# *11. Microseisms of Four Seconds Period observed with Horizontal Seismographs.*

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**1.** The microseisms at Hongô in Tôkyô, were classified by F. Omori[1] into three types, $q$, $Q_1$ and $Q_2$ according to periods of oscillations. The characteristics of these types were stated by Dr. T. Matuzawa[2] as follows: period and mode of $q$-type are 2∼3 sec. and regular, those of $Q_1$-type about 4 sec. and fairly regular, and those of $Q_2$-type are 6∼9 sec. and irregular. The connexion between microseisms and meteorological conditions has been investigated in many researches to explain how these oscillations are caused.

To obtain a further knowledge of the microseisms the present writer studied the amplitude and the period of $Q_1$-type oscillations with a harmonic analyser, and then the phase relation of microseisms observed at several places in a small area.

## Harmonic analysis of microseisms.

**2.** A portion of the record of microseisms at about 17 h. on March 14, 1934 (see Fig. 1) obtained with N–S component of an Imamura Portable Seismograph was studied by a Noguchi Harmonic Analyser[3]. The time interval of the analysed portion was 56·3 sec. In theory the figure of the analysed curve must be repeated equally in other intervals. In this analysis the above condition would be nearly satisfied, for the interval was at the middle portion of the total duration of the microseismic oscillations which continued almost stationary for several hours. The portion of the seismogram was enlarged photographically 10·8 times on a sheet of paper to fit for the use of the analyser. The static magnification of the seismograph was 50, so the final magnification of the record became 540 and the interval was 754 mm. long on the paper. The curve in Fig. 2 shows the record on a reduced scale of the actual.

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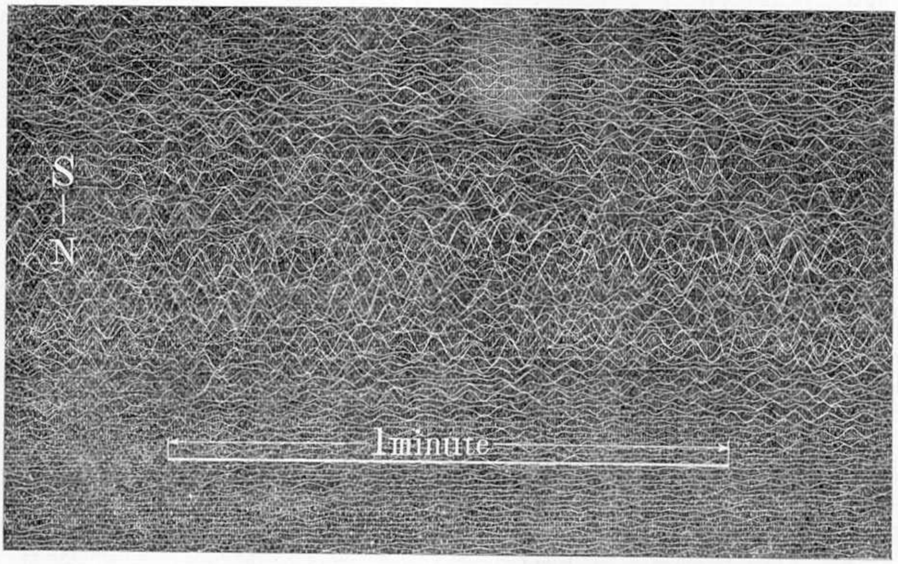
1) F. OMORI, *Bull. Imp. Earthq. Inv. Comm.*, **3** (1909), 1∼35.
2) T. MATUZAWA, *Journ. Fac. Sci. Imp. Univ. Tokyo.*, [ii], **2** (1927), 205∼263.
3) K. NOGUCHI, *Journ. Soc. Mech. Eng.*, **27** (1924), 975∼984.




(*Full size the actual.*)

Fig. 1. Portion of record of microseisms. March 14, 1934. Imamura Portable Seismograph. (The recording drum was driven at a speed of one revolution ten minutes.)

Fig. 2. Analysed portion of record of microseisms. March 14, 1934.

