1854, recorded in Tosa, and of the Nemuro-Kushiro (Hokkaido) earthquake of March 22, 1894, recorded at Nemuro.

The following table gives the daily number of the after-shocks of the Mino-Owari earthquake for the 30 days between Nov. 3 and Dec. 2, 1891, recorded *instrumentally* at the meteorological observatory of Gifu. (The after-shocks of the Mino-Owari earthquake have been discussed in detail in the Jour. Sc. Coll., Tokyo Imp. Univ., Vol. VII, and the Publications of the Earthquake Inv. Comm., No. 7.)

Frequency of the After-shocks.

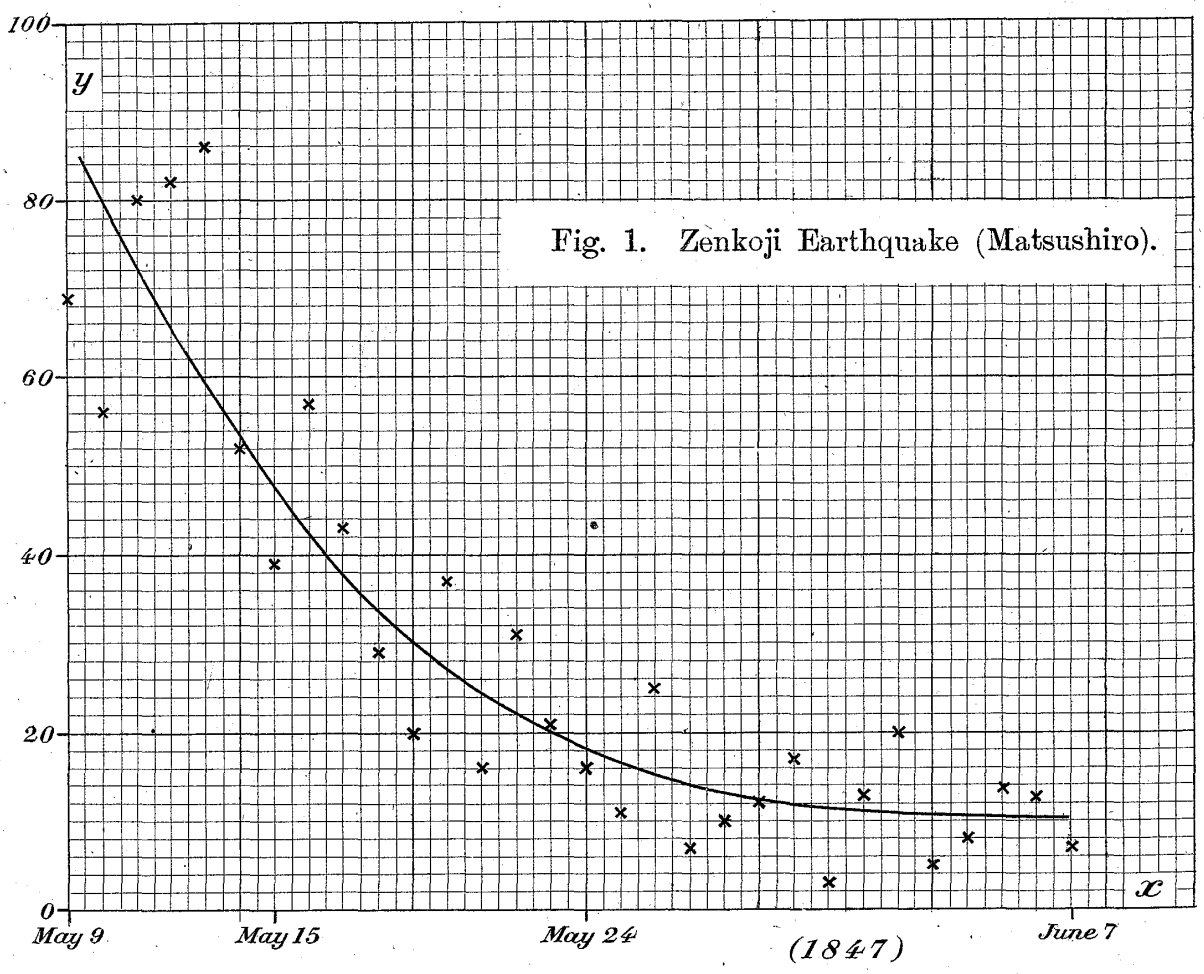

Fig. 1. Zenkoji Earthquake (Matsushiro).

{ x = Time, in Day.
{ y = Daily Number of After-shocks.

