15. *Statistical Investigations of Monthly Numbers of Earthquakes Felt at Tokyo.*

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The monthly numbers of earthquakes felt at Tokyo during 1872-1923 were published by Messrs Y. Yasuda and T. Kodaira.[1] And the numbers during 1924–1942 are found in the Seismometrical Report of the Earthq. Res. Inst. Since then although the recording is continued till now, it is not published yet.

The data before 1898 were omitted in the present investigations, because the recording depended only on human feeling and the positions of the epicentres were not determined seismometrically. During the period 1898–1947, 2916 earthquakes were felt at Tokyo, but in this number those felt there anomalously were omitted. The maximum annual frequency was 586 in 1923, the minimum 18 in 1945, and the maximum monthly frequency was 444 in September, 1923.

Table I.

Period	No. of years	No. of earthquakes	Annual mean	Monthly mean
1898–1947	50	2916	58.3	4.9
1936–1947	12	441	36.8	3.1

PERIODICITY OF EARTHQUAKES DURING 1872–1945.

The periodicity was investigated by the method of periodogram with the monthly numbers. As the results, periods of 12 months, 25 months and 50 months were found. Those longer than 50 months were studied with the annual frequencies. And on the periodogram, the amplitudes of 6 and 9 year period were noticeable.

1) Y. YASUDA and T. KODAIRA, Earthquakes observed in Tokyo during the period from September, 1872, to December, 1923. Tokyo, 1938.

RELATION BETWEEN MONTHLY NUMBERS AND INTENSITY OF FELT EARTHQUAKES.

Correlation between monthly earthquake numbers and intensity in Japanese seismic intensity scale, which classify the intensity in numbers 0–6, of the strongest earthquake in the month was studied. The strongest intensity in a month was adopted and weaker ones were neglected, because although many in number total energy of the weaker ones is usually small compared with that of the strongest.

The correlation ratio between the number and the intensity was obtained as 0.41 ± 0.02. Furthermore, the correlation was investigated by non-correlation test for the following contingency table.

Table II.

Monthly Number	Intensity scale 0	I	II	III	IV	V	VI	
0-4	27	150	105	70	14	0	0	366
5-9	0	44	56	71	10	1	0	182
10<	0	2	5	17	11	4	1	40
	27	196	166	158	35	5	1	588

Comparing the above values to those calculated under the assumption of non-correlation between the frequency and the intesity, χ^2 was obtained as 145. The probability corresponds to the above value of χ^2 is less than 0.001. Then it may be concluded that the intensity and the monthly numbers are correlative as the writer described in the investigation of the Itō earthquake swarm of 1930.[2)]

Table III.

Contingency table of intesity and earthquake number in the previous month.

Monthly Number	Intensity scale 0	I	II	III	IV	V	VI	
0-4	22	130	122	89	16	2	1	382
5-9	4	58	40	52	13	2	0	169
10<	1	7	10	11	6	1	0	36
	27	195	172	152	35	5	1	587

$$\chi^2 = 24.5 \quad 0.02 > P > 0.01$$

2) F. KISHINOUYE, *Bull. Earthq. Res. Inst.* **15** (1937), 791.

Correlations between the intensity of the strongest earthquake in a month and the monthly numbers of earthquake in the previous or the next months were investigated by the methods similar to the above.

Table IV.

Contingency table of intensity and earthquake number in the next month.

Monthly Number	Intensity scale							
	0	I	II	III	IV	V	VI	
0-4	21	135	124	92	16	4	0	392
5-9	5	55	38	49	13	0	0	166
10<	1	6	10	10	6	1	1	35
	27	196	172	151	35	5	1	587

$$\chi^2 = 32.7 \qquad 0.01 > P > 0.001$$

From the above results, the more earthquake number, the more probable the occurrence of a strong earthquake. And when a strong earthquake occurs in a month, the number of earthquakes will become large in the next month, but the strong earthquake has little correlation with the number of the previous month. In other words, even if the monthly earthquake number in a certain month is very large, a strong earthquake is not expected in the next month.

