# 19. *Relation between Tidal Phases and the Earthquakes.*

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(Read April 15, 1930.—Received Sept. 20, 1930.)

## Introduction.

The investigations on the relation between tidal phases and the occurrence of earthquakes, have already been made by Late Prof. Ômori[1], Prof. K. Honda[2] and others. In most of these investigations, however, the positions of the epicentres of the earthquakes referred to were not known and the earthquakes felt at a certain locality were taken together for the statistical investigation with regard to their lunar-hourly distribution.

The present investigation was made with the intention of studying the relation between the actual tidal phases and earthquakes, with reference to the numerous groups of the after-shocks which followed the recent destructive earthquakes, i. e. the Great Kwantô Earthquake[3] on Sept. 1, 1923, the Tango Earthquake[4] on March 7, 1927, the Tazima Earthquake[5] on May 23, 1925, and the Ômati Earthquake[6] on Nov. 11, 1918. In most of these cases, the positions of epicentres are approximately known and distributed within definite localities respectively, so that the comparison of the tidal phase in the neighbouring sea with the frequency of occurrence of these earthquakes may have a more definite significance than in the case of earlier investigations.

The materials for earthquakes were taken from the reports above cited, while for the tidal data, the Tide Table published by Naval Hydrographic Department was used.

1) F. Ômori, *Report E. I. C.*, 32 (1900), 54 (1906), etc.
2) K. Honda, *Pub. E. I. C.*, 18 (1904).
3) A. Imamura, *Bull. I. E. I. C.*, 101 (1928).
4) N. Nasu, *Report I. E. I. C.*, 101 (1927).
5) A. Imamura, *Journ. Fac. Sci. T. I. U.*, III (1929), Part 2.
6) F. Ômori, *Report I. E. I. C.*, 94 (1921).

## Method of Investigation.

To determine the tidal phase at the time of an earthquake, the following procedure was taken. The time of the semidiurnal maximum occurring within 6 hours of the shock was taken as the time-origin, and the time of occurrence of the shock was marked along the time axis. The number of the points thus plotted within the successive time interval of an hour each before and after the maximum was counted. In a few cases, about 3 percent in number, the point fell outside the range of $\pm 6$ hours, on account of the irregularity of the interval between the high waters. In these exceptional cases, the time of the earthquakes were counted from the neighbouring low water and plotted referring to $+6$ or $-6$ hours respectively. The number, $n_x$, at the time interval, $x$, was smoothed by taking $\frac{1}{4}(n_{x-1}+2n_x+n_{x+1})$ instead of $n_x$. Next, the value of $n$ divided by the mean value, i. e. $12n/\Sigma n$, which is denoted by $f$, and called the *reduced frequency*, was calculated and plotted as ordinate against the time axis.

For the comparison, the number of shocks, falling within the successive solar time intervals of two hours each, was also counted and similarly treated as before.

## Results and Discussions.

a) The After-shocks of the Great Kwantô Earthquake, and the Tide at Yokosuka.

For convenience's sake, we have taken the tide at Yokosuka for the comparison with the after-shocks of the Kwantô Earthquake.

According to Prof. Imamura's Report, the area of the region including the origins of the after-shocks was divided into the following four different localities :—

A. The area including Sagami Bay and the Province of Sagami as the main part.
B. Bôsô peninsula and the vicinity of its S. E. coast.
C. The drainage district of the River Tone.
D. Tôkyô and its environs.

In our present cases, the shocks originated in these respective areas are named A-, B-, C-, and D-type respectively, and investigated separately.

As to A-type, as the number of after-shocks on the first and second of september was extremely large, the after-shocks were divided into 5 epochs according to the following dates :—Sept. 1, Sept. 2, Sept. 3–6, Sept. 7—11, and Sept. 12–Oct. 1.

As to B- and D-types, they were divided into 3 epochs, Sept. 1–6, Sept. 7–11, and Sept. 12–Oct. 1.

As to C-type, the number of after-shocks were scanty, especially after Sept. 7, so that we were abliged to take only the interval, Sept. 1–6.

The values of the *reduced frequeney, f,* for these different epochs of each type are shown in Fig. 1. The curve (*p*) in Fig. 1 *f* is the curve corresponding to the "principal after-shocks" during the long period of Sept. 1, 1923—Feb. 12, 1928, for which 6 after-shocks immediately after the Great Earthquake on Sept. 1, are counted as 1.

The curves for the solar time distribution are shown in Fig. 2.

The curves showing the number of after-shocks for 4 types during the successive epochs of 4 hours from Sept. 1 to Sept 5, are shown in Fig. 3, from which the transference of the centre of the seismic activity first from the Sagami Bay to Bôsô peninsula and next to Tôkyô District, are clearly recognized.

