14. *Measurement of the Micro-tremor. I.*

By Kiyoshi KANAI, Teiji TANAKA
and Kaio OSADA,

Earthquake Research Institute.
(Read Jan. 26, 1954 and March 23, 1954.—Received March 31, 1954.)

1. Introduction.

It is certain that the ground is always vibrating at a minute amplitude about 1 micron. Such vibrations are called micro-tremor.

The studies concerning the micro-tremor were started soon after seismology had been established systematically as a branch of science. First it was noted that the mean period of micro-tremor of a definite place has a particular value.[1] Since then, only several studies about the amplitude besides those concerning period have been made intermittently.[2]

The present paper describes the systematical measurement of micro-tremor observed at various places in Tokyo, and the properties of ground deduced from the characteristics of micro-tremor are utilized for the determination of the coefficient of ground relating to earthquake-proof construction. At the same time it is intended that by researching the micro-tremor in full as a wave problem, contribution to the study of earthquake motion will be made.

2. Measuring instrument.

As the measurement in the present study needs much time, for financial reasons paper smoked by oil-lamp and needle for recording are adopted.

For measurement of horizontal motion inverted-pendulum-type transducer is used, and the vertical motion Ewing-type is used. Both have the natural period of 1.0 sec. The motion of the pendulum is transduced into the change of electrical quality by means of the moving coil. The sensitivity is 7.0 volt/kine. The amplifier is of resistance coupled 3 stages, the maximum amplification amount to 90 db and the

1) F. OMORI, *Bull. Earthq. Inv. Comm.*, **2** (1908), 1.
2) W. INOUYE, *Bull. Earthq. Res. Inst.*, **10** (1932), 83.
M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **15** (1937), 697.

conductance between input and output is 28 mho.

In order to make the behavior of the amplifier stable and to improve its characteristic, push-pull connection and the stabilized power supply are adopted.

This measuring apparatus may distinguished by the recorder.[3] Its constructional features are shown in Fig. 1. The mechanism is as follows. A moving coil supported by a bakelite plate of suitable stiffness moves back and forth in the radial magnetic field caused by a permanent magnet. The back-and-forth motion of the coil is changed into the rotary motion due to an Eden's spring.[4] The Eden's spring has a straw arm at the end, and a recording needle is at the end of the straw arm. Thus the motion of the moving coil is magnified 30 times. There are hardly any solid friction and play in the magnification system in which an Eden's spring is applied. The vibration system is activated by the electro-magnetic damping due to the coil bobbin made of duralumin.

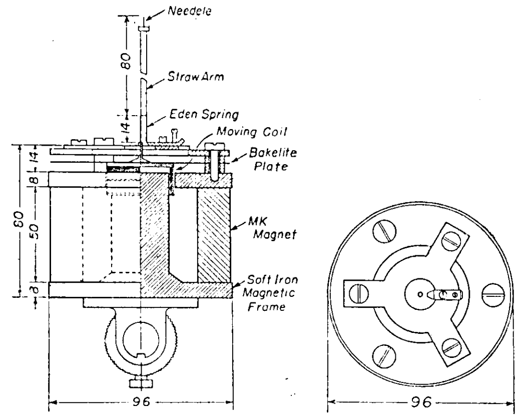

Fig. 1. Construction features of the recorder.

Two natural frequencies of the recorder are available, viz. 20 c/s and 40 c/s, by exchanging Eden's spring. D. C. sensitivities are 0.5 mA/mm and 2.0 mA/mm respectively.

The sensitivity of the vibrograph as a whole, that is the combination of transducer, amplifier and recorder,

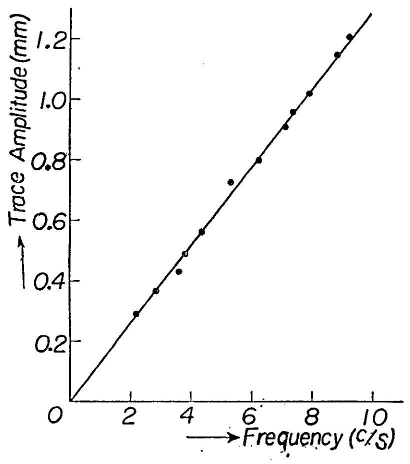

Fig. 2. Characteristic of the vibrograph. Trace amplitude means the record-amplitude corresponding to the 1 μ vibration-table amplitude, as the case of 1/500 of full gain.

