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5. On Microtremors. VIII.

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Contents

1. Introduction

In an ordinary place, a seismograph which has more than about a thousand times magnification, records the ground motions continuously.

Usually, the amplitudes of the motions are 0.1~1 microns, and the range of their periods are from 0.05, 0.1 sec to 1, 2 sec.

Such ground vibrations are called microtremors.

Microtremors are chiefly caused by artificial disturbances such as traffic, industrial machines and so on. Therefore, generally speaking, the larger the city, the greater the amplitudes of microtremors.

The study concerning microtremors was started soon after seismology had been established as a branch of science[1]. Otherwise, little research have been done intermittently, until several years ago[2], because it had been considered as a slight interest of phenomena in the study of natural science. In recent years, some investigations of microtremors

1) F. OMORI, "On Micro-tremors", *Bull. Earthq. Inv. Comm.*, **2** (1908), 1-6.

2) U. INOUYE, "Comparison of Earth Shakings Above-ground and Underground", *Bull. Earthq. Res. Inst.*, **12** (1934), 712-741 (in Japanese).

M. ISHIMOTO, "Observations sur des secousses d'une petite Amplitude", *Bull. Earthq. Res. Inst.*, **15** (1937), 697-705.

were carried out in order to develop the studies relating to not only natural microearthquakes but also explosion seismic waves[3].

From systematic measurements of microtremors which have been carried out at several thousands places in Japan, it was found that the properties of the ground as inferred from the characteristics of microtremors are utilizable for determining the seismic factor relating to earthquake-proof construction designs[4].

2. The period distribution of microtremors

The period distribution curve of microtremors shows a definite form for respective kinds of subsoils.

That is, when the formation of the ground relating to vibration characteristics is simple, as for instance, in the case of a simple stratified layer, a relatively sharp peak appears at about 0.1~0.6 sec on the period distribution curve of the microtremors.

3) Y. TOMODA and K. AKI, "Frequency Analysis of Local Tremors of the Ground by means of a Magnetic Microseismic Spectrometer", *Journ. Seism. Soc. Japan, Ser. 2,* **5** (1952), 17-22 (in Japanese).

C. D. V. WILSON, "The origins and nature of microseisms in the frequency range 4 to 100 c/s", *Proc. Roy. Soc. London,* **217** (1953), 176-188.

C. D. V. WILSON, "An analysis of the vibrations emitted by some man-made sources of microseisms", *Proc. Roy. Soc. London,* **217** (1953), 188-202.

K. AKAMATU, "On Microtremors", *Journ. Seism. Soc., Japan, Ser. 2,* **9** (1956), 21-39 (in Japanese).

K. AKI, "Space and Time Spectra of Stationary Stochastic Waves with Special Reference to Microtremors", *Bull. Earthq. Res. Inst.,* **35** (1957), 415-456.

K. AKAMATU, "On Microtremors II", *Journ. Seism. Soc., Japan, Ser. 2,* **11** (1958), 40-48 (in Japanese).

4) K. KANAI and T. TANAKA, "Measurement of the Microtremor", *Bull. Earthq. Res. Inst.,* **32** (1954), 199-209.

Subsoil Research Team, the Earthquake Research Institute, "Investigation into Seismic Characteristics of Subsoils in Tokyo", *Bull. Earthq. Res. Inst.,* **33** (1955), 492-495 (in Japanese).

K. KANAI, T. TANAKA and K. OSADA, "Measurement of the Microtremor. II. (Tokyo Metropolis)", *Bull. Earthq. Res. Inst.,* **35** (1957), 109-133 (in Japanese).

K. KANAI, T. TANAKA and K. OSADA, "Measurement of the Microtremor. III. (Yokohama City)", *Bull. Earthq. Res. Inst.,* **35** (1957), 135-148 (in Japanese).

K. KANAI, N. NASU, T. TANAKA and K. OSADA, "Measurement of the Microtremor. IV. (Sakata and Tsuruoka)", *Bull. Earthq. Res. Inst.,* **35** (1957), 149-162 (in Japanese).

K. KANAI, H. KAWASUMI, T. TANAKA and K. OSADA, "Measurement of the Microtremor. V. (Osaka City)", *Bull. Earthq. Res. Inst.,* **35** (1957), 163-180 (in Japanese).

K. KANAI, T. TANAKA, T. MORISHITA and K. NAKAGAWA, "Measurement of the Microtremor. VI. (Ichinomiya City, Aichi Prefecture)", *Bull. Earthq. Res. Inst.,* **35** (1957), 181-190 (in Japanese).

K. KANAI, T. TANAKA and K. OSADA, "Measurement of the Microtremor. VII. (Kawasaki City)", *Bull. Earthq. Res. Inst.,* **35** (1957), 191-200 (in Japanese).

On the other hand, when the formation of the ground is complex, more than two peaks appear at the periods between shorter than 0.2sec and longer than 1 sec on the curve mentioned above.

In fact, on a mountain a sharp peak appears at the period 0.1∼0.2 sec, while on firm diluvial ground such as up-town in Tokyo the peak is at the period 0.2∼0.4 sec. On the soft alluvial ground such as down-town in Tokyo the curve is irregular in shape and a number of peaks appear in the range of the period 0.4∼0.8sec. On especially thick soft ground the curve is flat, the period ranging from 0.05, 0.1sec to 1, 2sec.

Microtremors recorded on various kinds of ground by the microtremor recorder, with the corresponding period distribution curves are shown in Fig. 1.

The period distribution curve is, in many cases, influenced greatly by the properties of the first medium of layered ground. On the other hand, the curves on fresh rock as well as on bed rock are flat at periods ranging from less than 0.1 sec to larger than 1 sec.

From these facts, we can consider that the amplitudes of microtremors at ground surface become larger at such periods as are synchronous with the natural period of the subsoil from the feature of selective resonance.