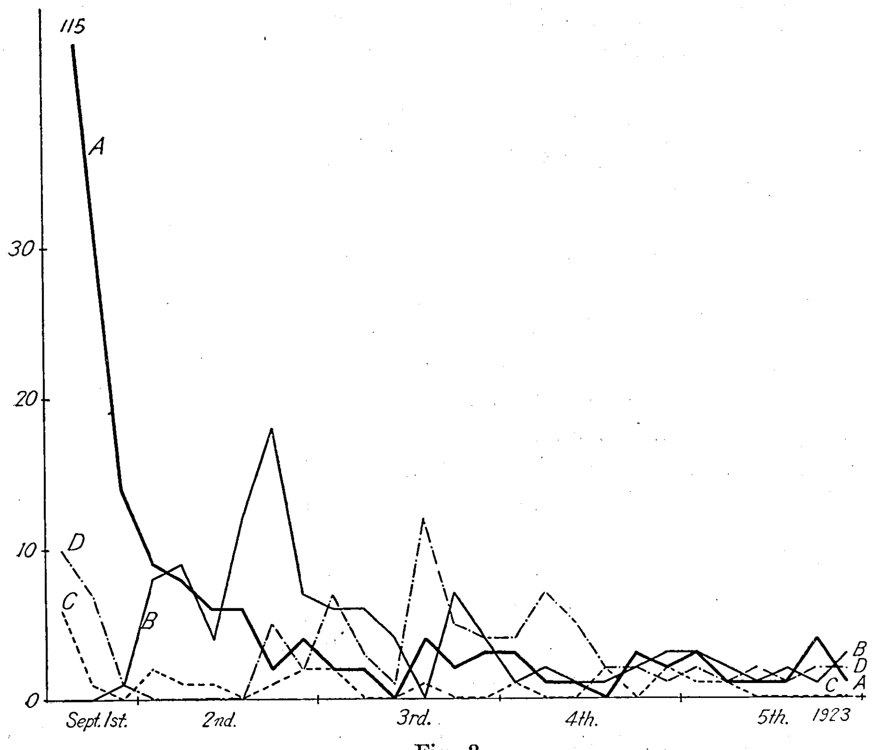


Fig. 3.

For the principal after-shocks during 4 years and 6 months above mentioned, there seems to exist a maximum frequency of occurrence of the shocks before 2 hours of the semidiurnal low water, a secondary maximum before 2 or 3 hours of the high water, and a minimum frequency near the high water.

Looking at Fig. 1, we may be able to remark the following :—

I) For A-type, the frequency of occurrence of the after-shocks, $f$, generally shows a maximum, a little before the low water and also a secondary maximum, is suggested between high water and the next low.

II) For B-type and D-type, which resemble to each other, $f$ is maximum about at the low water, in common with all the other types, and besides, shows another maximum about 2 hours before the high water, as may be seen from the curves for (B+D) and (A+B+D) alike.

This characteristic feature of $f$ may also be seen from the similar curve[7] for the shocks felt within the region of 160 km. from Tôkyô during the period of Jan.—Sept., 1926, so that we may consider this feature as real and proper to the region.

III) For C-type, (Fig. 1*d*) there appear two maxima of $f$, one before the low water, and the other immediately after the high water. The data are, however, too scanty to give a definite conclusion.

In general, it seems that the curves for the successive epochs change their forms with the lapse of time, though preserving some common feature. After a certain epoch, the curves seem to tend to a certain stable form.

It is interesting to see (Fig. 1*d*) that the curve of B-type, also in some measure, D-type shows a trend just opposite to that of A-type in the days of Sept. 1–6, and also that (Fig. 1*a*) the latter approaches to that of the former type, or inland type, afterwards.

The fact that the curves for different independent epochs show generally some common character as revealed in the mean curve of a long duration, may be considered as a proof for the existence of some real physical relation between the frequency of occurrence of shocks and the tidal phase.

The curves for solar time variation are shown in Fig. 2.

First, referring to the lowest curves of Fig. 2*a*, 2*b*, 2*c*, ......, which represent the mean variation for longer duration, we may observe a common semidiurnal wave of sensible amplitude, for all the types taken.

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7) The data for the curve was taken from Prof. Imamura's paper, *Bull. E. R. I.*, (1927). The curve is here omitted.

The curves strongly suggest the relation with the semidiurnal waves of the atmospheric pressure, the maxima of pressure corresponding to the minima of $f$. On the other hand, the fact that the curves for the successive epochs, separated by 6 or 12 days from each other, shows quite different, often inverted, course may be taken as an evidence for the presence of some conspicuous lunar period interfering with the solar one. It is only by taking an average of a longer period that the lunar term is cancelled and the solar semidiurnal wave is revealed.

b) After-shocks of the Tango Earthquake and the Tides at Kôbe and Wazima.

As the tidal amplitude in the Japan Sea is generally very small, it seemed at first probable that it will not much affect the variation of the load on the earth crust near Tango, so that we have tried to take the tide at Kôbe for the comparison. Afterwards, however, the tide at Wazima was also taken for comparison[8]

The after-shocks were firstly divided according to the dates into 15 parts, which are March 7–11, 12–20, 21–31; April 1, April 2–10, 11–20, 21–30, May 1–10, 11–20, 21–31, June 1–30, July 1–31, Aug. 1–31, Sept. 1–Dec. 31, in 1927 and Jan. 1–July 16 in 1928. These are similarly treated as in the case of the Great Kwantô Earthquake and are shown in Fig. 4 for the case of the tides at Wazima and in Fig. 5 for the case of the tides at Kôbe.

Next, the after-shocks, of which the positions of the epicentres are identified, are divided into 3 parts, namely, (1) those situated beneath the sea bed, (2) those on the northern side and, (3) those on the southern side of Yamada Fault.