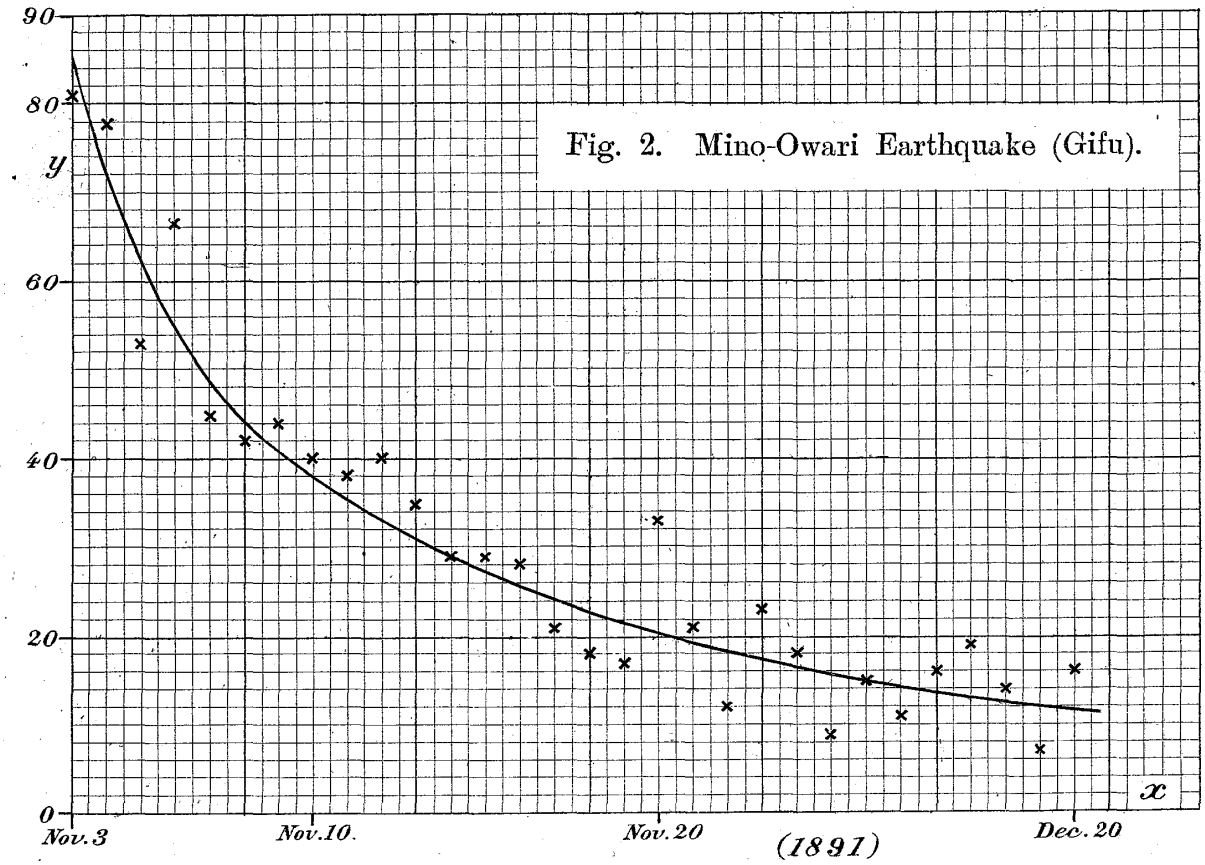

Fig. 2. Mino-Owari Earthquake (Gifu).

Frequency of the After-shocks of the Tenpo (1830) and Zenkoji (1847) Earthquakes.