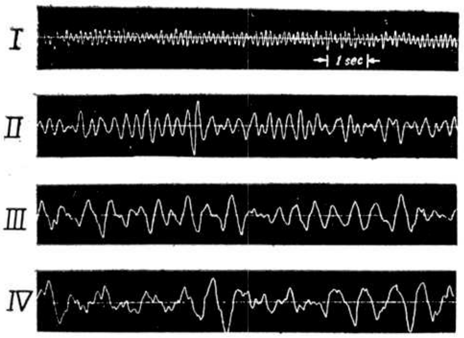

Fig. 1-a. Representative records of microtremors observed at the various kinds of ground. The symbols of I, II, III and IV represent the kinds of ground used in the Building Code of Japan.

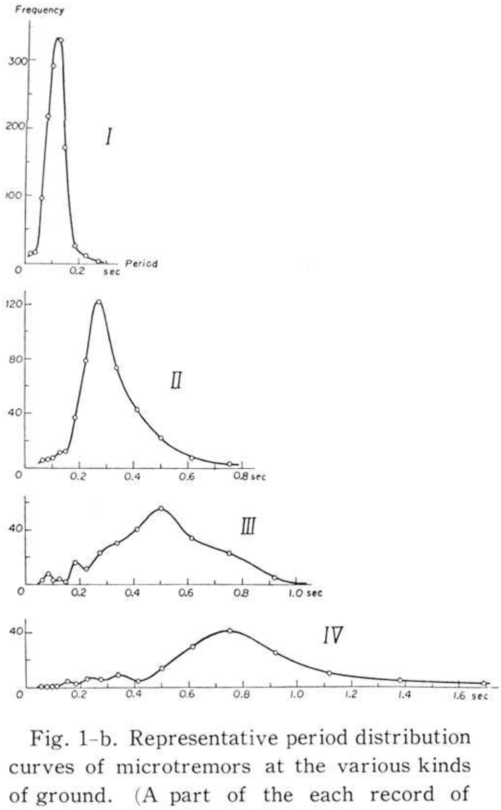

Fig. 1-b. Representative period distribution curves of microtremors at the various kinds of ground. (A part of the each record of them are shown in Fig. 1-a.)

3. The amplitude and the period of microtremors for time

The largest amplitude of microtremors during the daytime is much greater than at midnight, that is to say, the ratio of daytime to midnight is 2~10 times, because the amplitude of the microtremors depends greatly on the activity of the artificial vibration source surrounding the measuring place. Here, the largest amplitude is used to mean the average of the large amplitudes which often appear.

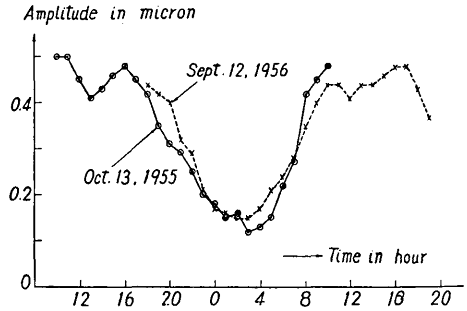

Fig. 2-a. Results (largest amplitudes) of microtremor measurements for a 24 hour period at the Earthquake Research Institute.

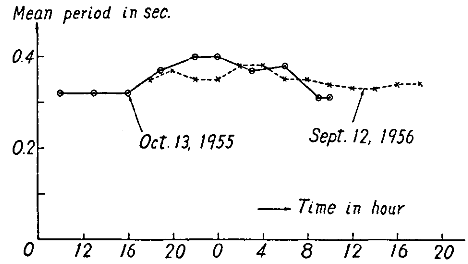

Fig. 2-b. Results (mean periods) of microtremor measurements for a 24 hour period at the Earthquake Research Institute.

The results of 24 hours of microtremor measurements at the Earthquake Research Institute are shown in Fig. 2. Fig. 3 shows the amplitude relationship between midnight and daytime at thirty spots in Japan, taking into amount various kinds of subsoil as well as artificial circumstances.

Fig. 3 tells us that the ratio of amplitude in the daytime to midnight is smaller in a noisy city than in the quiet country side. Regarding the largest amplitudes, the following empirical formula is obtained from Fig. 3:

$$(\text{midnight})=0.3\times(\text{daytime})^{1.5} \quad (1)$$

Fig. 4 shows the predominant, the mean and the largest period relations between midnight and daytime at twenty spots

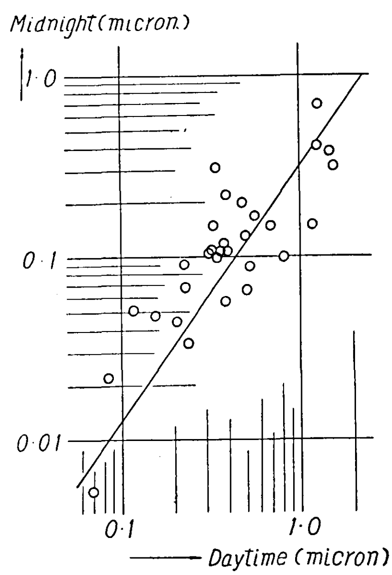

Fig. 3. Amplitude relation of microtremors between midnight and daytime.

in Japan with various kinds of subsoil.