The latter two parts were moreover divided into 4 or 5 parts according to the dates respectively, and compared with the tidal phase at Wazima, as shown in Fig. 6.

The frequency of the after-shocks plotted against the solar time, are shown in Fig. 7.

Individual curves shown in Fig. 4 and Fig. 5 are rather irregular and do not give any definite conclusion, except the invariable maximum

8) Mr. C. Tsuboi, who made a similar study of the Tango Earthquake referred to the tidal phase at Wazima, found the good correlation and informed me of his result. The comparison with Wàzima tides was then made in the similar manner as for Kôbe tides. I am obliged to him for his kind information.

of $f$ near the low water. The irregularity is, however, less in Fig. 4 than in Fig. 5. In Fig. 4, the individual curves show features more or less common to each other and to the lowest sum-curve. This will show that the earthquakes in this district is in some degree affected by the tides on the Japan Sea side. Fig. 5 is quite irregular if we compare the successive curves.

The sum-curve at the bottom of the figure, however, harmonizes very well with that of Fig. 4, if we take into account the difference of the tidal phase between Wazima and Kôbe amounting to about 5 hours on an average. In the latter station, the tidal waves are observed in irregular forms and this fact may also contribute to the irregularity of the curves in Fig. 5. At present stage, therefore, it is difficult to decide whether the Tango earthquakes are chiefly governed by the tides on the Japan Sea side.

On the other hand, it is very interesting to remark that the sum-curve of Fig. 4 shows some infallible resemblance to that of Fig. *1a*, *1b*··· etc. especially as regard to the maximum at the low tide and the minimum just preceding it.

From Fig. *6b*, we may be able to say the followings :—

i) The after-shocks occurred in the sea bed has its maximum frequency at about one hour and a half respectively before and after the high water.

ii) The shocks on the northern side of Yamada Fault has its great maximum of $f$ at about low water and the secondary at about high water.

iii) It is interesting to see that $f$ of the shocks in sea bed shows entirely opposite course compared with that of the northern side of Yamada Fault.

These result may suggest some essential difference in the mechanism of earthquakes for the two sides of Yamada Fault.

Examining the curves of Fig. 4, we may remark that the curves for March 7–11, 21–31, and April 1 show markedly different form compared with the others. Severe earthquakes occured on March 7 and April 1. We may suggest that some change of curve form might take place immediately after and before the great shock, and then the form gradually settle down to the normal form as is represented by the curve of total sum above mentioned.

From the lowest sum-curve of Fig. 7, which shows the average solar time distribution of $f$, we can see clearly that the frequency of shocks is maximum at about 8 o'clock and 23 o'clock of the solar time and it is minimum at about 3 and 18 o'clock. Comparing this with the corresponding curves in Fig. 2, we may notice that the curves for Kwantô and Tango are nearly reversed upside down. This suggests that the effect of the atmospheric semidiurnal waves is opposite on the two regions, one on the Pacific side and the other on the Japan Sea side.

c) The After-shocks of the Tazima Earthquake and the Tides at Wazima and Kôbe.

The after-shocks of the Tazima Earthquake of May 23, 1925, were treated similarly as in the case of the Tango Eorthquake and the results are shown in Fig. 8, for the tidal phase and in Fig. 9 for the solar time distribution.

From the curve (lowest in Fig. 8*a*) of the total sum for the tide at Wazima, we may be able to say that the frequency of occurence of shocks has its great maximum value at about the low water and also its small maximum value at about high water, while in the case of comparison with the tide at Kôbe (Fig. 8b), we see one more maximum of $f$.

From the curve (lowest Fig. 9) of the total sum for the solar time distribution, we can notice the maxima of $f$ at about 8 and 23 o'clock, and minima of $f$ at about 3 and 19 o'clock. This character of the curve is almost similar as in the case (Fig. 7 lowest curve) of Tango earthquakes. Another maximum of $f$ may be seen at about 15 o'clock.

d) The After-shocks of the Ômati Earthquake and the Tides at Wazima and Yokosuka.

The after-shocks of Ômati Earthquake on Nov. 11, 1918, are similarly treated as in the preceding cases, and are shown in Fig. 10 and Fig. 11.

From the resultant curve (Fig. 10*a*, lowest) for the tide at Wazima, we can see the greatest maximum value of $f$ at about low water as usual and the smaller secondary maximum of $f$ at about 2 hours after the high water. As for the curve (Fig. 10*b*, lowest) for the tide of Yokosuka, we see maximum values of $f$ at about the low water and at about 1.5 hours before and after the high water.

The amplitude of the sum-frequency curve for the tide at Yokosuka is only one thirds of that for the tide at Wazima, which may clearly show that the tide at Wazima affects the occurrence of shocks more than the tide at Yokosuka. This result seems quite reasonable if we consider that Ômati is situated much nearer to Japan Sea than to the Pacific and the mechanical linkage with the Japan Sea Coast is more direct than with the Pacific Coast.

Looking at Fig. 11 for the solar time distribution, we must admit that the solar effect on the occurence of shocks is exceptionally large in the case of Ômati, being of the same order as in the case of the tide at Wazima. We see here the maximum values of $f$ at about 9 and 18 o'clock and the minimum values at about 3 and 13 o'clock.

