INVESTIGATION OF THE GROUND IN THE NORTHERN PART OF THE CITY OF YOKKAICHI IN THE NORTH ISE INDUSTRIAL DISTRICT

Nobuji NASU *

For the purpose of establishing a heavy industrial zone, the reclamation work is contemplated in a comparatively wide area along the northwestern coast of the Bay of Ise, that is, along the sea-shore extending over the city of Kuwana in the north, Village of Kawagoye in the middle and the City of Yokkaichi in the south. To furnish useful materials to this establishment plan, a comprehensive investigation was made in the nature of the ground and as well as on the sea-bottom. A Committee [1] was organized in August, 1958, by the specialists of seismology, geology, architecture and civil engineering in compliance with the request of the Yokkaichi City Office.

In October, 1957, the Resources Council of the Science and Technics Agency made a recommendation to the Government of Japan to put the plan of the ground investigations in practice in which a synthetic measurement of the ground nature should be made all over the main cities of Japan with the purpose of increasing the reliability in the designs of important facilities and sometime retrenching the expenditures, if possible. It was endeavoured that the present investigation made by the Yokkaichi Ground Investigation Committee meets well with this purpose.

The ground investigation may be divided into the following items.

a) Geological investigation.
b) Investigation of the tectonic changes.
c) Soil tests.
d) Observations of micro-tremors
e) Classification of the ground.
f) Plan of utilizing the ground.

In the following paragraphs, some summaries of the results obtained with respect to these items will be given.

(A) Geological investigation.

Generally speaking, the geologic formation in the Yokkaichi region is simple as compared with that in the Kuwana and Kawagoye regions [2]. In the low flat area, there can be thought to exist fault lines trending approximately in the N-S direction underneath the ground. To the east of this fault zone, the base ground was subsided and upon which alluvial deposits accumulated with a considerable thickness.

The formation and the stratification of the sand and soil layers were made clear[3] along the sea-shore from the results of the borings, of which 9 were made by the Yokkaichi Ground Investigation Committee and 21 by the Tokai Iron Manufacturing Co,Ltd., Fig.1. The pre-existing data for deep wells were also used. As most of the borings were stopped at a depth of about 40 m, the geologic formation deeper than this depth

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was unable to be determined. In general, the stratification in this district is as below.

(1)	Upper sand and gravel layers	Alluvium
(2)	Upper clay layer	20 - 40 m thick
(3)	Lower sand and gravel layers	Alluvium
(4)	Lower clay layer	20 - 60 m thick
(5)	Tertiary	Upper Pliocene

(B) Tectonic changes [4)]

Along the leveling-route running near Yokkaichi, the precise leveling surveys were made in the past. Fig. 2 shows the changes in the land-level along this route which occurred ; (I) in a period of 1895 - 1929, (II) in that of 1929 - 1931 and (III) in that of 1931 - 1947 (or 1948). In these changes, the height of the bench mark No.174.1 (at Atsuta) was assumed to be unchanged.

There can be seen no remarkable change in the land-level near Yokkaichi along the leveling route. Because, the route runs along the hill side which is comparatively apart from the centre of the City of Yokkaichi. Consequently, it is likely that the changes in this figure do not represent the actual changes which are prevailing with a considerable amount in the coastal region.

A fault may be deducible in the underground at a certain place between bench marks Nos.1461 and 1462, there discontinuous changes were observable,especially in period (III).

(C) Soil tests [5)]

The first work of the soil investigation is to gather the data which are available for the nature and the distribution of the soils in this district. These data were very helpful for our investigations.

For the upper and lower sand layers, the standard penetration tests were made in the boring holes mentioned in (A). In this test,a tube(Raymond tube) is penetrated on the bottom of the hole by two feet by falling a weight of 140 lbs from a height of 30 inches to strike this tube at its upper end. The tube is 2 feet 8 inches long and 1 3/8 inches in diameter. During this penetration, the number of blow which is necessary to penetrate one feet, N , is recorded. This value of N is widely used as an index representing the relative density of the sand.

For the upper and lower clay layers,however, sixty samples were taken up by means of the thin-wall samplers during the boring work. For these samples, various tests were made in the laboratory such as, moisture-content, liquid-limit, plastic-limit, unit-weight, void-ratio, density of solid-particle, consolidation, mechanical analysis, compression test and shearing test. From the results of these tests, the characteristics of the soil could be made clear.

The upper sand layer is fairly compact and has a average strength. Fine sand is contained with very small percentages.

The upper clay layer is soft at shallow places, but it increases its strength with increasing depth. The clay has been proved to be normal and highly compressible.

The lower sand layer is generally well compacted, though there is local variation of the amount of content of the gravel and silt. As there are few data for the lower clay layer, its physical nature is not certain. But ,the layer is thought to be fairly consolidated and has a large shearing strength.

Among the physical constants which have been determined by our soil tests, the following constants will be useful for the engineering purpose.

1) Number of penetration

For upper sand layer : $N = 15$ (mean value), moderately compact.
For lower sand layer : $N = 30 - 50$, fairly compact.
$N \geqq 100$, when gravel is contained.

2) Angle of internal friction

For upper sand layer : 30°
For lower sand layer : 35°

3) Cohesion

For upper clay layer : $C = 0.1 - 0.65$ kg/ cm^2
For lower clay layer : $C = 0.5$ kg/ cm^2 or in some cases $C = 1.0$ kg/ cm^2.

4) Coefficient of compressibility

For upper and lower clay layers : $C_v = 20 - 60 \cdot 10^{-4}$ cm^2/sec.

5) Foundations of the pre-existing structures and their subsidence

As the nature of the soil has much influence upon the stability of the structure, an investigation was made upon the foundations of the pre-existing structures and their subsidence.

The buildings in this district are, in general, the reinforced concrete buildings shorter than the four-storied. Most of them are founded directly on the upper sand layer or supported by short piles driven in this layer. As these buildings are comparatively light in their weights, there is no damage which may be due to an unequal subsidence of the foundations.

However, in the manufactory buildings which bear heavy load extending over wide areas, there can be seen conspicuous subsidence which sometime impedes the function of the production equipments, so long as the buildings rest on the upper sand layer, even though they are built on the mat-foundations. The subsidence of such buildings is especially remarkable near the sea-shore.

On the other hand, in some of the buildings which have underground rooms and bear evenly distributed loads upon the foundations, only a slight subsidence can be seen.

The heavy equipments in the manufactories or the landing-stages are generally supported by the piles which reach the lower sand layer. Although they are of heavy weight, their subsidence and unequal settling are very slight.