3) T. TANAKA and K. KANAI, *Journ. Seism. Soc. Japan.*, [ii], **5** (1952), 43.

4) G. NISHIMURA, M. SUZUKI and E. FURUKAWA, *Bull. Earthq. Res. Inst.*, **32** (1954), 87.

amounts to the maximum of 1.0×10^4 cm/kine. This means the magnification is about 65,000 in case of sinusoidal wave of 1 c/s. The characteristic of the vibrograph as a whole is shown in Fig. 2. Fig. 3 is the photograph of the measuring equipment.

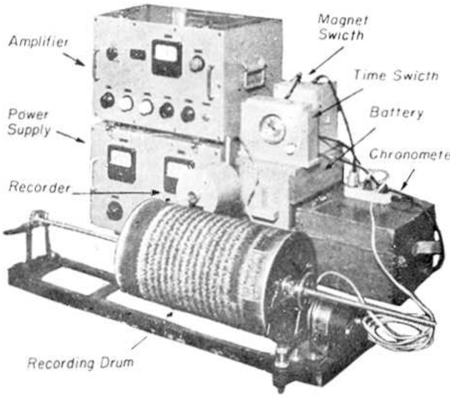

Fig. 3. Measuring equipment.

This time the micro-tremor observations were continued for 30 minutes in day-time and at midnight respectively. Midnight observation was performed automatically by using time-switch.

The sensitivity of amplifier was regulated according to place and time so that the maximum of the recorded amplitude may become 10 mm. The driving speed of records is 10 mm/sec. Time was marked by interrupting the output of amplifier at every 15 sec by using a specially made watch.

3. Relation of frequency to period of micro-tremor.

By taking any part of two minutes from the records of micro-tremor, the interval from the time the wave crosses 0-line till it comes to 0-line again is measured. The time thus read is doubled and it is considered to be the period. Then taking the period on the abscissa and the number of waves of each period on the ordinate, the curve of frequency-period is drawn as in Figs. 4–6. (Since this seismograph is an instrument which measures the velocity of waves, the time during which waves cross 0-line twice corresponds to the time needed for the maximum displacement of micro-tremor to come to the next maximum.)

Any place has a definite frequency-period curve of micro-tremor and it is very similar to that of the earthquake motion at the said place.

From Figs. 4–6 it is found that the frequency-period curves of micro-tremor observed in various place in Tokyo can be roughly classified into three groups. The curves which have one sharp peak belong to the first group, those having several peaks to the second, and to the last very flat curves belong.

Among the records of the micro-tremor in various places, the representative records belong to the first, the second and the third