The record was expressed as a function of time $t$ in the form

$$f(t)=c_0+\sum_{n=1}^{\infty} c_n \sin(nt+\phi_n),$$

where $n$ represents the order of harmonics, and magnitudes $c_n$, $\phi_n$ which denote amplitude and phase angle of the $n$-th harmonic were obtained. The results are shown in the following table.

Table I. Constants of Harmonics.

$T_n$: the period of the oscillation of the $n$-th order in seconds.

| $n$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $T_n$ | — | 56·3 | 28·2 | 18·7 | 14·1 | 11·2 | 9·38 |
| $c_n$ | 5·74 | 2·95 | 1·30 | 1·99 | 0·98 | 1·89 | 0·42 |
| $\phi_n$ | — | 113° 20′ | 80° 10′ | 134° 30′ | 126° 00′ | 55° 10′ | 335° 00′ |

(*to be continued.*)

Table I. (*continued.*)

| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| 8·05 | 7·04 | 6·26 | 5·63 | 5·11 | 4·69 | 4·33 |
| 1·59 | 0·69 | 2·92 | 7·68 | 9·81 | 26·30 | 36·21 |
| 76° 50′ | 347° 30′ | 149° 40′ | 39° 25′ | 39° 50′ | 23° 00′ | 78° 40′ |

| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|
| 4·02 | 3·76 | 3·52 | 3·31 | 3·13 | 2·96 | 2·82 |
| 30·09 | 33·63 | 11·25 | 10·70 | 10·54 | 3·79 | 0·84 |
| 284° 10′ | 249° 40′ | 268° 35′ | 355° 20′ | 65° 00′ | 131° 50′ | 113° 50′ |

| 21 | 22 | 23 | .... | 30 |
|---|---|---|---|---|
| 2·68 | 2·56 | 2·44 | .... | 1·88 |
| 1·72 | 2·35 | 0·99 | .... | 0·74 |
| 206° 05′ | 61° 00′ | 308° 00′ | .... | 238° 50′ |

The cases of $n>24$ are skipped in the results, but the case of $n=30$ was measured for the causion's sake.

**3.** The first maximum of the amplitude $c_n$ lay at $n=15$ and the second $n=13$, corresponding to 3·8 and 4·3 sec. of the periods of oscillations respectively. The harmonic constants of lower orders might be affected by taking the interval of the analysis erroneously. So the writer will discuss hereafter about the harmonics of the order higher than 10. Furthermore the effects of the free period of seismograph or the resonance effect upon the results must be considered, for the period was similar to the periods of the oscillations discussed here. In order to eliminate the resonance effect, the amplitudes of harmonics were reduced by dynamic magnification of the seismograph.

The constants of the instrument at the time of the recording were as follows: the mass of the pendulum-bob $M=7$ kg., the static magnification $V=50$, the period $T_0=6{\cdot}0$ sec., and the damping ratio $v=1{\cdot}26$. The above amplitudes as measured from the record were converted into harmonic earth movements $A_n$ by the well-known formula,

$$A_n=\frac{c_n}{\mathfrak{V}},$$

where $\mathfrak{V}$ denotes the dynamic magnification of the seismograph, or

$$\mathfrak{V}=\frac{V}{\sqrt{\{1-(T_n/T_0)^2\}^2+4\dfrac{0{\cdot}538\,(\log_{10} v)^2}{1+0{\cdot}538\,(\log_{10} v)^2}(T_n/T_0)^2}},$$

and $T_n$ the period of oscillation of the $n$-th harmonic.

The relationship between the corrected amplitudes and the periods is shown in Fig. 3.

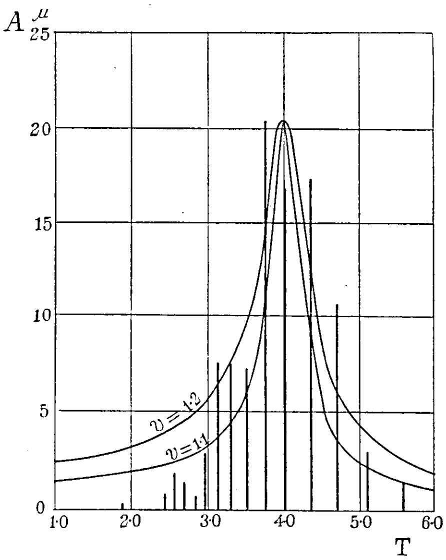



Fig. 3. Amplitudes of harmonics.