Correlation between the earthquake number in a certain month and the previous or the next months were studied further by the method of auto-correlation. For the comparison, the method was applied to the monthly frequencies at Utsunomiya, Mito and Wakayama.[3] The results are shown in the following table.

Table V.

Place	Interval	No. of Months	No. of Eqkes.	Correl. Coeff. of successive two months	Correl. ratio for the next month	Correl. ratio for the previous month
Tokyo	1898-1947	588	2269	0.20±0.03	0.28±0.03	0.26±0.03
Utsunomiya	1891-1936	543	2883	0.22±0.03	0.26±0.03	0.30±0.03
Mito	1897-1936	438	3646	0.23±0.03	0.26±0.03	0.28±0.03
Wakayama	1907-1936	318	1776	0.80±0.01	0.85±0.01	0.82±0.01

3) M. TAKEHANA, *Kensin-jihō*, **10** (1937) 118-146.

In the calculations the monthly numbers over 18 were omitted.

It may be deduced that the monthly numbers are distributed at random, and the clustering of earthquakes such as after-shocks does not affect the monthly frequency distribution.

ON THE DISTRIBUTION OF MONTHLY NUMBERS.

If the probability p is small and the total number N is large, the distribution may be expressed in Poisson's formula:

$$f(x) = \frac{m^x e^{-m}}{x!} \qquad \text{where} \quad m = Np\,.$$

The frequency-distribution of the earthquakes is usually expressed in Poisson's formula. In this formula if m becomes large, the distribution will approach to Gauss' normal distribution. This character of Poisson's formula will be seen in Fig. 1.[4]

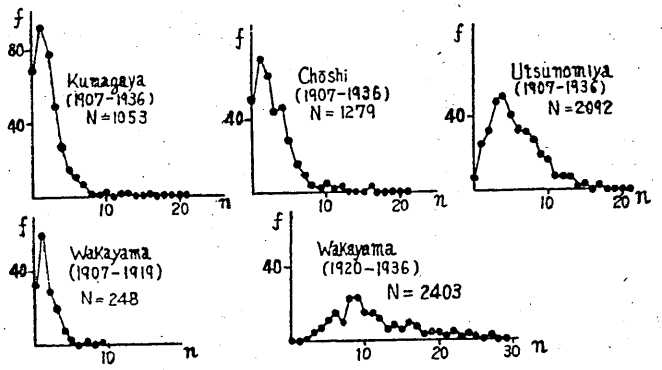

Fig. 1. Frequency-distribution of monthly numbers of felt earthquakes.

The frequency-distribution at Tokyo was expressed in the two formulae (Fig. 2):

$$f(x) = \frac{3.87^x e^{-3.87}}{x!}\,,$$

$$f(x) = \frac{x}{\sqrt{2\pi}\,2.54}\, e^{-\frac{(x-3.87)^2}{2\times 2.54^2}}.$$

4) M. TAKEHANA, loc. cit.

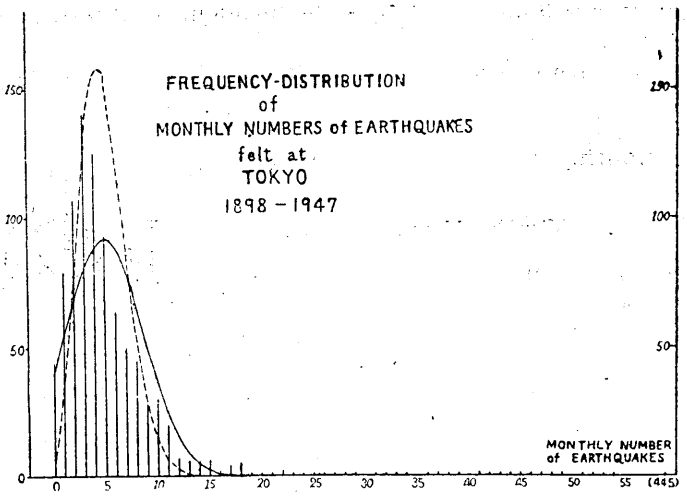

Fig. 2. Full line=Poison's distribution, Broken line=Gauss' distribution.