As shown in the above different cases the frequency curves of the after-shocks for the successive epochs separated from each other by several days or a little more than 10 days, do not show sufficient parallelisms. The sum-curve for a long duration of time show some feasures which seems to be real and physically significant.

One characteristic feature which is common to all the cases above mentioned is that the frequency of occurrence of the after-shocks is maximum at, or a little before the low water as shown in Fig. 12.

The secondary maximum appears before the high water in the case of Kwantô curve, whereas it is found a little after the high water for the cases of Tango, Tazima and Ômati curves, each referred to Wazima tides. Another feature worthy of notice is that a third maximum appear in the cases of Tango, Tazima and Ômati, when referred to the tides on the Pacific side.

Again, as to the $f$-curves referred to the solar time we may remark the following points, referring to Fig. 13: (i) Semidiurnal waves are suggested in all cases which are probably related with the daily variation of the atmospheric pressure. (ii) Kwantô curve is generally opposite to Tango and Tazima curves. (iii) Tango and Tazima curves are nearly parallel to each other. (iv) Ômati curve in A. M. is parallel to, but in P. M. opposite to Tango-Tazima curves.

Theoretical discussions of these results will be reserved for a future.

In conclusion, I wish to express my best thanks to Prof. T. Terada under whose supervision the entire work has been carried out and who has given me many useful suggestions throughout the course of my investigation.

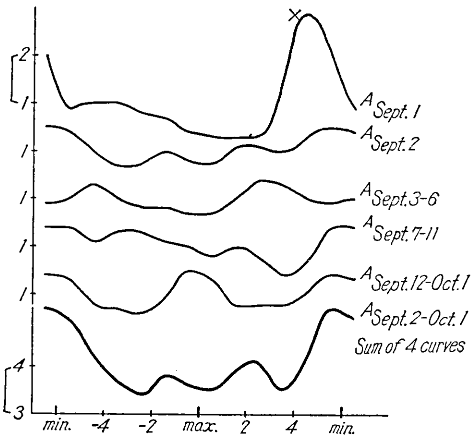


Fig. 1*a*. Frequency Curves of After-shocks of the Great Kwantô Earthquake, referred to the Tides at Yokosuka. A-Type.

× Marks the time, at which phase the Great Earthquake occurred.

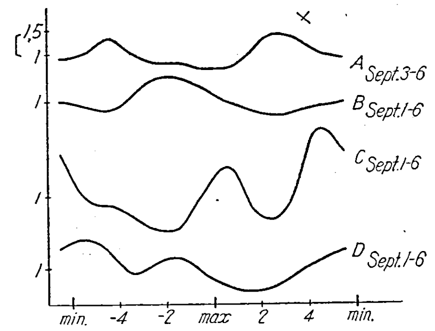


Fig. 1*d*. Comparison of 4-Types.

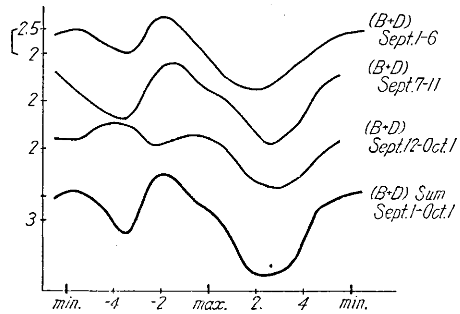


Fig.*e* 1. Sum B+D.

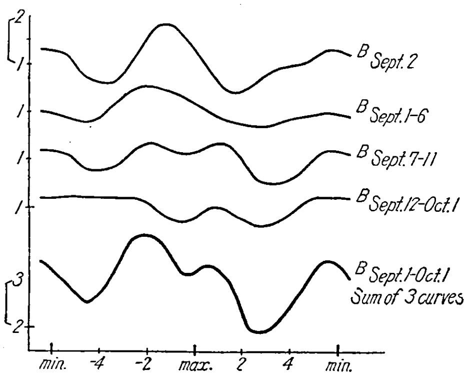


Fig. 1*b*. Do. B-Type.

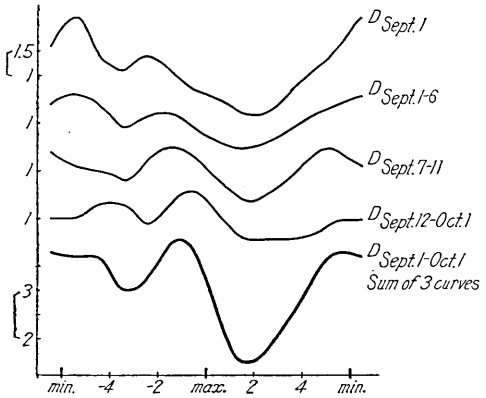


Fig. 1*c*. Do. D-Type.