**Frequency-distributions of periods of microseisms.**

**4.** The most investigators have determined the period of microseisms by frequency-distribution of different periods. So the writer also measured the number of observations of periods on the record shown in Fig. 1, and determined the period of microseisms to compare it with that which has been obtained from the same record by the harmonic analysis. The number of observations of different periods counted in a short interval may be affected with the length of periods, in other words the number of observations of longer periods are less than those of shorter periods in a definite interval. Then to reduce the effects of period, the frequencies were corrected by the following formula,

$$f_n = f'_n \frac{T_n}{T},$$

where $T$ denotes the period of a harmonic of which number of observations was regarded as a standard frequency, $f_n$ the relative frequency of the $n$-th harmonic to the standard period, and $f'_n$, $T_n$ frequency and period of the $n$-th harmonic. The distribution of the corrected frequencies is shown in Fig. 4. The diagram resembles to that in Fig. 3. Therefore the period of microseisms may be obtained by either harmonic analysis or frequency-distribution of periods. Yet there was a doubt about the frequencies

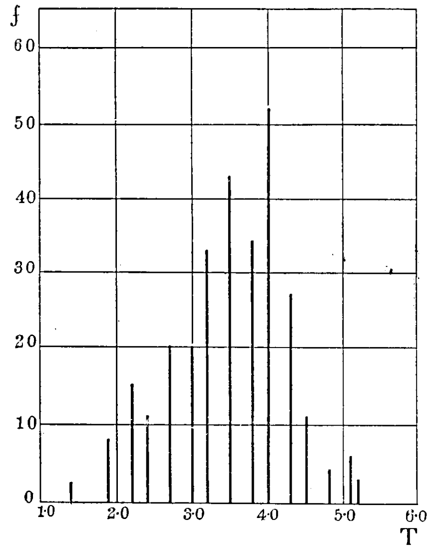



Fig. 4. Frequency-distribution of periods. Imamura Portable Seismograph.

that those would be affected with the resonance effect of the seismograph. Then the writer measured the frequency-distribution of periods on the seismogram recorded at the same time with a different type of seismograph, the period of which was longer. The instrument used for that purpose was an Omori Horizontal Pendulum Seismograph. Its instrumental constants were as follows: $M=60$ kg., $V=120$, $T_0=20{\cdot}3$ sec., and $v=1{\cdot}76$. (A portion of the seismogram is shown in Fig. 5.) The relative frequencies in this case are shown in Fig. 6. It might be proved that the frequency-distribution of periods was not affected with the resonance effect, for the distribution in Fig. 6 was not so different from that in Fig. 4.

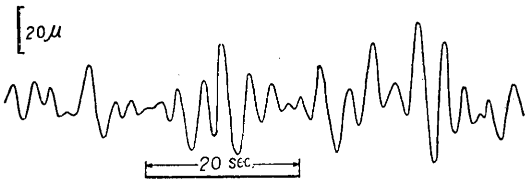



Fig. 5. Portion of record of microseisms. March 14, 1934. Omori Horizontal Pendulum Seismograph.

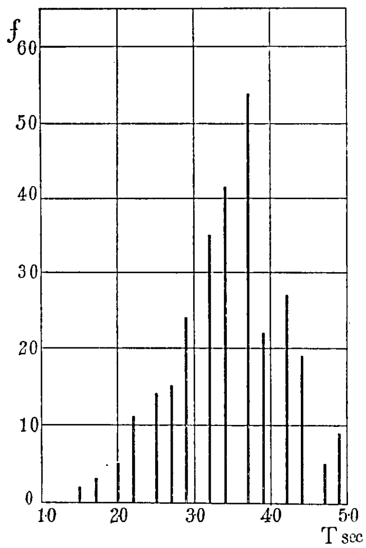



Fig. 6. Frequency-distribution of periods. Omori Horizontal Pendulum Seismograph.