Fortunately, a precise survey of subsidence could be carried out in the site of a manufactory where the buildings of various constructions were built one after another. Since the erection of these buildings, the subsidence was measured by the leveling survey referring to the points fixed on these buildings. The standard bench-mark was set on the ground fairly apart from these buildings. The survey was repeated in every three months. Fig. 3 shows the mean actual values of subsidence and the calculated values basing on the results of the soil tests.

In A and B are illustrated the subsidence of oil tanks. The foundations are constructed by replacing the superficial layer of a thickness of 4.5 m by sand so as to be supported directly by the upper sand layer. As the area of loading is comparatively wide, large stresses are produced in the upper clay layer and as a result, a remarkable subsidence is actually occurring.

C illustrates an example of the foundation supported by short piles driven in the upper sand layer. As the load on the foundation practically acts near the clay layer, a comparatively large amount of subsidence has been observed. In the calculation of the subsidence, it is assumed that a load of 6.9 kg/m^2 is distributed at a depth of the lower ends of the piles.

In D, is illustrated a foundation of the structure which has an underground room. In this case, the effective load which acts upon the clay layer is equal to the total weight minus the weight of the sand displaced. Therefore, the subsidence is very slight as compared with the case of the building which has no underground room. The subsidence-curve (D) is that of an underground water-tank supported by the piles driven in the clay layer. The load in this case is 12 ton/m^2. The bouyancy is estimated to be 14 ton/m^2. Therefore, no compressive force has been acting practically since the tank was constructed.

In E, a structure is shown which is supported by the piers constructed by the method of caisson. In this case, the subsidence is slight such that it measures 3 cm in the past four years and now practically stopped. This kind of piers proves to be safe against the unequal subsidence.

It is essentially important that the ground is not only safe against the load which acts on the foundation, but also against the subsidence which caused the damage upon the upper structure. Therefore, the design-load on the foundation, that is, the allowable bearing power must be chosen so as to satisfy these two conditions. If the various natures of the soil can be determined by the tests as in our present investigation, the amount of subsidence and as well as the allowable bearing power may be calculated. The foundation may be determined by using the diagrams as shown in Fig.4. In these diagrams, the safety-factor for the shearing strength of the clay is taken as 3, which will be necessary for securing the foundation against the failure.

We have experienced, however, that the unequal subsidence of the building is remarkable when the subsidence of the building as a whole is considerably large. In the case of the pier foundation or the mat-foundation which is effective to distribute the load widely in the soil layer, the amount of unequal settling is in a small proportion to the total subsidence when it is compared with that in the cases of the isolated and belt foundations. Actually, it has been found that the limit of the settling of the building as a whole which causes no damage due to unequal subsidence is 10 cm in the isolated foundation and 20 - 30 cm in the case of the mat and the pile foundations.

(D) Observation of micro-tremors [6)]

1) Micro-tremors on the land

The observation of the micro-tremors was conducted for three days from November 20 to 22, 1958. The points of observation were selected at 13 places in the City of Kuwana, 13 places in the Village of Kawagoye and 76 places in the City of Yokkaichi, Fig. 5 .

The instruments which were used in this observation were the electromagnetic seismographs registering one horizontal component motion on the smoked papers. This type of seismograph was consisted of the transducer, low-frequency amplifier and pen-writing oscillograph. In ordinary cases, the magnification was adjusted to be about 8,000 for a period of 0.4 second of the ground motion. The value is the peak value of the magnification in the frequency chracteristic curve of this seismograph.

The seismographs were set in the observation-car. At the point of observation, only the transducer was installed on the ground and the record of tremors is made in the car. The electric power was supplied by the secondary batteries by means of the invertor. Thus, we could make observation at any place, even there was no commercial electric supply. The record of tremors at one place was made for three minutes.

The method of constructing the frequency curve of the micro-tremors is as follows :

The record of tremors lasting two minutes is selected out of the record of three minutes. For all the waves in this two-minute-record, times are determined between two consecutive points at which the waves pass across the zero-line. The period of the wave is defined as the time which is twice as large as the time thus determined. The accuracy of determining the period is 0.02 second.

Let T_1 be a certain period of the tremor. The periods which differ from this value by a small amount, ΔT_1 , are represented by T_1 . Then, the number of waves lying in an interval of $T_1 + \Delta T_1$ is taken as the frequency of occurrence of the waves of which periods are T_1. In this case, the value of ΔT_1 is adjusted in proportion to T_1.
The specimen frequency-curves which were thus constructed are shown in Fig. 6 .

The amplitude of wave is determined by taking the mean value of the amplitudes of a certain number of successive waves which are recorded with comparatively large amplitudes.

2) Micro-tremors on the sea-bottom

The micro-tremors on the sea-bottom were observed at 16 points by means of the seismograph specially designed for the sea- observation. The transducer of this seismograph is contained in a brass case which has an electric heater of 80 watt/hour at its lower end, Fig. 7. The pendulum of the seismograph is an inverted pendulum having a natural period of vibration of 1.0 second. The brass case is hung by brass rings in a water-proof container. The electric heater is made so as to be in the solid paraffin in this container. After this container is set down on the sea-bottom, the electric current is supplied to the heater to melt the paraffin enabling the pendulum to rest in a vertical position automatically. The exact position of the pendulum is detected by means of the electric contact between the pendulum and the brass case. If the pendulum is found to be in a good position, the electric current is cut off to cool the paraffin which fixes the brass case to the container.

The instruments were set on a small boat. At a point of observation, the boat is anchored to set the seismograph on the sea-bottom. At this time, wires and cables are necessary to be made loose as possible.

From the results of the sea-observations, the classification of the ground was made similarly to the case of the observation on the land. The points of observation on the sea-bottom are distinguished by dashes attached to their serial numbers, Fig. 5.

It has been found that the characteristics of the tremors on the sea-bottom are very similar to those of the tremors which were observed on the land.

(E) Classification of the ground

1) First proposal of the classification

It has been known that the predominant period, the mean period and the largest period do not change their values whenever they are measured. Here, we must remember that the largest period is the one which is largest among those of the waves registered at a certain point by means of our seismograph which has a natural period of oscillation of 1 second. The physical meaning of this largest period is not yet made clear, but it is convenient to use this period in the classification of the ground practically.

In the case of the frequency-period curve in which the predominant period can be seen clearly, it is known that the value of the mean period agrees with that of the predominant period. Therefore, we may use the mean period instead of the predominant period.

In the classification of the ground, diagrams as shown in Fig. 8

are proposed to be used. As can be seen in these figures, the values of the largest periods are plotted against the mean periods which were determined for various points of observation. Border-lines are drawn in parallel to the ordinate and the abscissa of this figure to classify the points into four kinds, I , II , III and IV. The geological classification of the ground as is used, for example, in the seismic zoning map of Tokyo, is as follows :

Kind I, tertiary or other very hard ground (not commonly found near the ground-surface in Tokyo).