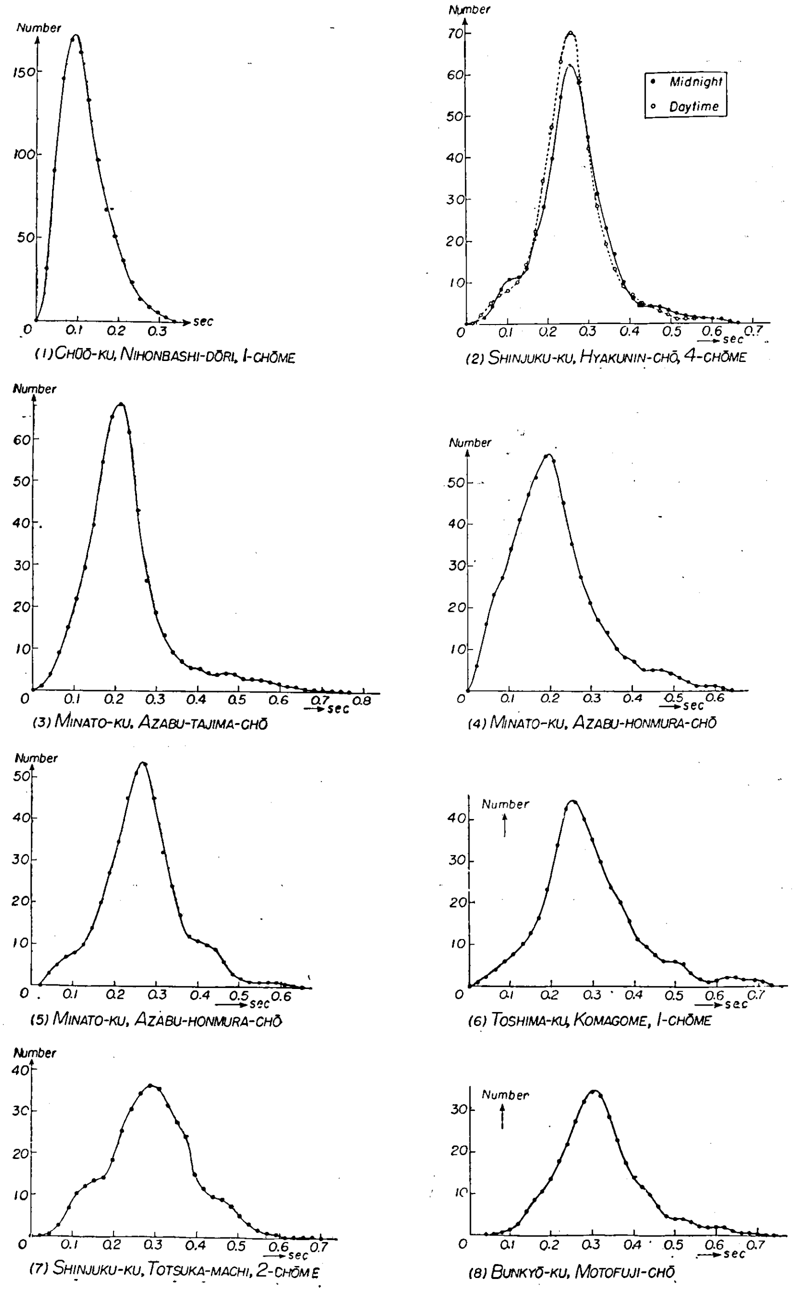

Fig. 4. Frequency-period curves belong to the first group.

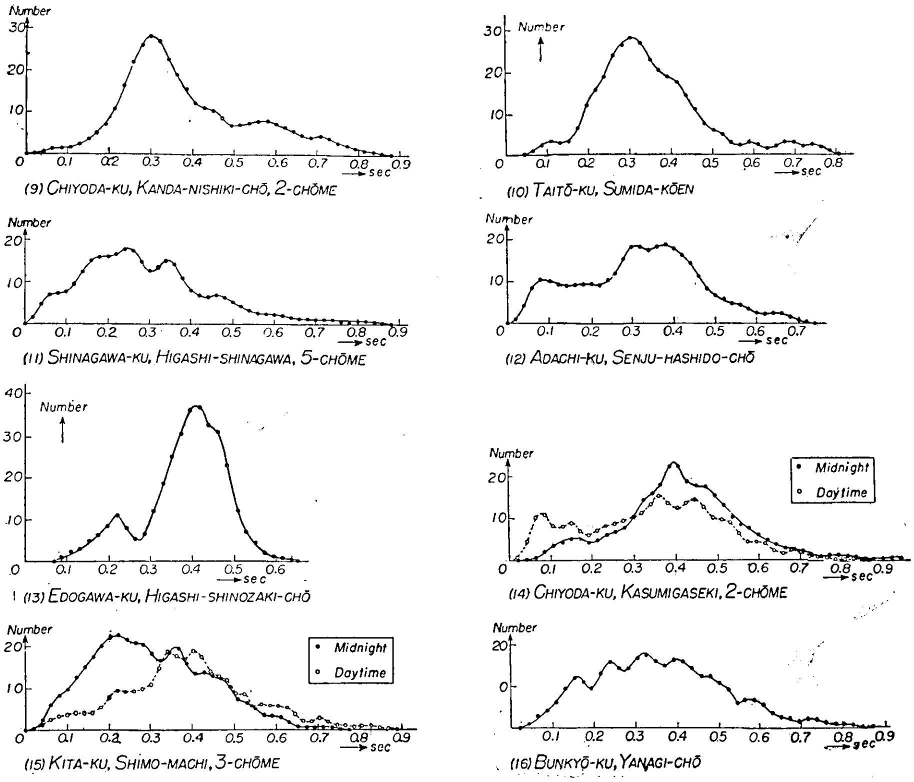

Fig. 5. Frequency-period curves belong to the second group.

groups concerning day-time and midnight are shown in Fig. 7.

Such a classification is illustrated in Fig. 8 as a geological map from which we can deduce the following: The curves of the first group belong to such geological formation as very thin alluvium, diluvium and tertiary. The curves of the second group belong to alluvium of over several meters' thickness. The curves of the third group appear at the special ground among the geological formation of alluvium with thickness of over 25 m.