**5.** The peak of the diagrams in Figs. 3, 4 and 5 obtained by three different methods coincided at the period of about 4 sec. But periods longer than 4 sec. are predominant in the case of the harmonic analysis, and contrary in the case of the frequency-distribution.

**6.** The amplitude of earth movements might be obtained by dividing the observed amplitude by the dynamic magnification of the seismograph. For instance the maximum double magnitude recorded with Imamura Seismograph was about $160\mu$ and that with the Omori Seismograph was about $80\mu$, and the corrected magnitudes by the dynamic magnification were equal in both cases at about $80\mu$. Then it was ascertained that though the constants of the seismographs were different, the true amplitude might be obtained by the reduction.

**7.** The writer considered hypothetically that the microseisms are a kind of free oscillations of the ground caused by many disturbances of different periods but equal amplitudes, and the amplitude-period diagram in Fig. 3 was considered to suggest a resonance effect of the self-oscillation of the ground. Though the assumption of equal amplitude be not true, it might be not irrational to consider that microseisms are caused by a number of disturbances as F. Omori[4] and Dr. T. Matuzawa[5] have stated. The idea of the experiment carried out by Professors T. Terada and U. Nakaya[6] would be also similar to the above hypothesis, for in their experiment a physical pendulum was subjected to irregular succession of impacts, magnitudes of which were nearly equal.

Assuming the free period of the ground was 4 sec., the damping ratio $v$ which fits the diagram was obtained. The values obtained lay between 1·07 and 1·22, so to make the calculation simple take $v=1{\cdot}1$ and 1·2, and the resonance curves were drawn on the diagram in Fig. 3. The relaxation times correspond to the above values of $v$ are 48·3 and 25·3 sec. respectively. Then if the hypothesis is true, the free oscillations of the ground will die out in a minute.

8. The microseisms in Fig. 2 are like beats of two harmonic oscillations. Assuming beats, periods and maximum double amplitudes of the component oscillations were calculated. The obtained values were $T_1=3{\cdot}8$, $T_2=4{\cdot}3$ in sec., $2A_1$ (max.)$=16{\cdot}6\mu$ and $2A_2$(max.)$=14{\cdot}6\mu$ and the damping ratios equal in both cases as $v=1{\cdot}1$. The combined amplitudes of the two oscillations as shown in Fig. 7.

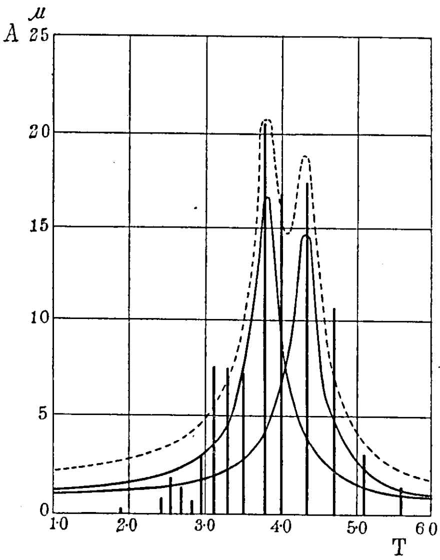


Fig. 7. Resonance curves. Dotted line shows sum of amplitudes in full lines.

## Identification of phases of microseisms at several places.

9. F. Omori compared records of microseisms observed at Hongô and Hitotubasi in Tôkyô, about 4 km. distant with each other, and studied the phase relation of microseisms at the two places. But he could not identify corresponding phases of oscillations. From January to March in 1927, Mr. Nasu[8] and the writer set temporarily three horizontal pendulum seismographs at three places near the Seismological

4) F. Omori, *Bull. Imp. Earthq. Inv. Comm.*, 5 (1911), 137.

5) T. Matuzawa, *loc. cit.*, 263.

6) T. Terada and U. Nakaya, *Bull. Earthq. Res. Inst.*, 5 (1928), 93~110.

7) F. Omori, *Bull. Imp. Earthq. Inv. Comm.*, 3 (1909), 119~117.