Kind II, consists mainly of diluvium or of the ground with gravel

strata 5 meters or more in thickness, forming the plateau of the uptown of Tokyo. The river basins located in the plateau which have the alluvial deposits are designated as Kind III, whereas the basin which has thin deposit is designated as Special Kind II.

Kind III, consists of alluvium 5 meters or more in thickness, which can be distinguished from the ground of Kind II by bluff formation.

Kind IV, consists of alluvium 30 meters or more in thickness or of reclaimed land. An exception is made for such thick alluvium where a firm gravel stratum lies near the ground surface, the ground is classified as Kind III.

In designating the boundary of each classified area. administrative considerations have been taken into account.

As point No.61,for example, lies in a space corresponding to Kind II in the foregoing figure, the ground represented by this point belongs to Kind II. Point No.42 lies in a space which is intermediate between III and IV, the ground near this point may be classified as Kind III - IV.

2) Second proposal of the classification

We have experienced that in a region where the ground is so soft that it may be classified geologically as Kind IV (or Kind III, sometime), nevertheless there appear short periods of tremors as the predominant period as in the case of a hard ground. On the other hands, it is recognized that the amplitudes of the tremors are usually larger on the soft ground than on the hard ground. Thereupon, it is convenient to plot the largest amplitude of the tremor aginst the predominant period. Thus, the classification of the ground can be easily made sometimes.

In Fig. 9, the largest amplitudes are plotted against the predominant periods,both in logarithmic scales.

From the above two proposals, the classification of the ground could be made at 76 points as shown in Fig. 5 . Among these points, there are 3 points at which the disturbances due to machineries of nearby factories were so large that the records of tremors were complicated and the classification became uncertain. These points are represented by circles in this figure.

(F) Plan of utilizing the ground

From the results of the investigation so far made in the northwestern part of the Ise Bay, the following utilization of the ground is recommendable.

In the northeastern plain extending from Kawagoye to Kuwana, the underground formation is likely uniform, that is, there lie the upper sand layer, upper clay layer, lower sand layer and lower clay layer.

The uppermost sand layer which is 2 - 10 m thick has a moderate strength as the sand layer and is capable of supporting the short concrete buildings.

The upper clay layer is fairly thick, about 35 m near the mouth of River Nagara, but it becomes thin and about 1 m near the River Kaizo. Although the strength of this layer increases with increasing depth, the layer is generally so soft that it is not suitable for the foundation of any structure. The subsidence of the foundation will be liable to occur, if this layer is laid under a continuous loading due to structures built on it.

In general, the lower sand layer has a thickness of about 30 m, but a thickness of only 1 m near the River Kaizo. The geological age of this layer is uncertain whether it is the earlier alluvium or the later diluvium. The layer is well compacted and favourable to the foundation of the structure.

As the lower clay layer is of an older age than the former layer, its hardness is sufficiently large as we can believe that there will be no objection occurring in the structure, if the foundation is laid on this layer.

As mentioned above, the uppermost sand layer may be used for the foundation of the short building, but the region where this layer is very thin or lacking and the upper clay layer appears directly on the ground surface is not suitable for any structure even if such a region is reclaimed. There the usage of the ground is strongly limited to the specially light facility.

In the erection of the heavy structure or of the manufacturing facility which needs special precision, the foundation must be reached the lower sand layer. In the region lying to the southwest of the River Machiya, this layer lies at comparatively shallow places. Therefore, this region may be used for the heavy industries.

As the lower clay layer has a possibility of consolidation in a long time owing to the gradual loss of contained water, whether the layer is loaded or not, there is a fear of sinking of the ground at the places where this layer is thickly accumulated. for examples, along the coast near Kuwana and Kawagoye. In the design of structure, the extent of the subsidence should be taken into consideration.

As the present investigation was limited to find out the suitable soil layers for the foundation of the heavy industrial facility, the borings specially made by our Committee stopped at comparatively shallow places (mostly at depth of 40 m), it is sufficient to determine the geological condition down to the tertiary layers. We are deeply impressed that the investigation which was made this time in the Yokkaichi district is very useful as the practical method of determining the nature of the ground, especially in the future ground investigations which will be made for the city-planning such as recommended by the Resources Council of the Science and Technics mentioned ahead of this paper.

Bibliography

1) Working-groups were organized by the members of the Earthquake Research Institute (N.Nasu, R.Takahasi, F.Kishinouye, H.Kawasumi and K.Kanai), the Building Research Institute (K.Takeyama and Y.Koizumi), Geological Survey Institute (N.Miyabe and M.Shiki), the University of Nagoya (I.Matsuzawa) and the Kambe High School (H.Akamine). Report of the Committee (in Japanese with summary in English) was published in November, 1958.

2) Isao Matsuzawa : General description of the geology in the northern coastal region of the Bay of Ise. (Report of the Committee cited in 1).)

3) Hideo Akamine : Geology in the northern area of Yokkaichi. (ditto.)

4) Naomi Miyabe : Tectonic changes in the northern Ise district. (ditto.)

5) Yasunori Koizumi : Report of the soil tests. (Report cited in 1).)
   (a) Nature of soils.
   (b) Foundations of pre-existing buildings and their subsidence.
   (c) Allowable bearing power on the foundation and consideration of the design of foundation.
   (d) Lists showing the results of soil tests.

6) Kiyoshi Kanai and Nobuji Nasu : Observations of micro-tremors. (ditto.)
   (a) Forewords.
   (b) Observation of micro-tremors on the land.
   (c) Observation of micro-tremors on the sea-bottom.
   (d) Consideration of the results.
   (e) General description of the micro-tremors.