Fig. 4 as well as Fig. 2 shows us that the predominant, the mean and the largest periods of microtremors change slightly with time and

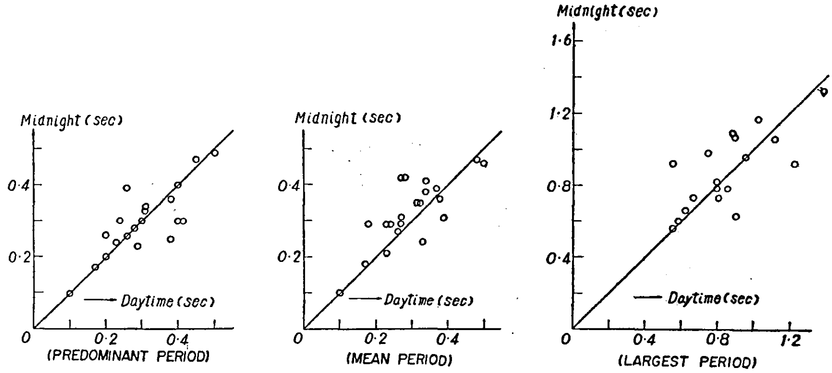

Fig. 4. Period relations of microtremors between midnight and daytime.

depend greatly on the vibration characteristics of the subsoil. Here, the largest and the predominant periods mean, respectively, the longest period of waves recorded by the microtremor recorder (1 sec natural period and proper damping) and the peak period of the period distribution curve.

4. Microtremors in the underground

Simultaneous observations of microtremors, using the bored-hole self-levelling vibrograph[5], at different depths at several places with different kinds of subsoil have been carried out by us.

(i) At Komaba, Tokyo.

Figs. 5 and 6 show, respectively, the boring log and the amplitude ratios of the ground surface to the 13.4 m depth at Komaba in Tokyo. It can be seen from Fig. 6 that the amplitude ratio mentioned above reaches its maximum at 0.25~0.30 sec period and its minimum at 0.35~0.40 sec period. On the other hand, Fig. 7 shows the period distribution curves at ground surface and at a depth of 13.4 m. It will be seen in Fig. 7 that the periods of 0.25~0.30 sec and 0.35~0.40 sec mentioned above, just correspond respectively, to the peak periods of period distribution curves at the respective places.

The amplitudes of microtremors of such periods as are synchronous

5) K. KANAI and T. TANAKA, "Self-levelling Vibrograph", *Bull. Earthq. Res. Inst.*, **36** (1958), 359-368.

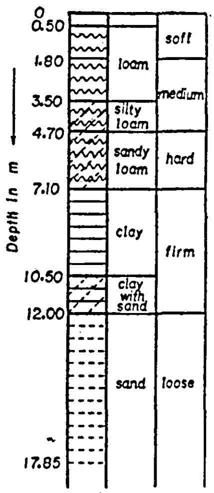

Fig. 5. Boring log at Komaba, Tokyo.

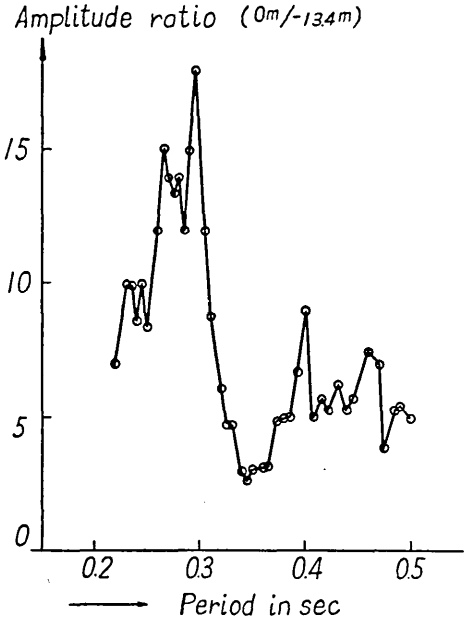

Fig. 6. Amplitude ratios of microtremors of the ground surface to the 13.4 meters depth at Komaba, Tokyo.

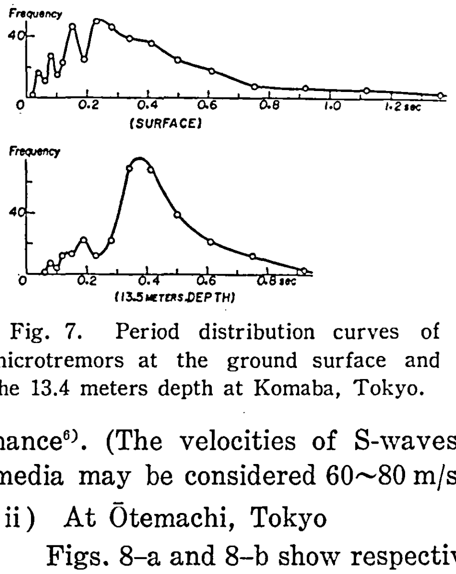

Fig. 7. Period distribution curves of microtremors at the ground surface and the 13.4 meters depth at Komaba, Tokyo.

with the natural ones of the strata, the superficial soft media of 4.70 m thickness and the intermediate loose sand layer of 5.6 m thickness, are relatively preponderant owing to the feature of selective resonance[6]. (The velocities of S-waves in the soft as well as the loose media may be considered 60~80 m/sec)

(ii) At Ōtemachi, Tokyo

Figs. 8-a and 8-b show respectively, the boring log and the relationship of the largest amplitudes to depths at Ōtemachi, Tokyo. On the other hand, the period distribution curves at the different depths are shown in Fig. 9.

It will be seen from Figs. 8-b, 9 and 8-a that, at a depth of 11.5 m, the largest amplitude is remarkably large, a very sharp peak

6) K. KANAI and S. YOSHIZAWA, "Relation between the Amplitude of Earthquake Motions and the Nature of Surface Layer. III", *Bull. Earthq. Res. Inst.*, **31** (1953), 275-279.