8) Mr. N. Nasu measured velocities of seismic waves caused by falling heavy masses from records at the four stations. N. Nasu, *Disin (Earthquake)*, 1 (1929), 355~364, and *Jap. Journ. Astron. Geophys. Abstracts.*, 11 (1934), 48~49.

Institute of the University to study the phase relation of microseisms at different places. The positions of the temporary stations are shown in Fig. 8. The station A was in the compound of the First Higher School, B in the Seismological Institute, and C and D in the compound of the Hospital of the University. All these stations are on tertiary loam, and the distances between these stations are shown in the following table.

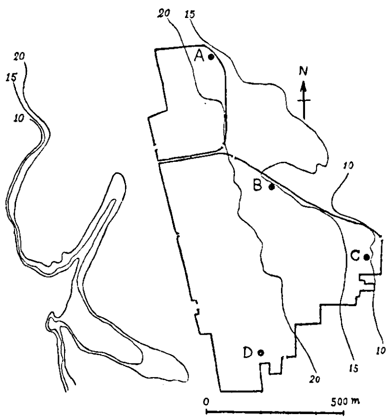



Fig. 8. Positions of stations.

Table II. Distances between Stations. (m.)

| | A | B | C |
|---|---|---|---|
| B | 520 | — | 920 |
| C | 920 | 430 | — |
| D | 1090 | 610 | 520 |

Four seismographs of the same type were not available for the observation. At the stations A and B the Imamura Horizontal Pendulum Seismographs of N-S component were set, and at C and D the Omori Horizontal Pendulum Seismographs of the same component. The constants of the two types of seismograph were nearly similar as shown in Table III.

Table III. Constants of Seismographs.

| Station | Instrument | $M$ | $V$ | $T_0$ | $v$ | Speed of drum |
|---|---|---|---|---|---|---|
| A and B | Imamura horiz. pend. seismograph | 35 kg. | 120 | 12·0 s. | 2·4 | 60 mm./min. |
| C and D | Omori horiz. pend. seismograph | 40 | 120 | 20·0 | 1·8 | 25 |

The time marks were put on the seismograms simultaneously at every minutes with electric current of a circuit which was closed by a chronometer being used in the Institute.

The records of microseisms were in tangle as shown in Fig. 1, and it was very hard to find corresponding minute marks on records. So the comparison of records of four stations was drawn only in several cases. The corresponding phases of microseisms with period about 4 sec. could be identified at the four stations as shown in Fig. 9. The ratios of mean amplitudes for 1 min. at the stations A, B, C and D reduced by static magnification were 1 : 1·3 : 1·4 : 1·3. But there is no similarity among the records of microseisms with period shorter than

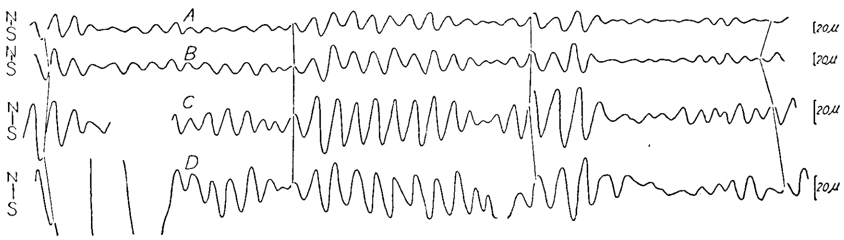



Fig. 9. Comparison of records of microseisms $Q_1$-type, Feb. 26–27, 1927. Thin lines indicate minute-marks at the same time. The records C and D are enlarged about twice to render time scale comparable.

4 sec. written at the four places for several minutes before the earthquake occurred at 18 h. 05 m. on Feb. 25, 1927 (Fig. 10).

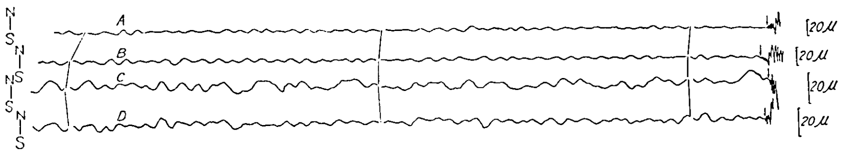



Fig 10. Comparison of records of microseisms of $q$-type. Arrows indicate the arrival time of the earthquake, $18^h\ 05^m\ 17{\cdot}9^s$ on Feb. 25, 1927.