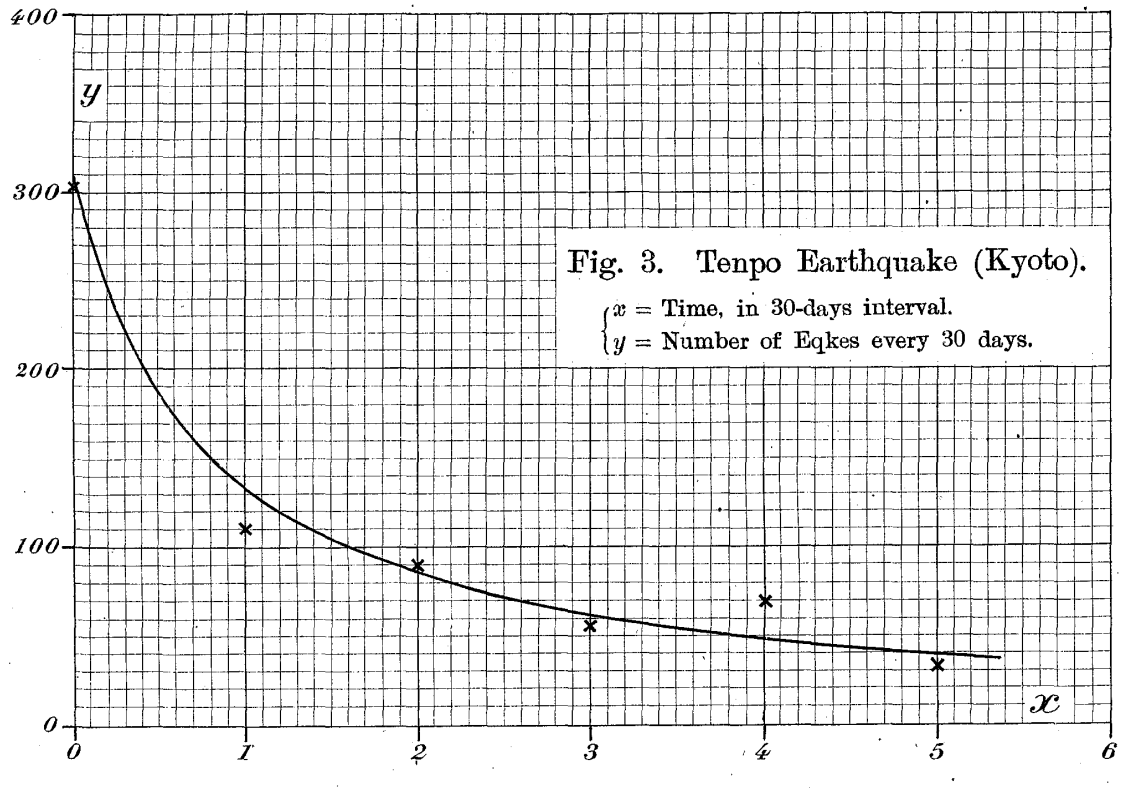

Fig. 3. Tenpo Earthquake (Kyoto).
x = Time, in 30-days interval.
y = Number of Eqkes every 30 days.