On the other hand the curves of the first group correspond to the mathematical results concerning the relationship of amplitude-period in case of a surface layer.[5] The curves of the second group are very similar to the calculated results concerning the case when there are two or three layers of different vibrational impedance between the bed rock

5) K. KANAI, *Bull. Earthq. Res. Inst.*, **28** (1950), 31.

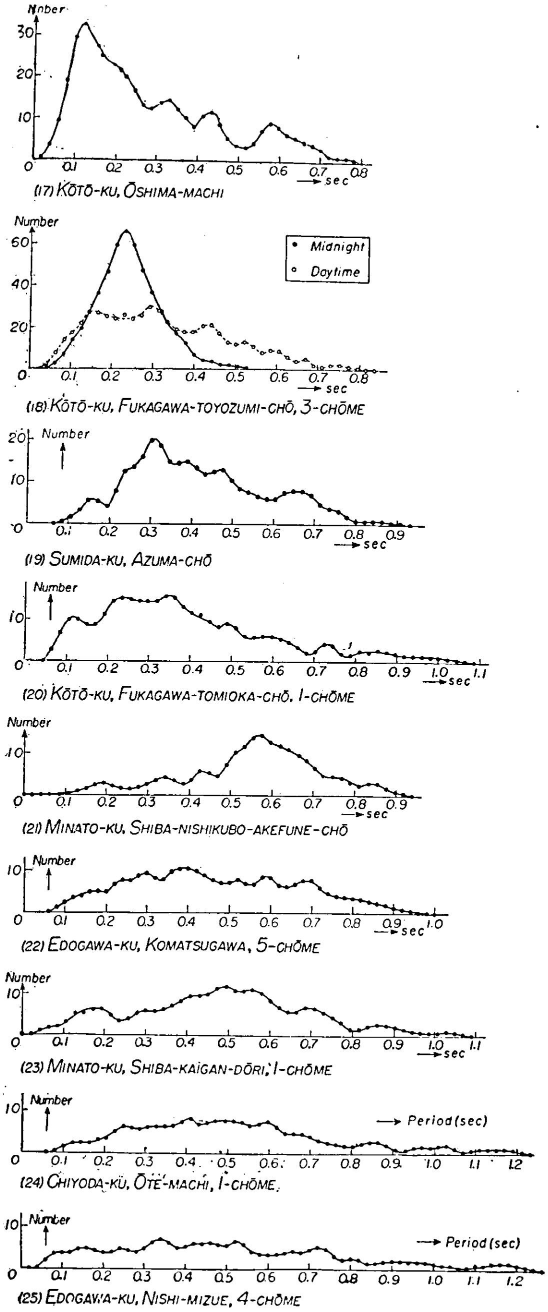

Fig. 6. Frequency-period curves belong to the third group.

and the surface,[6] while the curves of the third group coincide with the calculated results in the case when surface layer consists of many layers of different vibrational impedance.[7]

From Figs. 4–6 it is clear that in some places, for example, (2) and (14), the curves of frequency-period retain similar figure regardless of day or night, while in other places, for example, (15) and (18), there are differences between the curves obtained at day-time and those obtained at midnight. By comparing micro-tremor with earthquake it is found that the curves of frequency-period of micro-tremor observed at midnight in any place corresponds to those of earthquakes of near distance from the origin observed at the same place, and the curves observed at day-time resembles those of earthquake of remote distance from the origin.[8]

Fig. 8. Relation of the classification of frequency-period curves of micro-tremor to geological formation in Tokyo. ○: 1st group; ◉: 2nd group; ●: 3rd group. Hatched zone: diluvium or tertiary; blank zone: alluvium. Large and small letters of number represent position number and the thickness of alluvium in m respectively.

4. Relation of amplitude to period of micro-tremor.

If the period and amplitude of the waves of micro-tremor are read one by one from the records, they can be plotted as shown in Figs. 9–12.

From these figures it is known that the amplitude is at its maximum at the period when the waves reach the maximum in number. Also it is found that the relation of the lower limit of amplitude to the period which traces a going-up slope appears to follow a certain law. Picking up the minimum amplitudes of respective periods and their ratio to the minimum amplitude of a definite period they are plotted in Fig. 13

6) K. KANAI, *Bull. Earthq. Res. Inst.*, **31** (1953), 219,
K. KANAI and S. YOSHIZAWA, *Bull. Earthq. Res. Inst.*, **31** (1953), 275.