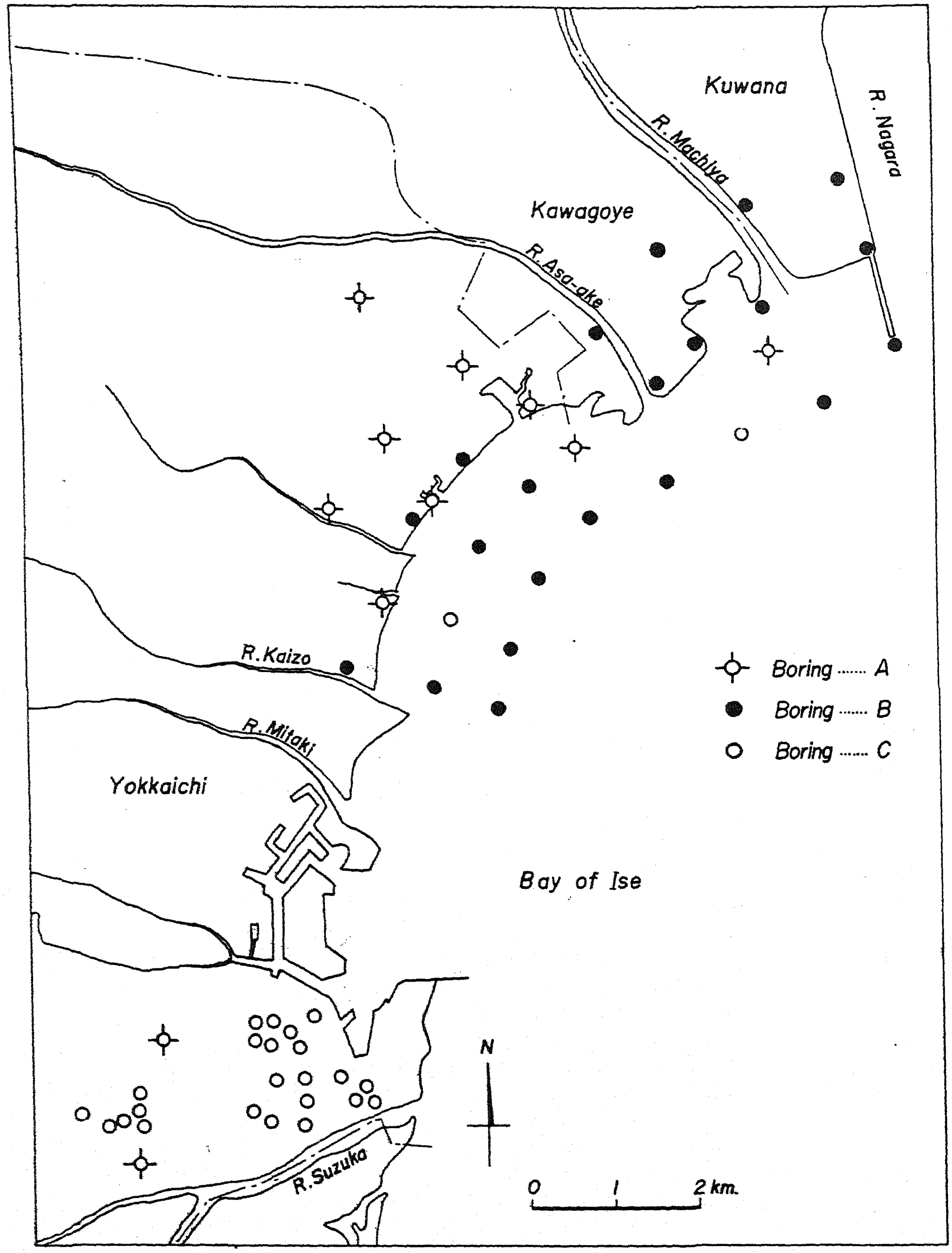

Fig. 1. Positions of borings.

Boring A....Sampling and standard penetration test were made.
Boring B....Penetration test was made only.
Boring C....Other borings of which data were used as reference.

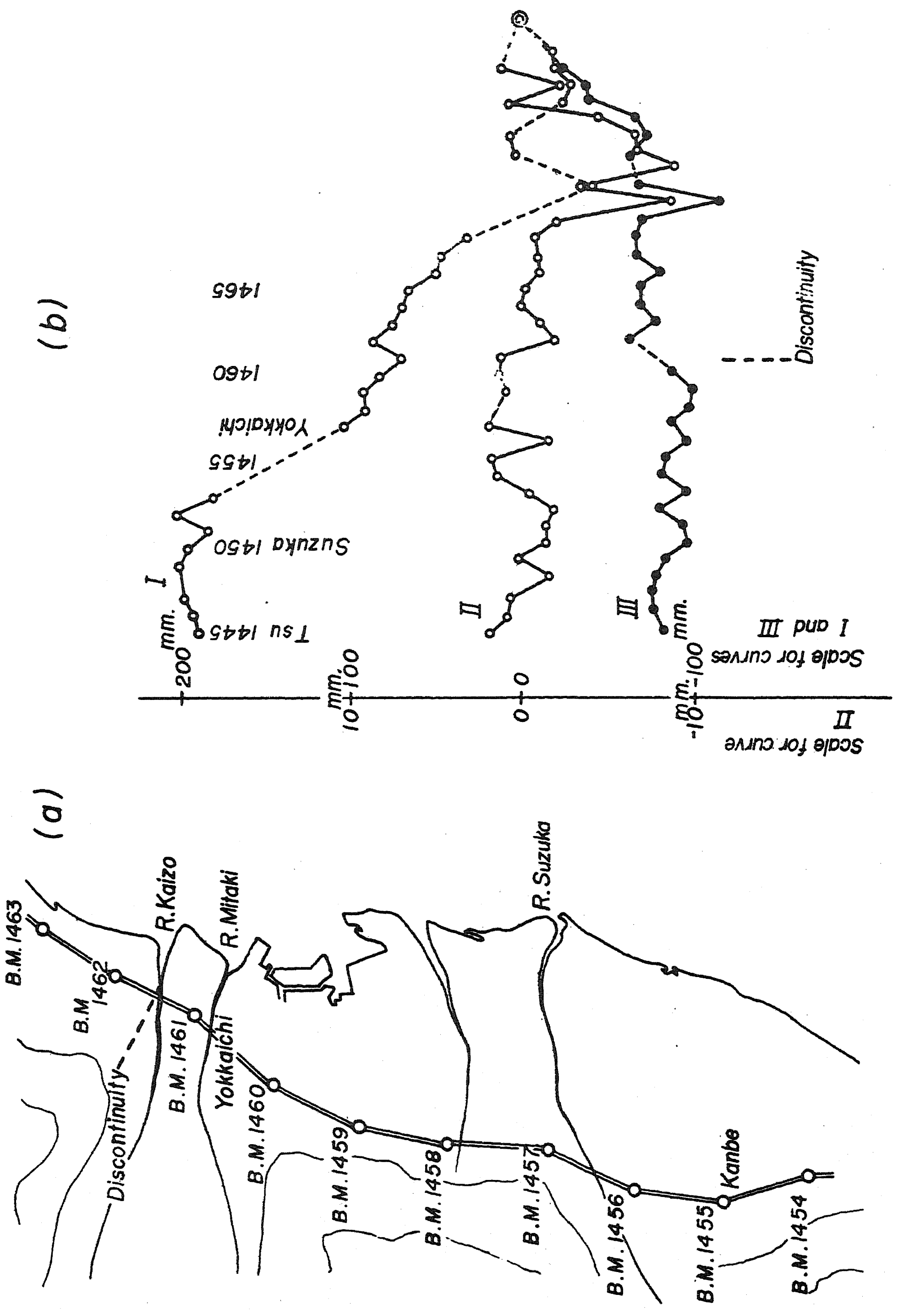

Fig. 2. (a) Leveling route. (b) Tectonic changes.