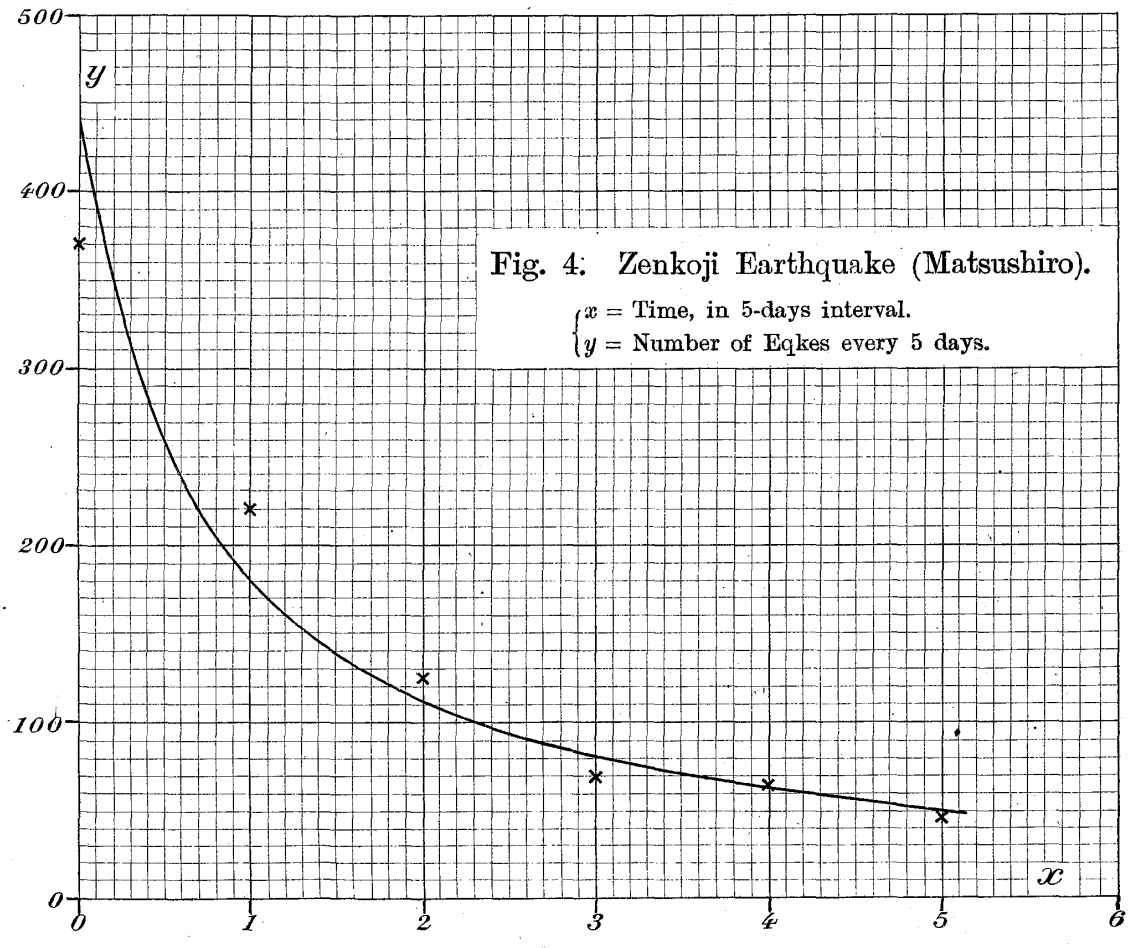

Fig. 4. Zenkoji Earthquake (Matsushiro).
x = Time, in 5-days interval.
y = Number of Eqkes every 5 days.

TABLE IV.—AFTER-SHOCKS OF THE MINO-OWARI EARTHQUAKE OF OCT. 28, 1891. OBSERVED AT THE METEOROLOGICAL OBSERVATORY OF GIFU. NOV. 3—DEC. 2, 1891.

Date.	Daily Number of Eqkes.	Date.	Daily Number of Eqkes.
Nov. 3	81	Nov. 19	17
4	78	20	33
5	53	21	21
6	67	22	12
7	45	23	23
8	42	24	18
9	44	25	9
10	40	26	15
11	38	27	11
12	40	28	16
13	35	29	19
14	29	30	14
15	29	Dec. 1	7
16	28	2	16
17	21		
18	18	Sum.....	.....**919**

The variation with time of the after-shock frequency at Gifu during the 30 days, beginning with the 6th day after the initial disturbance, is graphically shown in Fig. 2. It will be observed that the mean curve resembles in general that in Fig. 1, which indicates the similar relation for Matsushiro with respect to the Zenkoji earthquake, during the 30 days beginning with the 2nd day after the latter. Further the total numbers of the after-shocks of these two great earthquakes during the respective 30 days intervals were nearly alike, namely, 919 and about 900.

The following is a comparison of the after-shock frequencies of the two earthquakes under cosideration during the 30 days, respectively (i) 7 months and (ii) 1 year after their occurrence :—

Zenkoji Eqke.		Mino-Owari Eqke.	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(i) Dec. 1-30, 1847.	73 shocks. 12 sounds.	(i) May 28-June 26, 1892.	23 shocks. 11 sounds.
(ii) April 27-May 26, 1848.	27 shocks. numerous sounds.	(ii) Oct. 28-Nov. 27, 1892.	46 shocks. 8 sounds.

Hereby it is to be noticed that the record of the Mino-Owari after-shocks, which was made instrumentally at the meteorological observatory of Gifu, includes a number of insensible shakings and may be taken to be much more accurate than that of the old Zenkoji shocks, which was carried on without instrumental aid.

From what has been said above it seems that the number of after-shocks of the Zenkoji earthquake of 1847 was not less than that of the Mino-Owari earthquake of 1891.

4. ***After-shocks of the Tenpo earthquake of 1830.*** The earthquake of the 1st year of Tenpo (1830), on Aug. 19, which caused considerable damage in the city of Kyoto and the vicinity, was followed by numerous after-shocks whose daily numbers at Kyoto are given in Table V; their total number in the interval of 6 months up to Feb. 28, 1831, being 681. The numbers of the after-shocks during the successive intervals of 30 days, denoted by $x=0, 1, 2, 3, 4$, and 5 respectively, were as follows:—

x	30 days Interval.	Number of the after-shocks actually recorded at Kyoto $=y$.	Number of the after-shocks calculated by Equation (2).
0	Aug. 20, 1830-Sept. 18, 1830.	302	306
1	Sept. 19, „ -Oct. 18, „	111	134
2	Oct. 19, „ -Nov. 17, „	90	86
3	Nov. 18, „ -Dec. 17, „	57	63
4	Dec. 18, „ -Jan. 16, 1831.	71	50
5	Jan. 17, 1831-Feb. 15, „	33	41