7) K. SEZAWA and K. KANAI, *Bull. Earthq. Res. Inst.*, **13** (1935), 484.

8) M. ISHIMOTO, *Bull. Earthq. Res. Inst.*, **12** (1934), 234 and **13** (1935), 592.

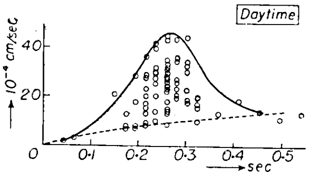

Fig. 9. Amplitude-period curves of micro-tremor at, (2), 4-chōme, Hyakunin-chō, Shinjuku-ku.

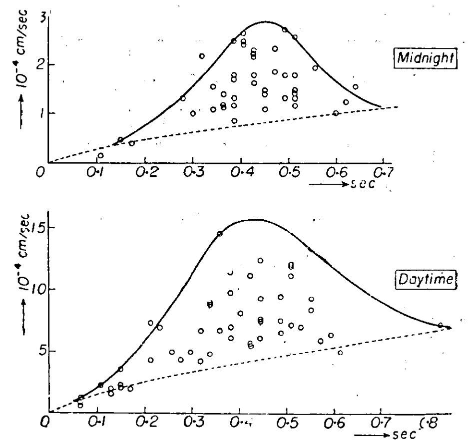

Fig. 10. Amplitude-period curves of micro-tremor at, (14), 2-chōme, Kasumigaseki, Chiyoda-ku.

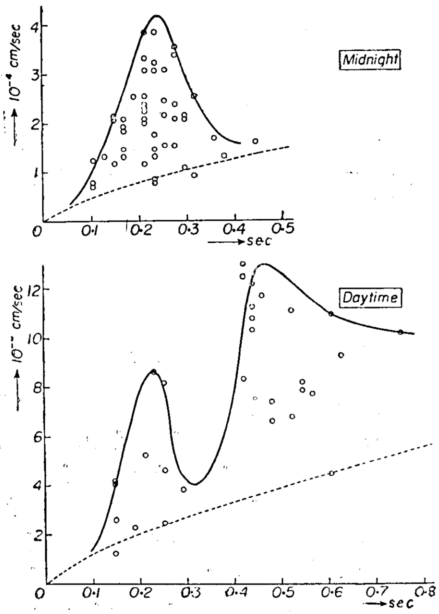

Fig. 11. Amplitude-period curves of micro-tremor at, (18), 3-chōme, Fukagawa-toyozumi-chō, Kōtō-ku.

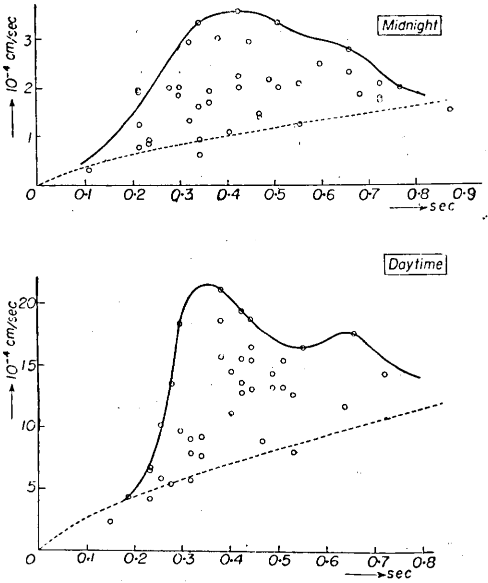

Fig. 12. Amplitude-period curves of micro-tremor at, (20), 1-chōme, Fukagawa-tomioka-chō, Kōtō-ku.

which, roughly speaking, proves the relation of $V \propto T^{0.7}$, at least, at the period ranging 0.1∼1 sec. Such a relation is represented by the lower curves written in Figs. 9–12.

Now let the lower limit of amplitude be the amplitude of the original waves of micro-tremor. Then it may be considered that the upper boundary indicates the amplification concerning every period. The maximum amplitudes shown in Figs. 9–12 being divided by the amplitudes of lower limit at the corresponding periods, the numerical values of the maximum amplification of grounds are given as shown in Table I.