**10.** After several weeks the three seismographs were removed to other places. Two of them were set at about 1500 m. S. of the Institute on northern and southern banks of a deep canal called Otyanomidu, and another was set at Hitotubasi where F. Omori had observed microseisms as mentioned before. But corresponding phases were not identified in this case.

**11.** The writer also in 1927 compared records of microseisms at two places in Kamakura about 50 km. S.S.W. of Tôkyô[9]. One of the two stations was on the ground of tertiary the other of alluvium, and the distance between them was about 1800 m. In this case also corresponding phases were not identified and it was found that periods of microseisms at the two places were different: at the former 4·0 and 2·1 sec. and at the latter about 3·4 sec.

## Conclusion.

**12.** According to the above results, the writer considers that microseisms at Hongô with period about 4 sec. are a kind of free oscillations of a land-block which bounded by vertical planes of discontinuity. And the variation of amplitude like beats may be due to oscillations of different periods of the block in two modes.

But the observations are not sufficient to yield definite results, for

9) The result of the observation is not yet published.

they were obtained from records of N–S component only. So the writer intends to observe microseisms further with seismographs of three components at more places closely distributed. For such purposes the free period of seismographs may be 20∼30 sec., and the speed of the recording drums must be made faster. Moreover time marks may be more sharply put on record by wireless time signals sent from the Astronomical Observatory to enable identification of phases more accurate. Lastly the writer wishes that similar observations are carried out at many places, and furnish an explanation of the microseisms.

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## 11. 水平動地震計によつて觀測された週期４秒の脈動

地震學教室　岸　上　冬　彦

東京本鄉に於いて記錄された $Q_1$ 型と大森博士に名付けられた週期約４秒の脈動を調べた.

第一に今村式簡單微動計の南北動の記象の一部（第２圖）を野口式調和分析器によつて分析した. その結果, 振動週期 3·8 秒と 4·3 秒に當るものの振幅が大きかつた(第３圖). 今迄には脈動の週期は, 色々の週期の觀測される回數の頻度分布から求められてゐたので, 比較の爲その方法を同じ記象紙について用ひた(第４圖). 此の地震計の週期は約６秒で脈動の週期が４秒であるから記象に共鳴の影響が入つてゐる恐れがあるので, 此の心配が理論上ない樣に週期の長い大森式地震計の記象で前の測定と殆ど同時刻の部分をとつて頻度分布を調べた(第６圖). 其の結果でも週期約４秒の所に頻度の極大が現はれた. 要するに方法を變へても得られた週期は等しかつた.

振幅と週期の關係を示す圖は共鳴曲線に似てゐるので, 地面が一つの４秒週期の振動體と假定し外から一樣な振幅で色々な週期の振動が與へられて地面が自己振動を起したものとしてその減衰率を求めて見た. その値は 1·1∼1·2 位になつた.

第二に昭和２年に第一高等學校の運動場の北隅（第８圖の A), 大學病院の小兒科の裏 (C) と外來患者診療所の南側 (D)との３個所に３個の 120 倍の水平振子地震計を臨時に据え, 地震學教室 (B) にある同樣の器械と合計４個所に同一の時計から１分每に合圖を送つて脈動の位相の比較觀測をした. 約４秒週期の脈動では同位相の振動が見出せた(第９圖)が, 短い週期のものでは判らなかつた(第 10 圖). 次にお茶の水の南北兩岸と一つ橋とに地震計を移して教室と記象の比較をしたが, 此の場合には位相の對應は出來なかつた.

以上の事實から初めの４個所は１個の地塊の上にあつて, ４ 秒週期の脈動はその地塊が自己振動を起すことによつて生ずると考へた.

以上は南北動のみの觀測の結果であるが, 今後東西動と上下動も含めた十分な觀測をして見たい. 終りに將來の脈動觀測に關する二三の計畫を記した.

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