The relation between the time x and the corresponding seismic frequency y, illustrated graphically in Fig. 3, is found to be as follows :—

$$y=\frac{237.9}{x+0.777} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The figures in the last column of the preceding table have been calculated by Equation (2). As a trial, putting $x=60\times12=720$ (or approximately 60 years), we find $y=0.33$. Hence, $12y=4$ is the approximate calculated value of the annual seismic frequency in Kyoto, about 60 years after the earthquake in question, provided its after-shocks be supposed to have been continued for so long a time interval. Now, the value of x considered above corresponds to the year 1890, and the average annual number of earthquakes recorded at the Kyoto meteorological observatory during the 11 years between 1885 and 1895, was, as shown in the following list, approximately 5, agreeing fairly well with the result deduced from Equation (2).

YEARLY NUMBER OF EARTHQUAKES IN KYOTO. 1885–1895.

Year.	Number of Earthquakes.	Year.	Number of Earthquakes.
1885	5	1891	102*
1886	2	1892	25*
1887	6	1893	5
1888	5	1894	6
1889	2	1895	14
1890	2	*Mean.*	**5**

* The numbers for 1891 and 1892 have been omitted in taking the mean, as the majority of the disturbances in these two years were the after-shocks of the Mino-Owari earthquake of Oct. 28, 1891.

TABLE V.—DAILY NUMBERS OF THE AFTER-SHOCKS OF THE KYOTO EARTHQUAKE OF AUG. 19, 1830. KYOTO. AUG. 20, 1830—FEB. 28, 1831.

Year.	1830					1831	
Month. / Day.	VIII	IX	X	XI	XII	I	II
1		13	4	2	3	3	2
2		11	4	6	3	0	2
3		12	2	4	3	4	2
4		11	1	1	1	4	1
5		4	1	4	2	4	2
6		2	3	2	1	2	0
7		5	3	2	1	1	1
8		6	4	1	3	2	1
9		6	9	2	3	2	3
10		5	3	6	1	3	1
11		5	3	0	2	4	2
12		6	4	7	2	2	1
13		6	4	4	2	1	0
14		12	3	5	1	2	3
15		7	4	5	1	3	3
16		3	4	1	1	4	2
17		3	1	2	2	1	3
18		3	3	3	2	0	2
19	(Great Eqke.)	3	3	2	4	0	3
20	20	1	2	0	2	0	2
21	20	11	1	1	2	0	2
22	20	4	3	1	3	0	3
23	20	1	4	2	3	1	0
24	12	2	2	2	2	0	0
25	13	3	3	3	1	0	0
26	13	9	5	3	2	1	0
27	13	6	3	2	2	0	0
28	13	6	5	2	0	0	0
29	13	1	3	2	3	2	—
30	13	4	1	2	2	2	—
31	12	—	1	—	2	2	—

5. ***Comparison between the after-shock frequencies of the Tenpo and Mino-Owari earthquakes.*** The following table gives the number of after-shocks during the successive 30 days intervals for the Tenpo and Mino-Owari earthquakes, beginning respectively with the 2nd and the 42nd days after the initial disturbances.

Tenpo Eqke of 1830 (Kyoto).		Mino-Owari Eqke of 1891 (Gifu).	
30 days Interval.	Number of After-shocks.	30 days Interval.	Number of After-shocks.
(Commencing with the 2nd day after the Earthquake)		(Commencing with the 42nd day after the Earthquake)	
$x=0$	302	Dec. 8, 1891–Jan. 6, 1892	294
1	111	Jan. 7, 1892–Feb. 5, „	110
2	90	Feb. 6, „ –March 6, „	72
3	57	March 7, „ –April 5, „	62
4	71	April 6, „ –May 5, „	73
5	33	May 6, „ –June 4, „	37

The numbers of the Mino-Owari after-shocks, which are the numbers of the earthquakes instrumentally observed at Gifu and do not include the cases of the *jinari*, or mere sounds, will thus be seen to be very nearly equal, on the whole, to the corresponding figures for the Tenpo earthquake. That is to say, the monthly after-shock frequency during the earlier epoch of the latter earthquake was practically identical with that of the former, with a time retardation of 40 days. (See Figs. 3 and 4.)

6. ***Conclusion.*** The foregoing §§ seem to indicate that the after-shocks of great earthquakes are governed by time relations which are more or less alike in the different cases. The three disturbances of Zenkoji, Tenpo, and Mino-Owari, all originated along great earthquake zones, the similarity of the causes probably tending also to the similarity of the phenomena of after-shocks.