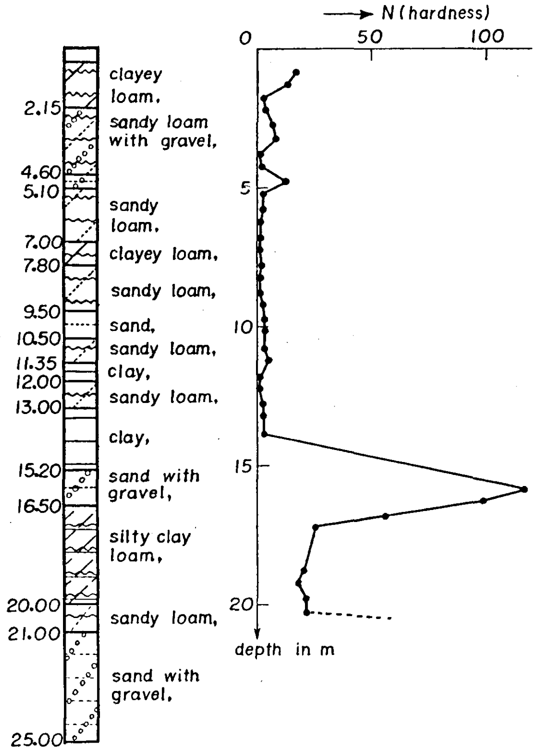

Fig. 8-a. Boring log at Ōtemachi, Tokyo.

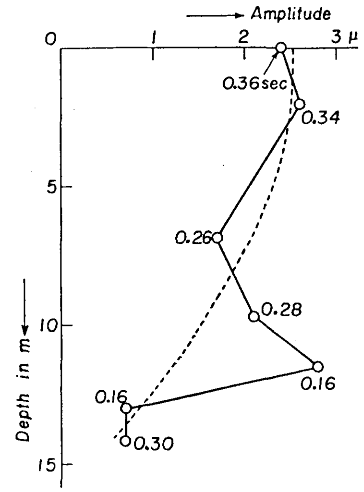

Fig. 8-b. Relation of the largest amplitude of microtremors to the depth at Ōtemachi, Tokyo.

appears in the period distribution curve and the hardness of the soil is not considerable. Then, from the above facts, it is possible to consider that amplitudes of about 0.1 second per period which are synchronous with natural ones of a clay layer of about 12 m in depth are considerably preponderant, owing to the selective resonance. It seems that the broken line in Fig. 8-b probably means the amplitude distribution of waves of about 0.35 sec per period which synchronize with the natural period of the surface layer overlying the

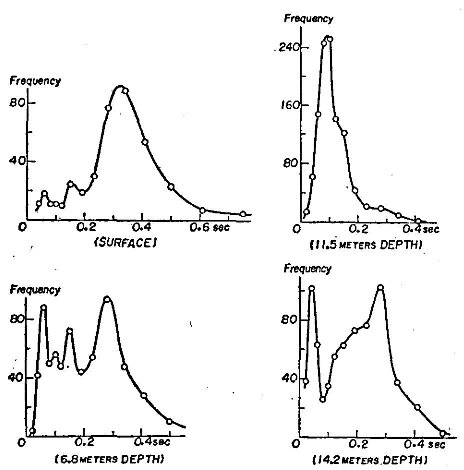

Fig. 9. Period distribution curves of microtremors on the different depths at Ōtemachi, Tokyo.

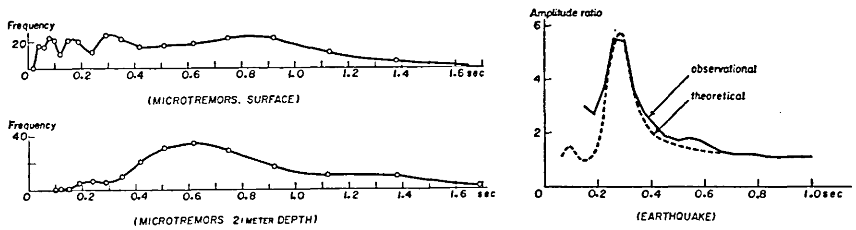

Fig. 10-a. Period distribution curves of microtremors on the different depths at place A, Tōkaimura.

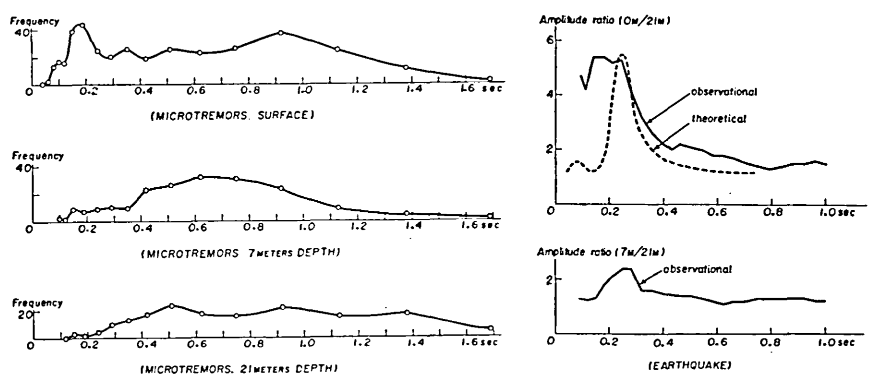

Fig. 10-b. Period distribution curves of microtremors on the different depths at place B, Tōkaimura.

15.20 m deep gravel layer. (The average velocities of S-waves in the intermediate clay layer and the surface layer mentioned above may be assumed, respectively, to be 80 m/sec and 170 m/sec) At any rate, it should be borne in mind that the amplitude distribution of microtremors to the depth is not as simple as had been considered formerly.

Fig. 10 shows the period distribution curves of microtremors at different depths at two places at Tokaimura, Ibaraki prefecture, together with the average amplitude ratios of the ground surface to the depth of the seismic waves observed at the same places.

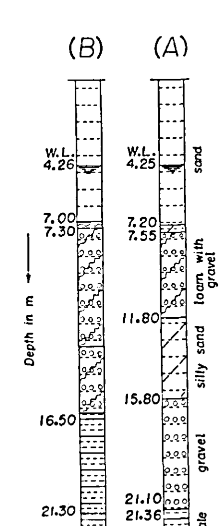

Fig. 10-c. Boring logs of places A and B at Tōkaimura.