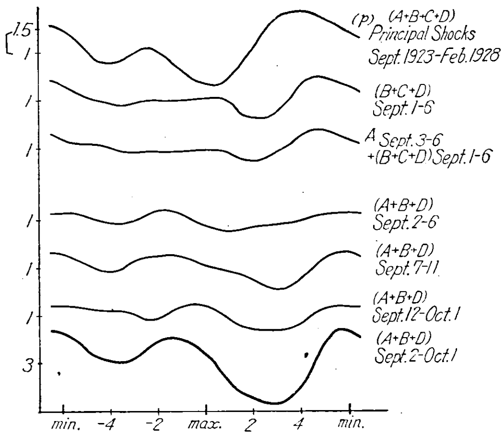


Fig. 1*f*. Sum of different Types.

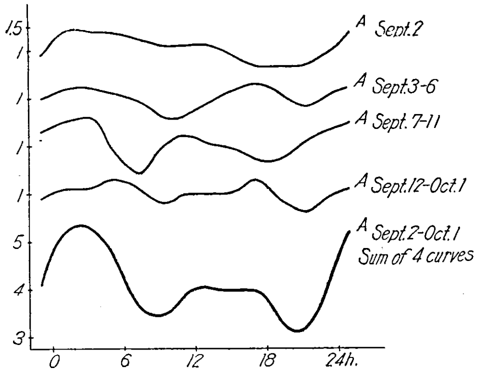


Fig. 2*a*. After-shocks of the Great Kwantô Earthquake referred to Solar Time.
A-Type.

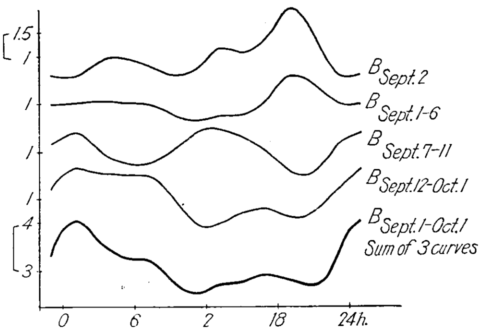


Fig. 2*b*. Do. B-Type.

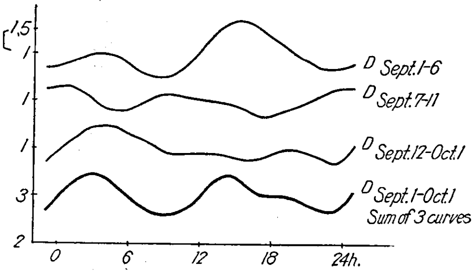


Fig. 2*c*. Do. D-Type.

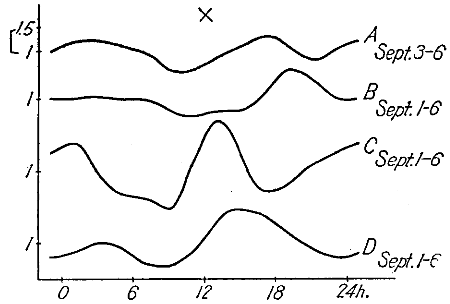


Fig. 2*d*. Do. Comparison of 4 Types.

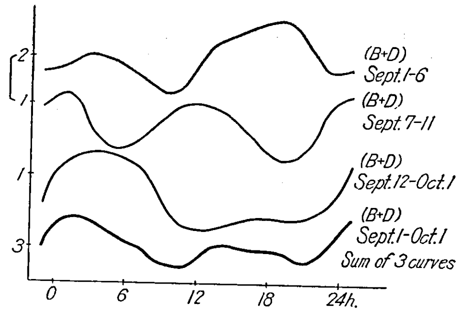


Fig. 2*e*. Sum B + D.

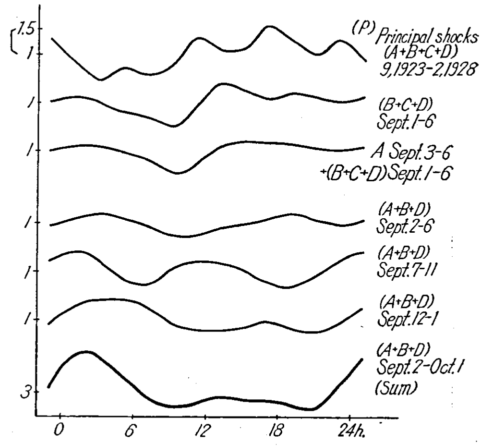


Fig. 2*f*. Do. Sum of different Types.

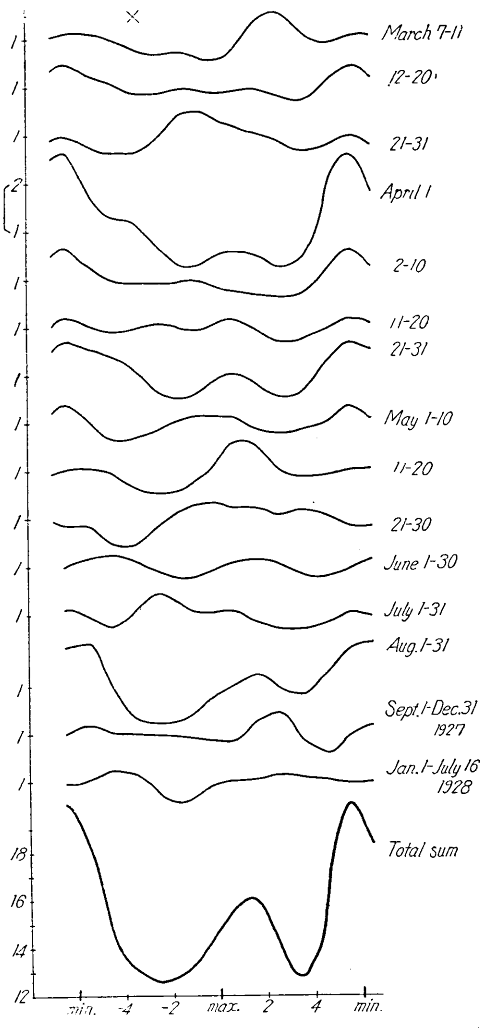


Fig. 4. After-shocks of the Tango Earthquake, referred to Tides at Wazima, 1927 & 1928.
× Marks the time, at which phase the Great Earthquake occurred.