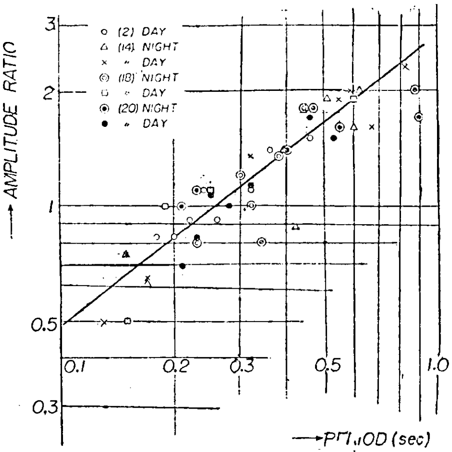

Fig. 13. Relation of lower limit amplitude to period.

The maximum amplification which shows slight difference between day and night at every place and is independent of the property of ground becomes 3–4 in general. (As the amplitude of lower limit is considered to be twice as large as the original amplitude, which is due to the reflection of waves at free surface, the doubled values of the calculated results mentioned above are regarded as the amplification of ground. Those values coincide with the amplification of earthquake motion at ground surface[9].)

Table I.
The values of the maximum amplification of grounds.

Position	Time	Value
(2)	Day	4.4
(14)	Night	3.5
	Day	3.6
(18)	Night	4.4
	Day	4.1, 3.8
(20)	Night	3.2
	Day	3.2

$V \propto T^{0.7}$ means that displacement D is in the relationship of $D \propto T^{1.7}$ and this coincides with the displacement-period relation of earthquake motion which was described in the preceding paper.[10]

5. Conclusion.

As the results of the measurement of micro-tremor made at many places in Tokyo, the following become clear :

9) K. KANAI, K. OSADA and S. YOSHIZAWA, *Bull. Earthq. Res. Inst.*, **31** (1953), 227.
10) K. KANAI and M. SUZUKI, *Bull. Earthq. Res. Inst.*, **32** (1954), 187.

(i) The relation curve of frequency-period of micro-tremor shows a definite form for respective districts. This form coincides with that of earthquake motion and has a close relation with the geology of a district. On the firm ground a sharp peak appears at 0.1–0.3 sec period, and on the soft ground at 0.4–0.6 sec. On especially soft ground the curve is flat at the period ranging 0.3–1 sec.

(ii) The frequency-period curve of earthquake motion of near distance from the origin has a similarity to that of micro-tremor observed at midnight, and that of earthquake motion of remote distance from the origin is similar to that of the micro-tremor observed at day-time.

(iii) Presuming the cause of micro-tremor, the relation of displacement to period at every place is considered to be $D \propto T^{1.7}$, at least, at the period ranging $0.1 \sim 1$ sec. This is coincident with that of the earthquake motion at bed rock.

(iv) In the case when the presumption in (iii) is taken into consideration, the maximum amplification of micro-tremor is considered almost independent of the property of ground and becomes 6–8 in general. Such values correspond to those of earthquakes.

From the results of the measurement of micro-tremor described in this paper it is shown that there seem to be some similarities between the generation mechanism of micro-tremor and seismic waves which arrive at bed rock.

In conclusion we wish to express our thanks to the Science Section of Educational Ministry and the Bureau of Architecture, Tokyo-Metropolis, for the financial aid granted us for the present investigations. Thanks are also due to the residents of the observation districts for their cooperation, and to Miss S. Yoshizawa who assisted us in preparing this paper.

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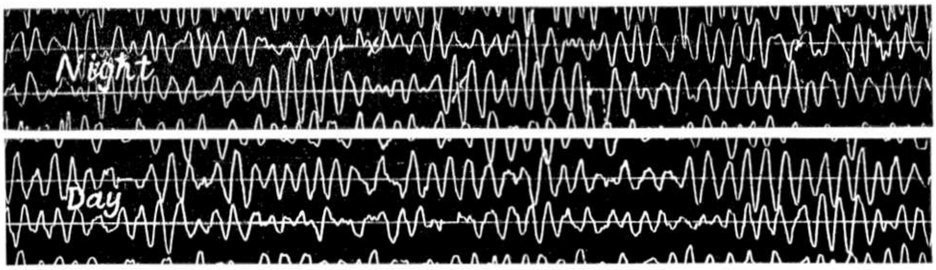
14. 常時微動の測定 第1報