It will be seen from Fig. 10 that

there is considerably good agreement between the resonance-like period of grounds by earthquakes and the frequent periods of microtremors at the ground surface.

5. Microtremors on the sea-bottom

Observations of the microtremors on the sea-bottom have already been made at more than twenty points, in Tokyo Bay, Dōkai Bay and Ise Bay, Japan, by means of the use of the sea-bottom self-levelling vibrograph[7]. From the results, it has been found that there is con-

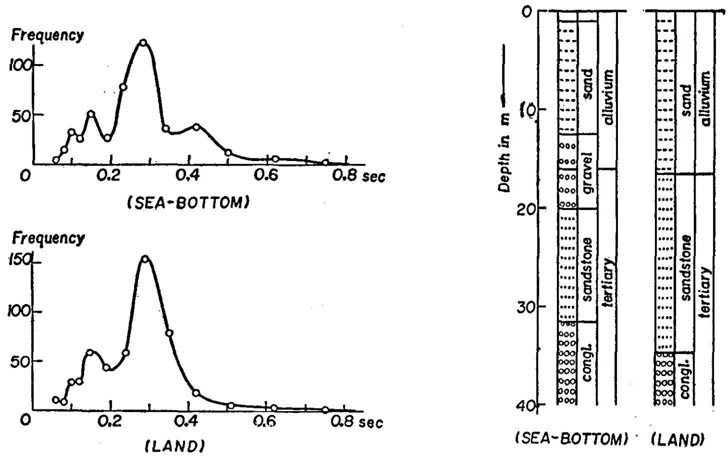

Fig. 11-a. Comparative period distribution curves of microtremors on the sea-bottom and on the land in Dōkai Bay area, and the boring logs of these places, respectively.

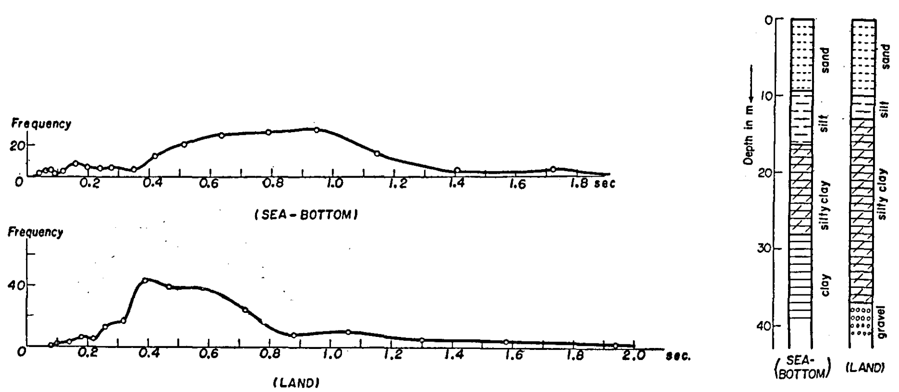

Fig. 11-b. Comparative period distribution curves of microtremors on the sea-bottom and on the land in Ise Bay area, and the boring logs of these places, respectively.

7) *loc. cit.*, 5).

siderably good similarity between the characteristics of the microtremors on the sea-bottom and the ones on the land.

Fig. 11 shows some examples of the comparative period distribution curves of microtremors observed on the sea-bottom and on the land. Fig. 12 represents the relation between the largest amplitudes of the microtremors and the offing distances from the coast-line of Ise Bay[8]. Roughly speaking, it will be seen in Fig. 12 that the largest amplitude of the microtremors on the sea-bottom increases with the offing distance from the coast-line, except in the case of No. 15. On the other hand, roughly speaking, the thickness of soft deposits increases also with the distance mentioned above. Therefore, it may be said that the largest amplitudes of microtremors depend greatly on the thickness of the soft deposits and differ slightly according to the distance mentioned above.

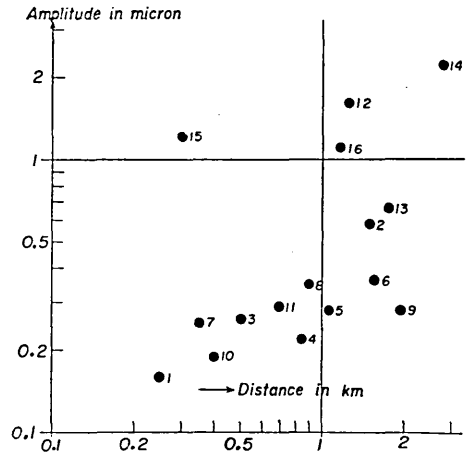

Fig. 12. Relation between the largest amplitude of microtremors and the offing distance from the coast line in Ise Bay.

6. Local geology and microtremores

Fig. 13 shows the relations among the mean periods as well as the largest amplitudes of microtremors and the local geological formations at the Misaki area, Tokyo. It will be seen from Fig. 13 that the harder

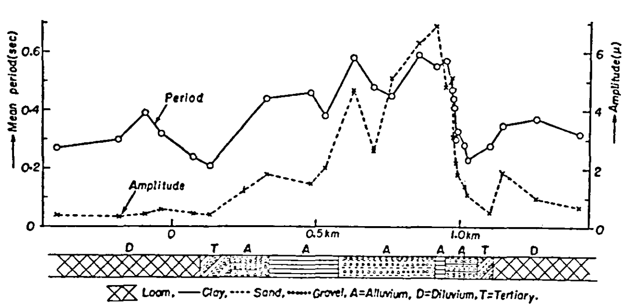

Fig. 13. Relation among the mean period and the largest amplitude of microtremors and the local geological formation at Misaki, Tokyo.