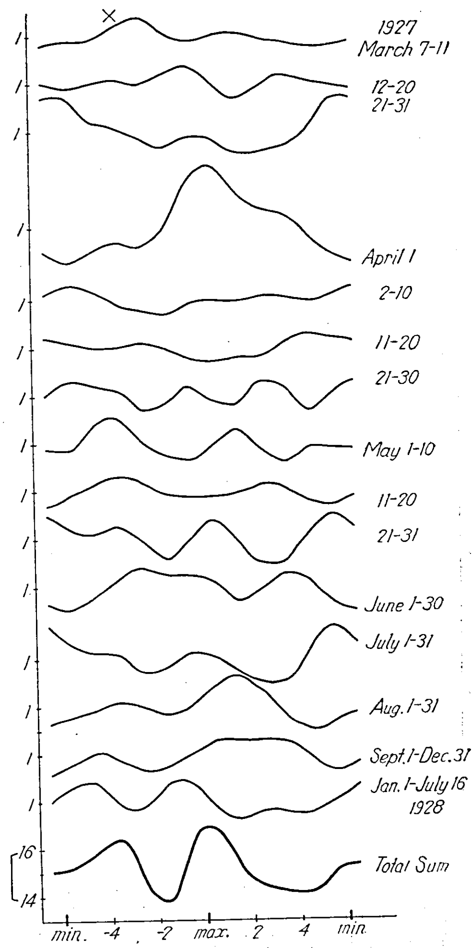


Fig. 5. After-shocks of the Tango Earthquake, referred to Tides at Kôbe, 1927 & 1928.

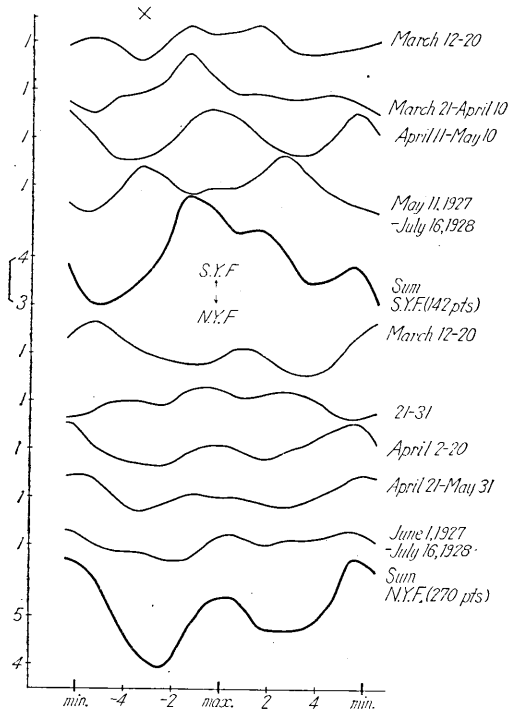


Fig. 6*a*. After-shocks of the Tango Earthquake, referred to Tides at Wazima, March 11, 1927—July 16, 1928. S. Y. F. means South Side of Yamada Fault, and N. Y. F., North Side.

× Marks the time, at which phase the Great Earthquake occurred.

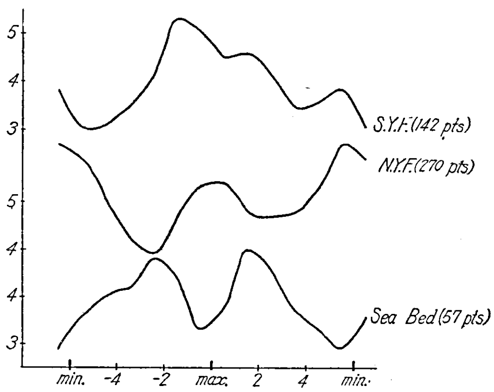


Fig. 6*b*. Comparison of 3 Types.