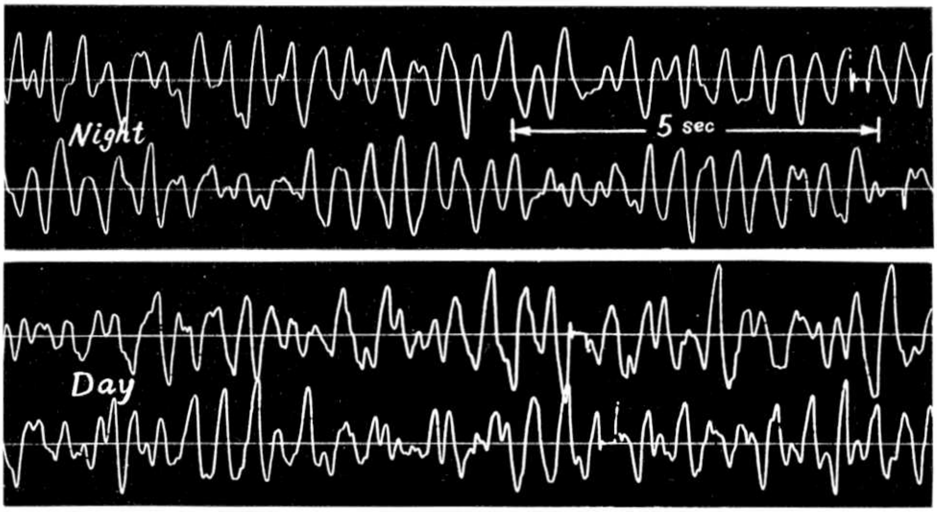
地震研究所 金井清 田中貞二 長田甲斐男

東京都内の多くの場所で常時微動を観測した結果，次の事柄がわかつた.

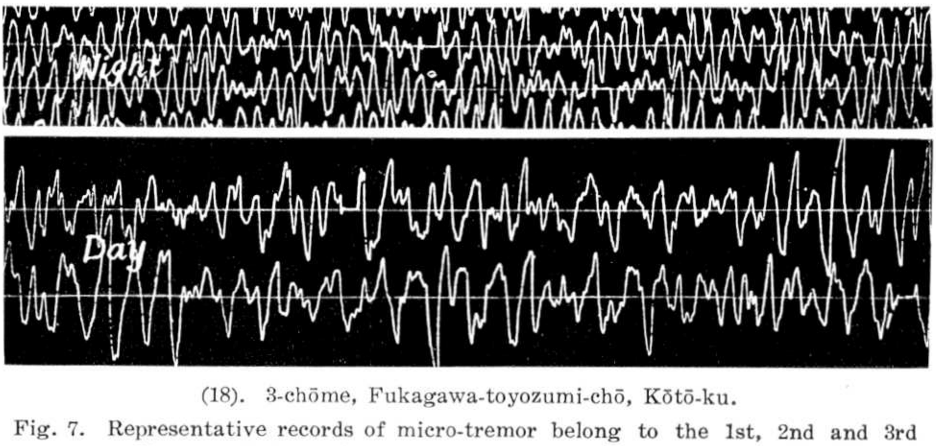
(i) 常時微動の頻度一周期関係は各場所について，きまつた型である．この型は，同じ場所における地震動の頻度一周期関係の型によく似ており，その場所の地質と関係が深い.



(2). 4-chōme, Hyakunin-chō, Shinjuku-ku.



(15). 3-chōme, Shimo-machi, Kita-ku.



(18). 3-chōme, Fukagawa-toyozumi-chō, Kōtō-ku.

Fig. 7. Representative records of micro-tremor belong to the 1st, 2nd and 3rd groups. Upper: midnight; lower: day-time. Original size.

即ち，堅い地盤では 0.1～0.3 sec に鋭い山ができる．軟い地盤では 0.4～0.6 sec に山ができる．非常に軟い地盤では 0.3 sec から 1 sec 以上にわたつて平である．

(ii) 常時微動の深夜の頻度—周期曲線は近地地震のものに似ており，昼のものは遠地地震のものに似ている．

(iii) 常時微動を起すもとになるものを，或解析のやりかたの結果から仮想すると，少くとも 0.1～1 sec のものについては，変位と周期の関係は $D \propto T^{1.7}$ と考えられる．

この関係は基盤における地震動のものに合う．

(iv) (iii) のように考えると，常時微動の地盤による最大増巾度は 6～8 となる．この値は地震動の場合に合う．

(v) 常時微動の頻度—周期曲線は，耐震構造上からの地盤係数を求める手段として利用することができそうである．