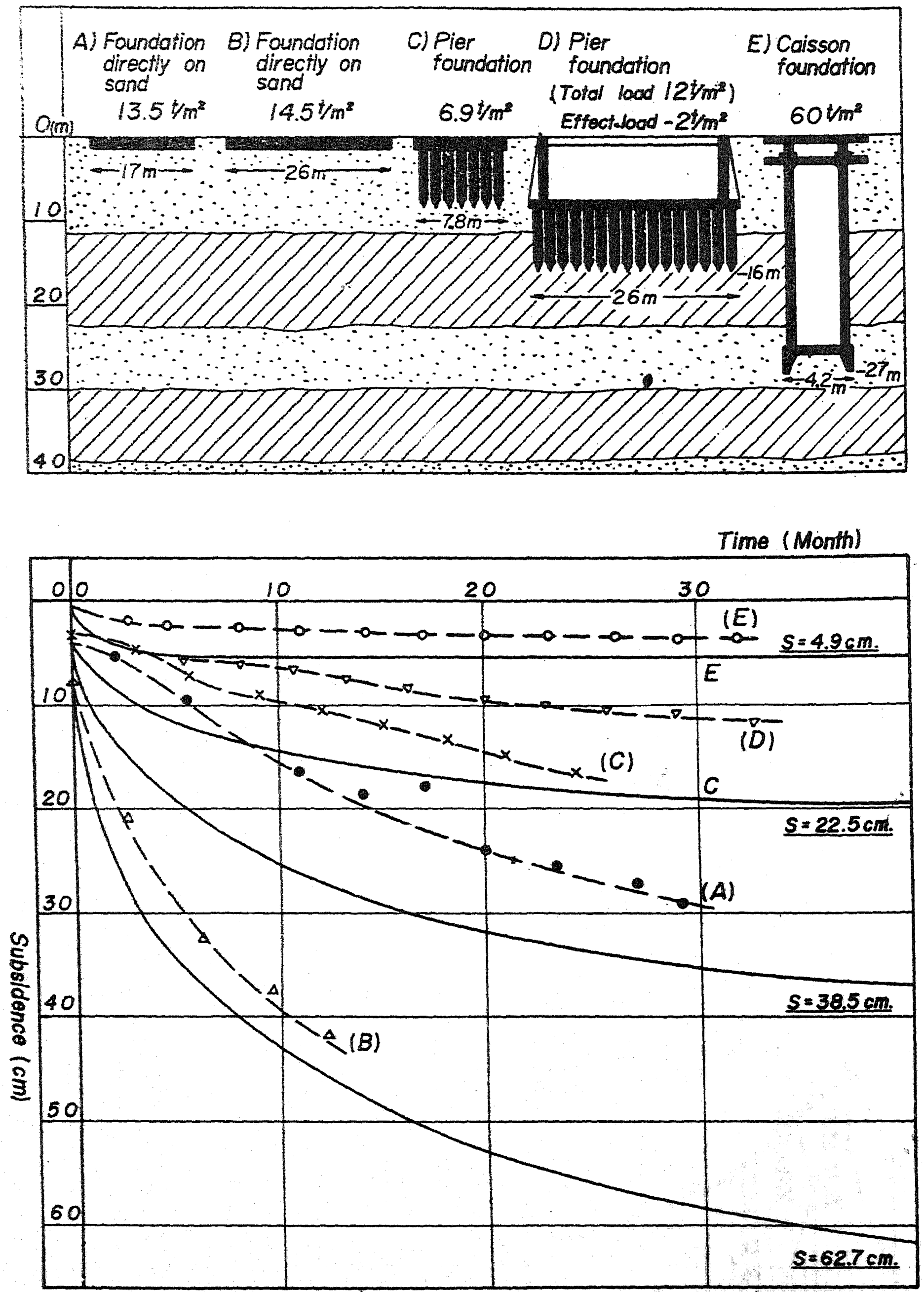

Fig. 3. Subsidence of various structures.

Curves in full-lines are calculated and those in broken-lines are actually observed.