To examine which formula fits better to the actual frequency-distribution, the χ^2-test was applied over again. The values of χ^2 which correspond to the above formulae were obtained as 82.9 and 64.5 respectively. Although the probability of the occurrence of these values are estimated to be less than 0.001 in both cases, the normal distribution was in better accordance than Poisson's. In other words, the monthly numbers are nearly to be considered as at random and uniformly distributed.

If the variation of annual mean frequencies can be expressed in the normal distribution as above stated, the annual mean number of earthquakes in the next year will be expected by the fiducial limits of the theory of statistics.

If $\bar{f}$ denotes the mean value and σ the standard deviation, the next mean value f will be obtained by the formula,

$$f = \bar{f} + \alpha\sigma$$

The fiducial limits for the allowable error 0.02 of each year are shown in Table VI. Except the year 1923 in which the great earthquake occurred, in most years, 37 annually in 49 years, numbers of the next years were within the fiducial limits. In early 1946, many earthquakes took place at Tokyo compared with those in the previous years, and the citizens were uneasy for the occurrence of a strong earthquake. But the fear might be decreased if the above consideration admitted. The correlation between the annual frequencies and the number of cases of the agreement to the theory was examined by the χ^2-test. The value of χ^2 was obtained as 8.57,

so the number of earthquakes might be independent of fitness of the fiducial limits in this case.

Lastly, the author thanks Miss M. Kotaka for her assistance of this investigations.

Monthly Numbers of Earthquakes felt at Tokyo

Year	Monthly Number f												Annual Number	Mean Monthly No. $\bar{f}$	Stand. Dev. σ	Fiducial Limit $\alpha\sigma$
	J	F	M	A	M	J	J	A	S	O	N	D				
1898	1	4	2	4	2	7	9	7	5	0	4	2	47	3.9	2.6	2.1
99	2	4	7	8	4	2	4	9	2	3	2	2	49	4.1	2.4	2.0
1903	2	6	5	2	2	5	1	4	1	3	8	3	42	3.5	2.0	1.6
1	3	1	0	4	3	3	4	4	6	3	7	3	41	3.4	1.8	1.5
2	4	5	5	3	4	6	4	4	2	2	2	8	49	4.1	1.7	1.4
1903	5	9	3	3	3	2	5	2	1	5	6	1	45	3.7	2.3	1.9
4	6	3	3	4	4	2	10	5	2	7	3	3	52	4.3	2.4	1.9
5	0	2	3	4	4	5	3	1	3	5	2	3	35	2.9	1.7	1.4
6	4	6	2	9	13	0	2	8	3	5	3	0	55	4.6	3.6	3.0
7	2	3	3	4	2	3	3	1	2	7	4	3	37	3.1	1.7	1.4
8	5	0	1	0	4	2	4	3	2	2	1	4	28	2.3	1.7	1.4
9	2	3	10	3	5	2	8	5	3	4	6	6	57	4.8	2.4	1.9
10	2	1	0	3	6	4	4	3	10	7	7	5	52	4.3	2.6	2.2
11	4	3	5	3	2	3	1	4	5	5	12	6	53	4.4	2.7	2.2
12	10	2	5	3	10	5	3	6	3	5	4	7	63	5.3	2.5	2.1
13	1	5	5	4	6	5	5	4	4	3	3	2	47	3.9	1.4	1.2
14	4	5	4	1	3	4	4	1	2	5	0	3	36	3.0	1.6	1.3
15	0	1	4	9	10	5	3	3	1	5	16	2	59	4.9	4.5	3.6
16	1	4	3	2	2	2	3	10	2	4	5	2	40	3.3	2.3	1.9
17	8	6	4	3	1	4	3	4	3	5	9	3	53	4.4	2.2	1.8
18	2	3	5	10	5	1	6	2	2	4	2	3	45	3.7	2.4	2.0
19	2	3	2	5	6	5	4	4	0	2	3	1	37	3.1	1.7	1.4
20	2	3	1	1	3	2	6	2	1	2	1	8	32	2.7	2.1	1.7
21	2	1	1	2	1	0	1	0	1	1	3	11	24	2.0	2.8	2.3
22	4	4	5	10	4	4	3	1	2	2	5	1	45	3.7	2.3	1.9
23	7	5	6	0	6	17	5	3	444	33	34	26	586	—	—	—
24	31	1	2	4	3	4	2	3	5	2	0	3	60	5.0	2.5	2.1
25	7	5	1	1	2	4	2	1	1	2	5	3	34	2.8	1.9	1.6
26	10	10	5	4	7	5	7	6	2	3	7	2	68	5.7	2.6	2.1
27	4	3	6	3	5	2	4	9	9	8	9	3	65	5.4	2.6	2.1