8) *Report of the Yokkaichi Ground Invest. Comm., Yokkaichi City* (1959), 105-111 (in Japanese).

the subsoil, the longer the period and the larger the amplitude of the microtremors. Otherwise, in Fig. 13, the correlations among the periods as well as the amplitudes of the microtremors and the local geological formations seem surprisingly close because the distances between the observation points were rather short.

Fig. 14 shows typical comparative figures of the period distribution curves of microtremors at a granite quarry in the vicinity of Wakamatsu City, Kyūshū.

As seen in Fig. 15, the observation site sketch, observation points A and B are, respectively, on weathered and on fresh granitic rocks, and the distance between A and B is only twenty meters. It will be natural to consider that the spectrum of microtremors under the weathered layer at A is somewhat flat like the ones at the surface of B and the amplitudes at A of 0.06 sec period which are synchronous with the natural ones of the weathered layer, become considerably preponderant owing to the feature of selective resonance.

Theoretical explanations of these facts are under investigation.

Strictly speaking, the characteristics of microtremors depend not only on the subsoil conditions, that is, the physical constants and the dimensions of each material and the disposition of the materials which are made up of

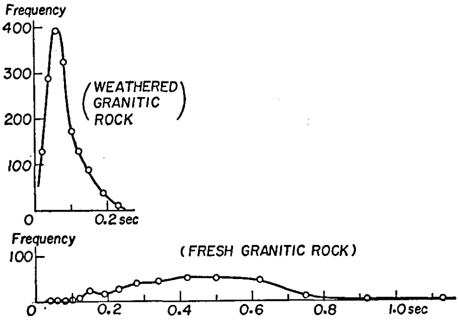

Fig. 14. Period distribution curves of microtremors at a granite quarry.

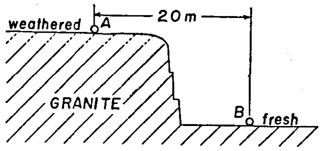

Fig. 15. Sketch of the microtremor measurement site at a granite quarry.

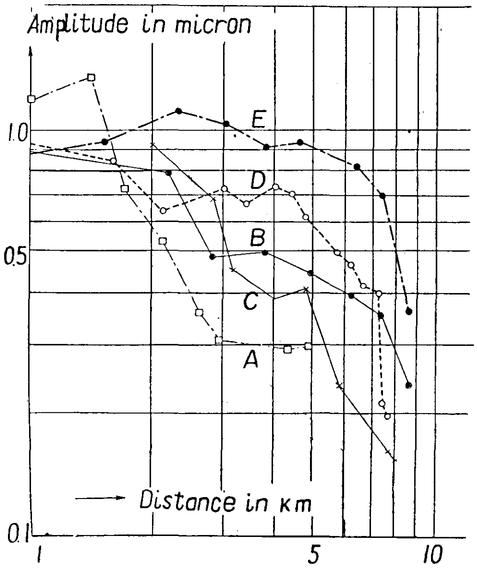

Fig. 16. Largest amplitude distributions of microtremors observed along the quiet roads which run from Sakata City.

so-called subsoil, but also on the activity conditions of artificial disturbances, that is, traffic, industrial machines, etc. Fig. 16 represents the largest amplitude distributions of microtremors observed along the five roads, which run radially from Sakata City in Yamagata prefecture, Japan, in the quiet farm country. There are few artificial disturbance sources, throughout the whole area where the five roads run. From Fig. 16, the average attenuation coefficient of microtremor amplitude, with regard to the distance from the margin of Sakata City, where exist almost all the artificial generation sources of microtremors in the area, is obtained as follows:

$$A \propto x^{-1.3} \qquad (2)$$

where A and x are, respectively, the maximum amplitude and the distance mentioned above.

It is natural that the values of the deviations from the amplitude-distance lines of $A_0x^{-1.3}$ may be considered as the effects of the vibration characteristics of the subsoils themselves. Therefore, the middle part of the road D and the greater part of the road E are considered to compromise deep weak subsoils.

7. Earthquakes and microtremors

Figs. 17 and 18 show, respectively, the relation between the number of small earthquakes and their predominant periods and the period distribution curve of microtremors at Aoyama in Tokyo. These figures, as mere examples, tell us that the peak period of microtremors will be the most expectant predominant period for earthquakes.

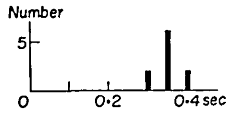

Fig. 17. Relation of the number of earthquakes to their predominant periods at Aoyama, Tokyo.

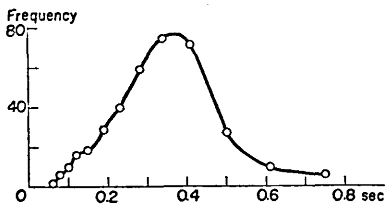

Fig. 18. Period distribution curve of microtremors at Aoyama, Tokyo.

Figs. 19 and 20 show, respectively, the period distribution curves of earthquakes observed with strong motion seismographs as well as of microtremors at San José, California, and Seattle, Washington, in the U.S.A. Figs. 19 and 20, are also mere examples which show us that the correlations between the period distribution curves of earthquakes and the ones of microtremors are considerably good.

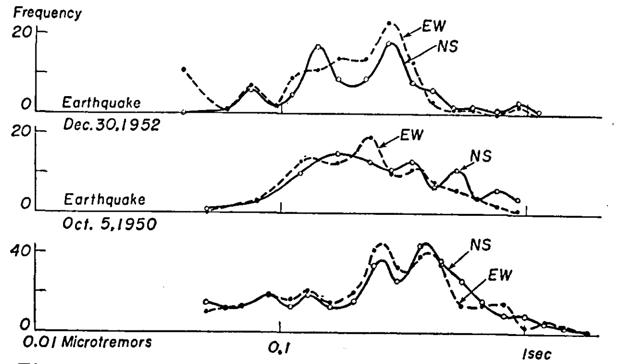

Fig. 19. Period distribution curves of the earthquakes and microtremors at San José, California.