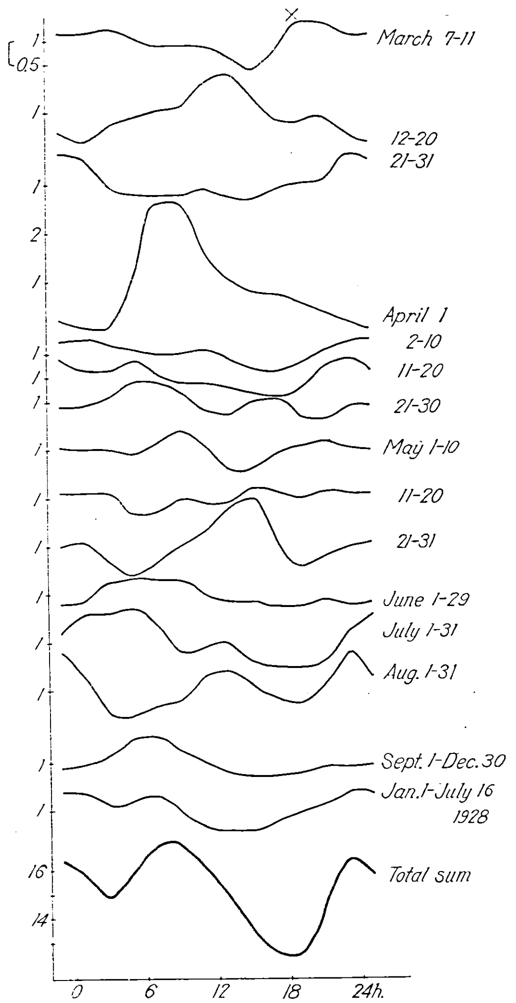


Fig. 7. After-shocks of the Tango Earthquake referred to Solar Time.

× Marks the time, at which phase the Great Earthquake occurred.

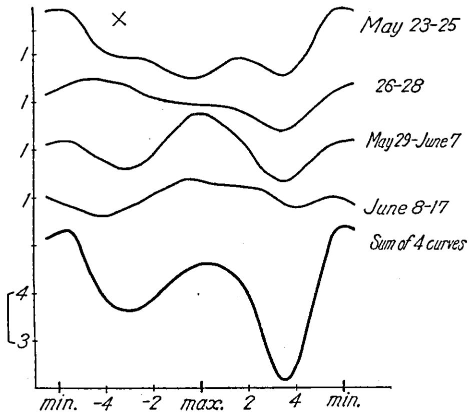


Fig. 8*a*. After-shocks of the Tazima Earthquake, 1925, referred to Tides at Wazima.

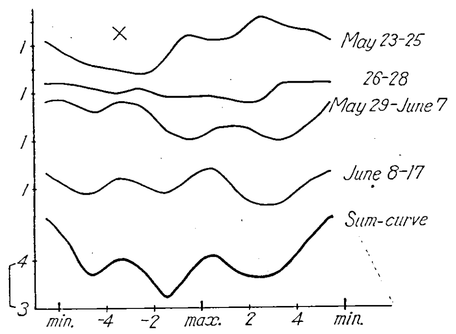


Fig. 8*b*. Tazima Earthquake, 1926, referred to Tides at Kôbe.

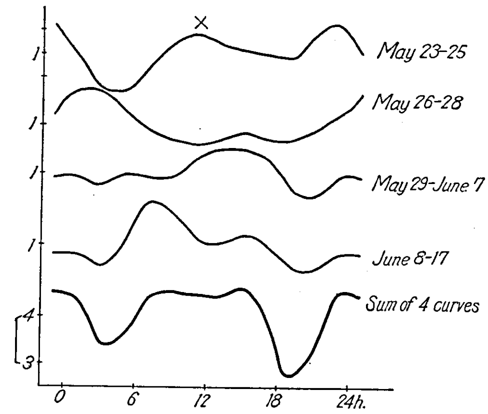


Fig. 9. Tazima Earthquake, 1925, referred to Solar Time.

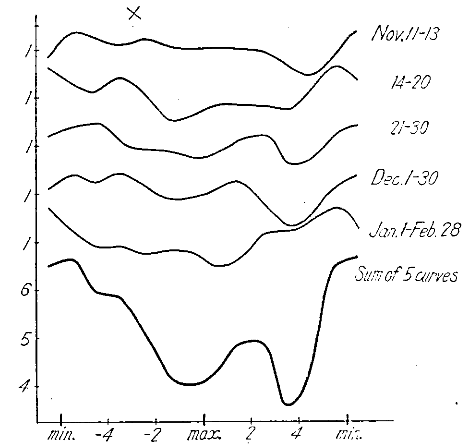


Fig. 10*a*. After-shocks of the Ômati Earthquake 1918 & 1919, referred to Tides at Wazima.

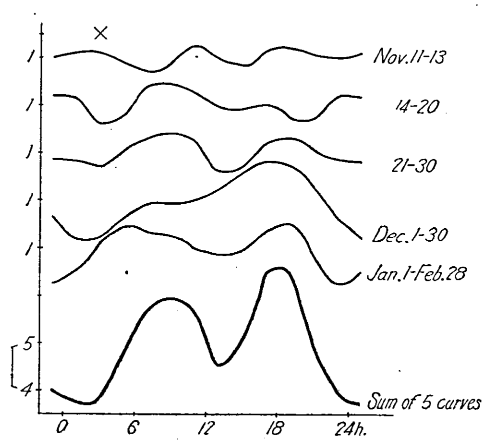


Fig. 11. After-shocks of the Ômati Earthquake 1918 & 1919, referred to Solar Time.