Year	Monthly Number f												Annual Number	Mean Monthly No. $\bar{f}$	Stand. Dev. σ	Fiducial Limit $\alpha\sigma$
	J	F	M	A	M	J	J	A	S	O	N	D				
1928	6	5	7	8	16	4	8	6	2	8	3	5	78	6.5	3.4	2.8
29	5	4	5	4	3	6	6	2	5	3	4	3	50	4.2	1.2	1.0
30	4	4	4	5	13	3	1	7	5	5	3	4	58	4.8	2.8	2.3
31	3	6	12	3	5	11	12	4	14	6	5	8	89	7.4	3.8	1.3
32	0	8	11	5	2	4	5	4	6	8	3	3	59	4.9	2.9	2.4
33	2	7	5	7	3	4	6	3	5	9	7	5	63	5.3	2.0	1.6
34	4	10	3	7	6	9	5	5	3	0	10	3	64	5.3	2.9	2.4
35	10	6	8	8	3	11	10	3	9	4	2	4	78	6.5	3.1	2.5
36	2	1	2	3	1	4	3	1	2	5	4	3	31	2.6	1.3	1.0
37	4	3	2	3	4	1	3	0	4	4	3	3	34	2.8	1.2	1.0
38	3	2	0	5	4	8	6	5	4	2	25	12	76	6.3	6.4	5.2
39	4	2	7	2	5	6	4	2	2	6	1	3	44	3.7	1.9	1.6
40	6	2	5	1	2	7	1	3	3	1	7	3	41	3.4	2.2	1.8
41	1	3	4	3	4	3	4	0	2	3	3	0	30	2.5	1.4	1.1
42	2	3	2	1	5	0	6	3	4	1	3	2	32	2.7	1.7	1.4
43	4	1	6	7	2	3	2	3	0	3	1	0	32	2.7	2.1	1.7
44	0	4	3	3	5	2	2	0	0	0	1	8	28	2.3	2.4	1.9
45	10	1	0	1	0	3	0	0	1	1	1	0	18	1.5	2.7	2.2
46	6	5	0	6	3	0	4	3	5	3	3	8	46	3.8	2.3	1.9
47	3	5	3	4	3	2	3	2	1	3	0	0	29	2.4	1.4	1.2
Total	216	191	197	202	221	205	214	175	(606) 162	219	262	216	(2916) 2472	—	—	—
Mean	4.3	3.8	3.9	4.0	4.4	4.1	4.3	3.5	(12.0) 3.2	4.4	5.2	4.3	49.4	4.1	—	—

The cost of this investigation was mostly defrayed from the Scientific Research Expenditure of the Department of Education.