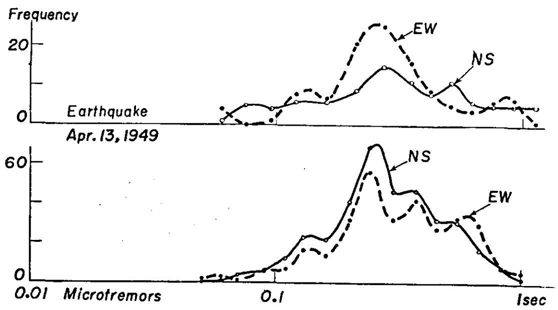

Fig. 20. Period distribution curves of the earthquake and microtremors at Seattle, Washington.

Generally speaking, the predominant period of an earthquake motion is closely connected with the maximum frequent period of the microtremors.

Furthermore, in a place in which the period distribution curve of microtremors has a single peak, the peak period coincides clearly with the predominant period of the earthquake motions. On the other hand, in a place in which the period distribution curve of microtremors has more than two peaks, the predominant period of the earthquake motions takes usually either of them and sometimes many of them.

8. Classification of the ground by microtremors

(i) The first proposal in ground classification. It has been stated, in Section 3, that the predominant, the mean and the largest periods change their values slightly whenever they are measured. (Here, the largest period means the largest wave recorded by the microtremor recorder which has a one second natural period and proper damping.) It is convenient to use the largest and the mean periods in a practical classification of the ground even though their physical purports have not as yet been made clear.

Therefore, a diagram as shown in Fig. 21, which has been obtained after the trial and error method, considering the results of microtremor measurement as well as the subsoil conditions, is taken as the first proposal in a classification of the ground. The symbols I, II, III and IV in Fig. 21 represent the kinds of ground the same as used in the Building Code of Japan, and the standards for a designation of these kinds are presented in Section 10.

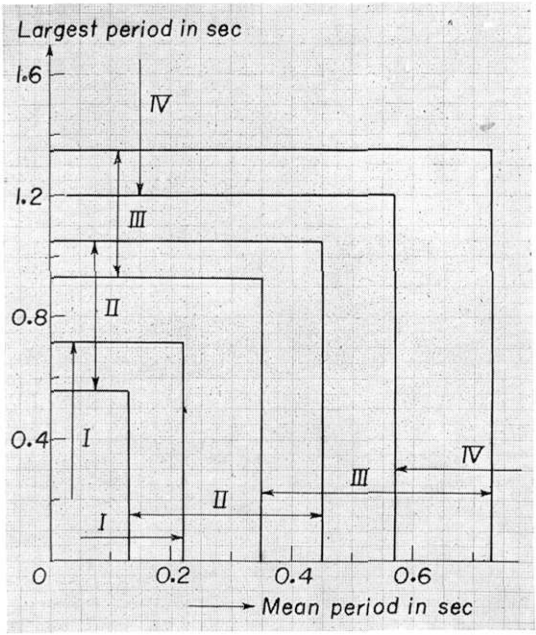

Fig. 21. The first proposal in the classification of the ground by microtremor measurement. Symbols I, II, III and IV represent the kinds of ground used in the Building Code of Japan.

(ii) The second proposal in ground classification. We have experienced many cases in which the results of ground classification by the first proposal alone are considered to be unnatural. Now, some of them are described as follows:

(a) The predominant period of the short period appeared on a very thick soft ground, because such ground consisted of plural layers and the influence of the uppermost layer is remarkable.

(b) The period distribution curves on fresh rock, bed rock and sand hill take a very flat form.

Thereupon, it is inevitable that the largest amplitude of the microtremors should be taken into consideration in a classification of the ground even though the largest amplitudes change their values not only with time but also through artificial circumstances.

Consequently, the diagram of the relation of the largest amplitude to the predominant period, which has also been obtained after the same method as the first proposal as shown in Fig. 22 is adopted auxiliarily.

It is called the second proposal in ground classification.

(c) Earthquake damage and the types of ground classified by microtremors.

The relation between the percentage of earthquake damage to Japanese wooden houses in the case of the 1944 Tōkai earthquake at the Kikugawa River district, Shizuoka prefecture obtained by Ooba[9] and the kind of ground classification at each place arising from the first proposal together with the second one is shown in Fig. 23.

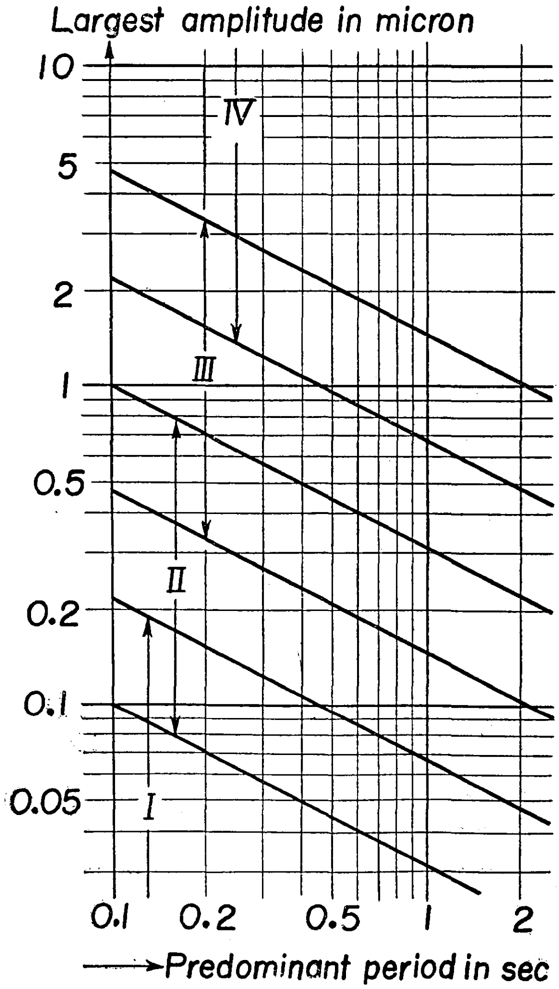

Fig. 22. The second proposal in the classification of the ground by microtremor measurement. Symbols I, II, III and IV represent the kinds of ground used in the Building Code of Japan.