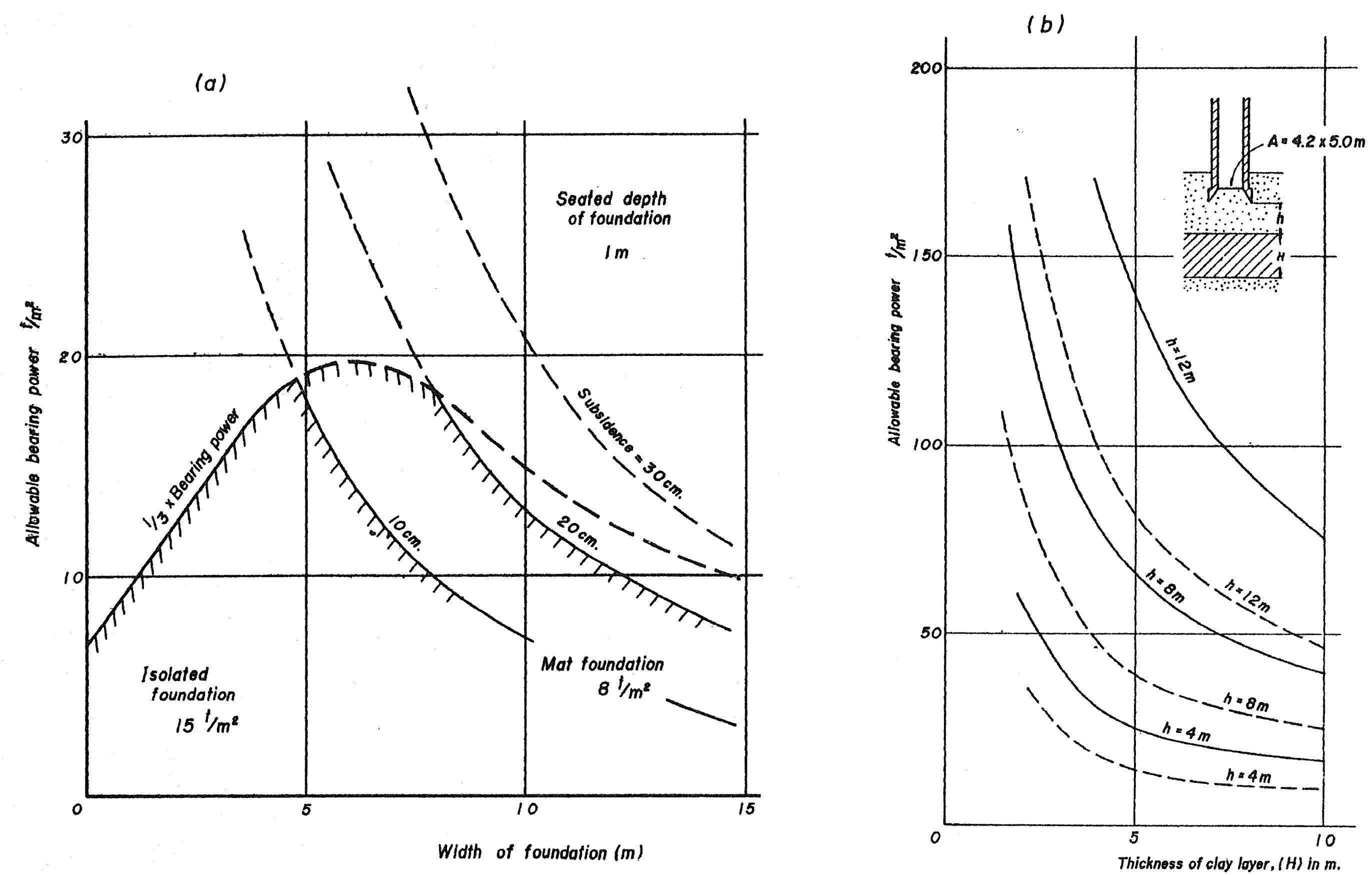

Fig. 4. (a) Allowable bearing power on the foundation supported by the upper sand layer 10m in thickness. Loads on the foundation which are reaponsible for the subsidence of 30, 20 and 10cm are calculated. Thick-line indicates the one-third of the maximum bearing power. Values of the bearing powers commonly used for the reinforced concrete buildings are shown according to the type of foundation.

(b) Load intensity on the pier of which base-area is 4.2X5.0m. Loads are responsible for the subsidence of 3 and 5cm. Calculation was made for various values of H and h.

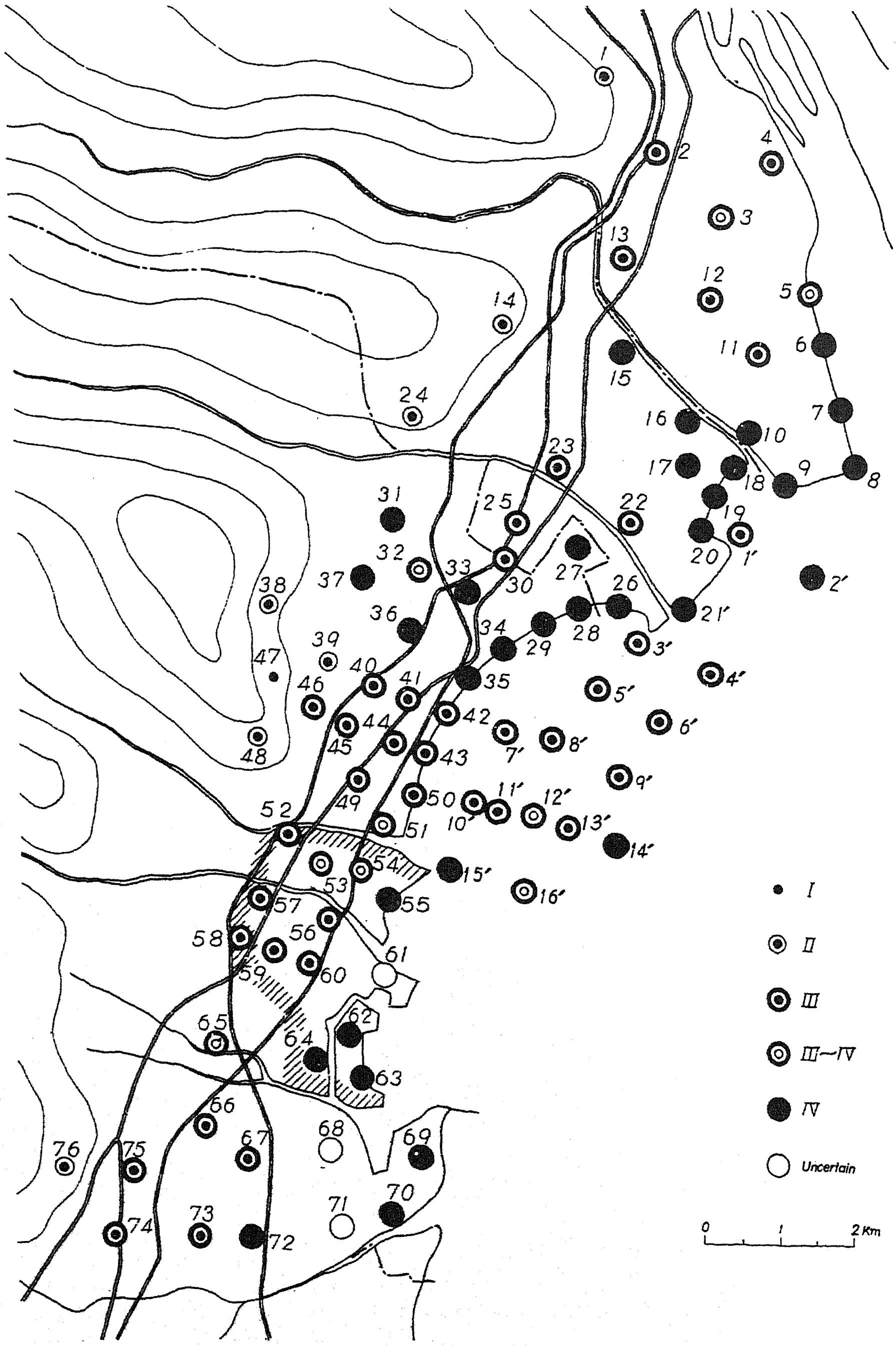

Fig. 5. Points of observation of the micro-tremors and the designated kinds of ground at these points.