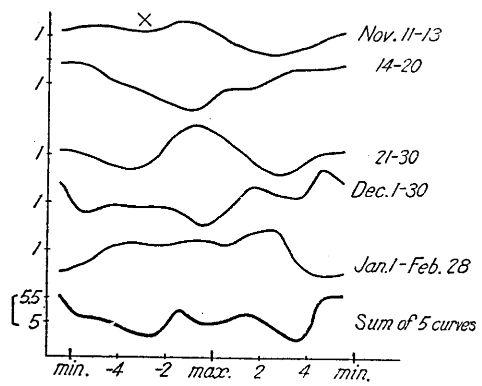


Fig. 10*b*. Ômati Earthquake, 1918, referred to Tides at Yokosuka.

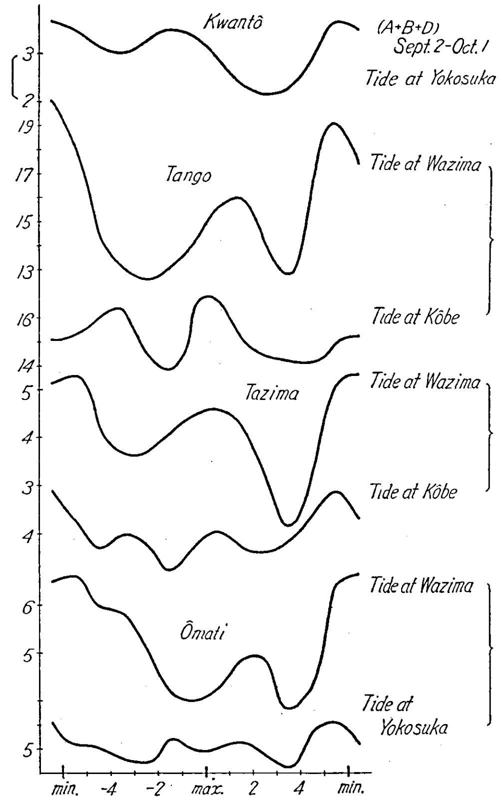


Fig. 12. Comparison of 4 Districts: Tidal Phase.

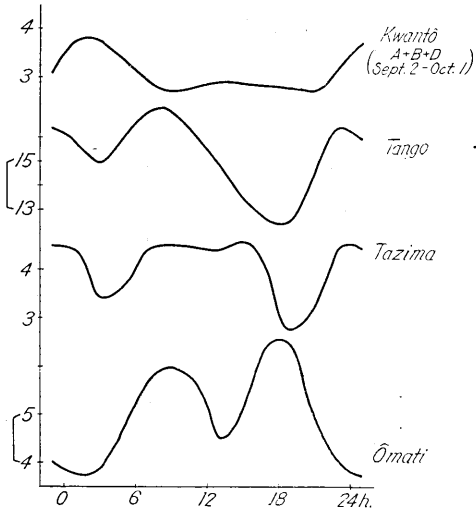


Fig. 13. Comparison of 4 Districts: Solar Time Distribution.

## 19. 地震と潮汐との關係

山口生知

地震と潮汐との關係に就ては故大森博士や、本多光太郎博士其他の人々に依つて既に研究されてゐる。併し之等の多くの場合は震源の位置が判明しないので或る地方に感じた地震を一纏めとして研究された。

それ故に我々は震源の位置の知れて居る最近に起つた左の四つの大地震の餘震に就いて其の附近の海の潮汐と比較研究した。即ち第一は大正十二年九月一日に起つた關東の大地震、第二は昭和二年三月七日に起つた丹後の地震、第三は大正十四年五月二十三日に起つた但馬の地震、第四は大正七年十一月十一日に起つた大町の地震とそれぞれ其の附近の潮汐との關係を調べたのである。

其の調べ方は高潮時を時間の起點として其の前後潮汐の如何なる位相の處に餘震の時刻が分布されて居るかを調べて見た。其の結果四箇所共いづれの地方にも共通に低潮時（寧ろ少しく其の前）に於て餘震が最も多く起つて居ると云ふ著しい性質があり又關東の場合には高潮時の前に於て、丹後、但馬、大町の場合に於ては高潮時の少しく後に於て餘震の回數の第二の最大があると云ふこと、それからも一つ注意に價することは丹後、但馬、大町の場合に於て太平洋岸の潮汐に對し餘震の回數の第三の最大が存在すると云ふことである。

又も一つ面白いと思ふ結果は丹後の地震に就いて第六圖bに示す通り海底に起つた餘震と山田斷層の北部に起つた餘震とは潮汐の位相に對して反對の關係にあるが山田斷層の南部に起つた餘震と海底の餘震とは潮汐に對して寧ろ類似の關係にあると云ふことである。此の結果は山田斷層の南北兩地方の地震の機巧に就いて根本的の差異のあることを暗示するものと思はれる。

又別に參考の爲め太陽時に對する餘震の分布をも調べて見たところ其の結果として第十三圖に示す通り四箇所共いづれの地方にも共通に地震に及ぼす大氣壓の影響と思はるゝ半日の週期の餘震回數の波が表はれて居る。併して丹後、但馬の波はお互に殆ど並行にして關東の波は一般に丹後但馬と反對であり大町の波は午前中は丹後、但馬の波と並行であるが午後は反對になつてゐると云ふ結論に到達したのである。

以上地震に及ぼす潮汐の影響並に大氣壓の影響に關する理論的の論議は將來の研究に委ねたいと思ふ。