It will be seen in Fig. 23 that the correlations between the earthquake damage ratios and the kinds of ground determined by the results of microtremor measurements are satisfactory.

9) S. OOBA, "Study of the Relation between the Subsoil Conditions and the Distribution of the Damage Percentage of Wooden Dwelling Houses in the Province of Totomi in the case of the Tonankai Earthquake of December 7th, 1944", *Bull. Earthq. Res. Inst.*, **35** (1957), 201-295 (in Japanese).

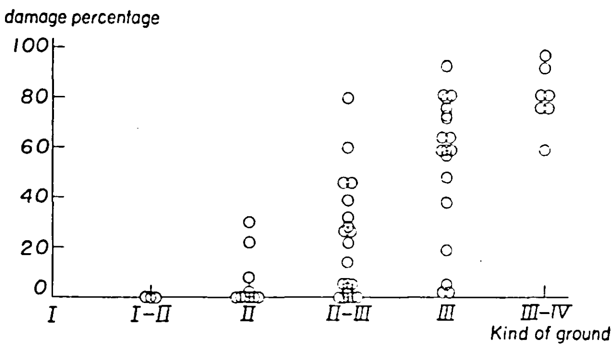

Fig. 23. Relation between the earthquake damage to Japanese style wooden houses and the kind of ground after microtremor measurements.

9. Conclusion

The response of a structure to destructive earthquake motions depends greatly upon the composition of the ground on which the structure stands.

It was found by us that any place has a definite type of period distribution curve of its microtremors, and it has considerably good similarity with that of the earthquake motions at the same place.

It has been ascertained from the present investigations that microtremor measurement is useful as a means not only for anticipating the features of destructive earthquake motions but also for determining the seismic force coefficient to be considered in earthquake proof construction design. In conclusion, the authors wish to express their hearty thanks to the members of the Subsoil Research Team, the Earthquake Research Institute, for their kind discussion in the course of this investigation and to the U. S. Coast and Geodetic Survey for co-operation in using the strong motion seismograms. The authors are much obliged to Messrs. T. Suzuki and K. Osada and to Miss S. Yoshizawa without whose help this work could not have been done.

10. Appendix

(i) The standards for the designation of four kinds of ground according to the Building Code of Japan are as follows:

Kind I: Ground consisting of rock, hard sandy gravel, etc., classified as tertiary or older strata over a considerable area around the structure.

Kind II : Ground consisting of sandy gravel, sandy hard clay, loam, etc. classified as diluvial, or gravelly alluvium, about 5 metres or more in thickness, over a considerable area around the structure.

Kind III : Ground consisting of alluvium 5 metres or more in thickness, which can be distinguished from the ground of Kind II by bluff formation.

Kind IV : Alluvium consisting of soft delta deposits, topsoil, mud, or the like (including heaping up, if any), which depth is about 30 metres or more.

Land obtained by the reclamation of a marsh, muddy sea bottom, etc., of which the depth of the reclaimed ground is about three metres or more and where thirty years have not yet elapsed since the time of reclamation.

(ii) Standerds for reducing the numerical values of the horizontal coefficient of the seismic force in the Building Code of Japan, with reference to the kinds of ground, is shown in Table I.

Table I.

Kind of ground	Type of construction			
	A	B	C	D
I	0.6	0.6	0.8	1.0
II	0.8	0.8	0.9	1.0
III	1.0	1.0	1.0	1.0
IV	1.5	1.0	1.0	1.0

A : Wooden construction.
B : Steel framed construction.
C : Reinforced concrete construction, steel frame and reinforced concrete construction, or steel-concrete composite construction.
D : Masonry, brick, concrete block and other constructions.

5. 常時微動について 第8報

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田 中 貞 二

常時微動の測定結果については，現在までに，19 回にわたつて地震研究所談話会で発表し，そのうち，東京，横浜，庄内，大阪，一宮，川崎の測定結果は，すでに，地震研究所彙報に第1報～第7報として掲載した.

本報告では，常時微動の一般的性質を，第1章～第8章で述べ，第9，10章では，常時微動の測定結果を地震工学上の地盤種別判定に利用する方法について述べる.

常時微動の頻度曲線と，同じ場所での地震動の頻度曲線および振巾スペクトルとに密接な関係のあることは，われわれの研究によつて，非常にはつきりしてきたが，日本では，まだ，強震動の満足な記録が得られていないので，それらの相関性が果して破壊的地震動にもあてはまるかどうか，いい換えると，常時微動によつて求められた地盤の振動的性質が地震工学上の構造物設計資料として，果して，役立つかどうかという点では，必らずしも，明確な答えが出されたとはいえなかつた.

筆者たちは，最近，アメリカ合衆国における強震計，普通地震計の設置場所，ならびに設置予定地の約 200 カ所で，常時微動の測定を行なつた．現在，それらの場所で得られた強震記録の各種方法の解析結果と常時微動の測定結果との比較検討を行なつているが，従来，地震動と常時微動には密接な関係があるという普通地震の比較で得られた結果が，強震動にもあてはまるという実例のごく一部を第7章で紹介した.

なお，東海地震の木造家屋の被害率と常時微動の性質からきめた地盤種別との間に，相当よい相関のあることもわかつた (第 23 図参照).

強震動と常時微動との関係については，次回に詳しく報告するつもりである.