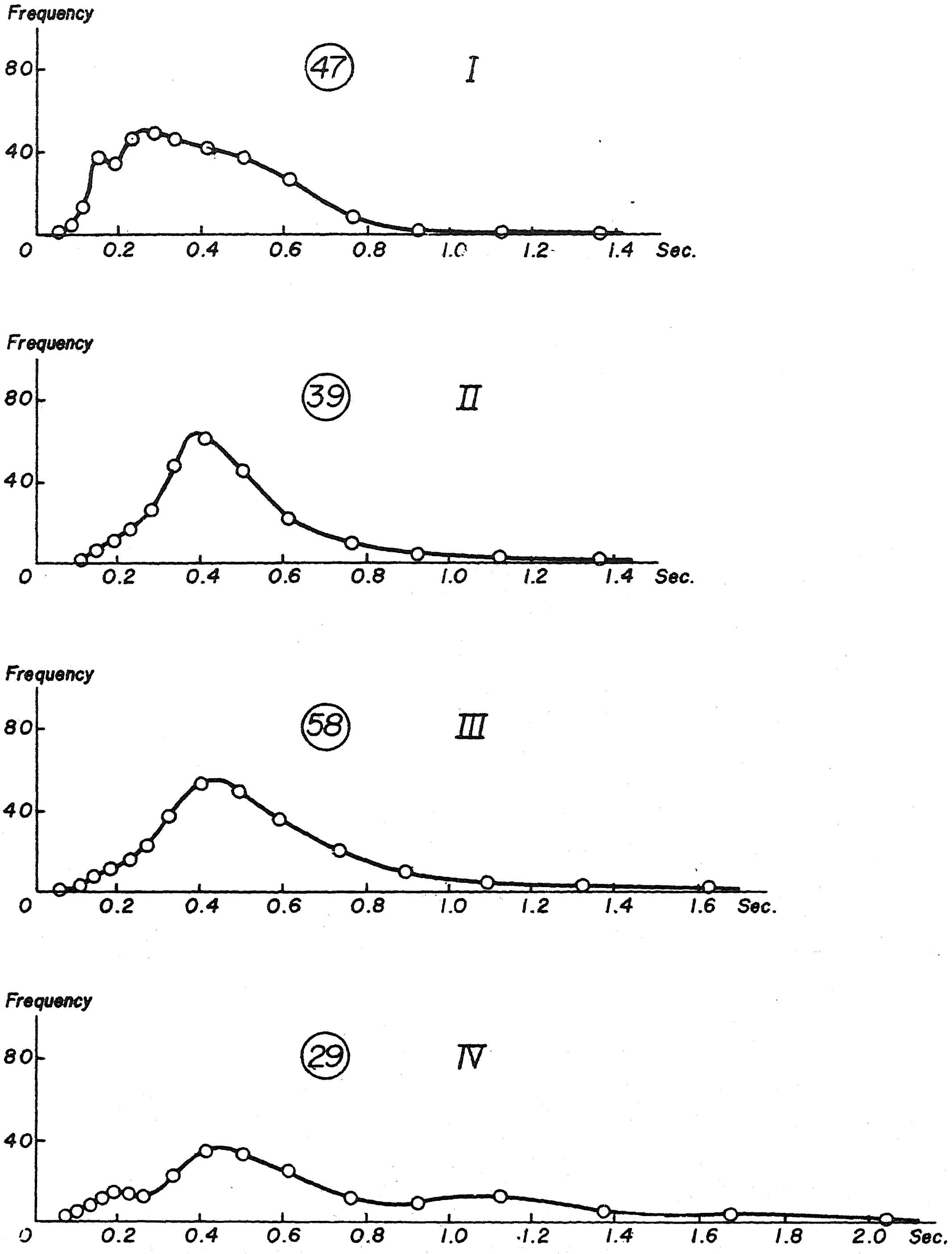

Fig. 6. Specimen frequency-curves of micro-tremors.

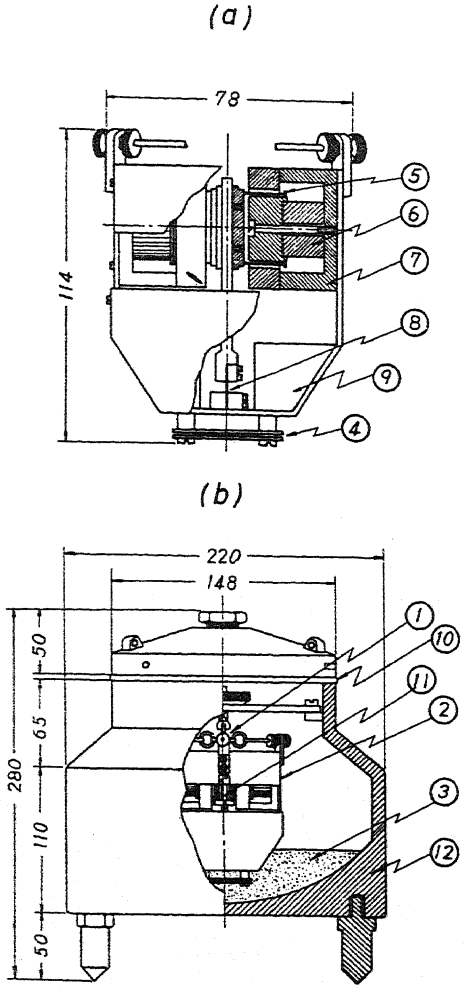

Fig. 7. Seismograph for sea-observation.

(a) Pendulum of seismograph and brass case.

4 .. electric heater, 5 .. moving coil, 6 .. core piece of magnet, 7 .. parmanent magnet, 8 .. supporting spring of pendulum, 9 .. additional weight.

(b) Water-proof container.

1 .. hanger, 2 .. brass case, 3 .. paraffin, 10 .. packing, 11 .. electric contact for detecting the vertical position of the pendulum, 12 .. container.

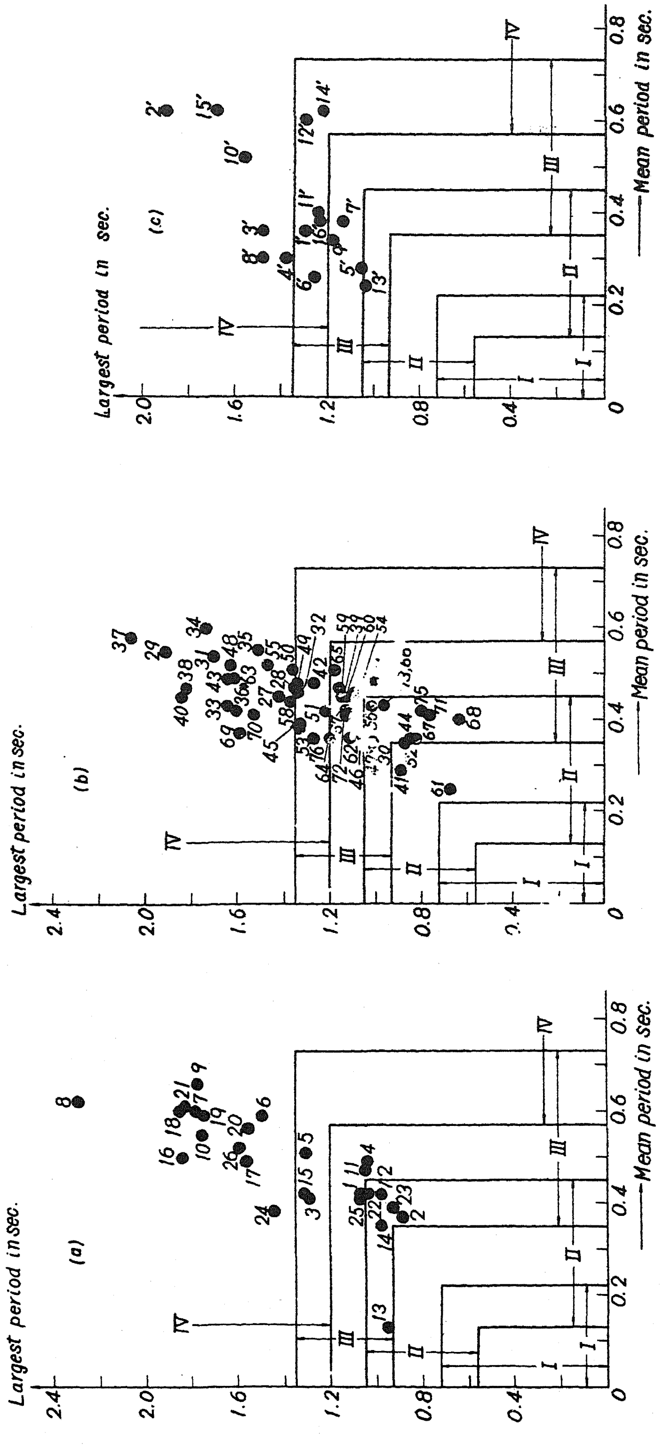

Fig. 8. Classification of ground (First proposal).

(a) On the land : Kuwana and Kawagoye areas.

(b) On the land : City of Yokkaichi.

(c) On the sea-bottom.

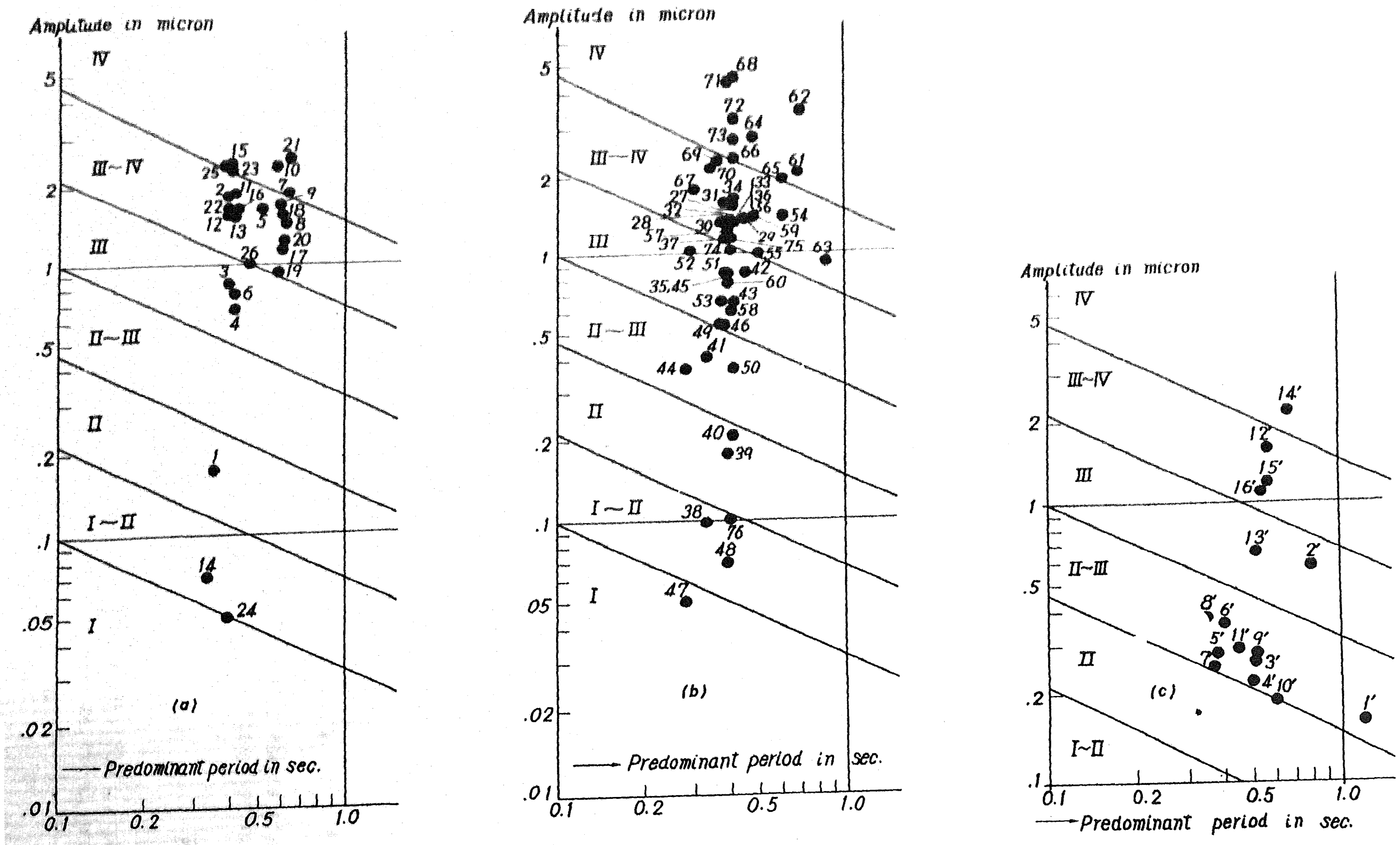

Fig. 9. Classification of ground (Second proposal).

(a) On the land : Kuwana and Kawagoye areas. (c) On the sea-bottom.

(b) On the land : City of Yokkaichi.

DISCUSSION

V. A. Murphy, New Zealand Government Railways, New Zealand:

1. Please refer to the 3rd paragraph on the 7th page of your paper.
   Kind III what do you mean by bluff formation?

2. Refer to the last paragraph on the 7th page of your paper.
   How many points are necessary before classifying the kind?

3. Refer to the middle of page para. on the 8th page of your paper starting "In general ...... structure".
   How do you define "diluvium"? Is it done by soil testing or by geological age?

N. Nasu:

1. The explanation is not good, I think.

2. One point for one place.

3. Not by the soil test, but by the geological consideration.