

GROUND INVESTIGATIONS IN CITY-AREAS IN JAPAN

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In the city planning or the site-selection of the industrial facilities, the ground formation is one of the important factors which should be taken into consideration. According to the subsoil condition, the type of the foundation of structure is decided, and consequently the quality of the ground has a close relation between the construction cost of the facilities, and as well as to the safety against the earthquake. Needless to say, the subsidence of the ground which has become a great trouble in various cities, such as Niigata, Osaka, Amagasaki, Tokyo, etc., is closely related to the formation, especially to that of the soft and weak ground.

Recently, the city accomodation and the industrial facilities are trending to be developed on a scale becoming larger and larger, or with an increasing degree of precision, and actually there have been built several super-heavy weight structures and the buildings which required a high precision of level never experienced in the past. Although there are many recent plans of establishing the city accomodations or the industrial facilities on various grounds which are made by reclaiming the land from shallow sea or low marshy areas by drainage, it should be borne in mind that, if the plans are thoughtless as lacking in a full investigation of the ground nature, the plans are apt to encounter with various obstacles in the future.

The investigation of the ground, however, was rather few in number in the past. We can point out only a few examples, such as the geological investigation in Tokyo and Yokohama made by the Reconstruction Bureau after the great Kwanto earthquake of 1923, and the compilations of the pre-existing data for borings in several areas made by the efforts of architects, geologists and others.

In October, 1957, the Resources Council of the Science and Technics Agency presented to the Government a document entitled "Advice for the promotion of the ground investigation plan in city-areas" in which was emphasized the necessity of the ground investigation which should be started promptly in the main cities by establishing a certain new national organization. In response to this advice, the Ministry of Construction started the regular investigation work in 1960, under the name of "The Ground Investigation in Cities." The Special Committee was organized in the Ministry for this purpose. The Committee enacted the "Instructions for collecting and arranging the pre-existing materials available for the ground investigation in city-areas" and the "Standard specifications of the ground investigation works in city-areas", in July, 1960, and decided to follow these instructions and the specification in every future investigation as possible.

Before this time, a rather comprehensive investigation was made of the ground near Yokkaichij in Mie Prefecture, with the results already reported in our previous paper. ¹⁾ This investigation furnished us a good opportunity of fixing our principle and methods of the ground investigation in city-areas.

Generally, the ground investigations have been executed in co-operations, both technically and financially, with the Ministry of Construction and the local public organizations, such as, the Prefectural Government or municipal offices concerned. In every investigation, the Local Committee for the Ground

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Investigation was organized by the regular specialist-members of the Ministry and the persons in the local organization.

From the beginning of 1963, the greater part of the planning and execution of the investigation was entrusted by the Ministry to a newly established Committee named the "Committee for Ground Investigation in Cities of the Whole Country" ²⁾ and at present, the office of this Committee is in the Resources Exploitation Research Institute, a foundational juridical person.

Although there was a change in the matters of jurisdiction over the Committee, the regular specialist-members were not altered. The regions which have been, or are being, investigated by the Committees above mentioned up to present are as follows : (See, also Fig.1.)

1. Marginal region of the Bay of Ise. (in 1960,1961)
2. Marginal region of the Bay of Tokyo. (in 1960,1962)
3. Imizu area in Toyama Prefecture. (in 1961)
4. East Mikawa region, Aichi Prefecture. (in 1961)
5. Tokushima and Komatsujima areas (in 1961,1962)
6. Kashima area, Ibaragi Prefecture. (in 1962)
7. East-Iyo area, Ehime Prefecture. (in 1962)
8. Sendai and Shiogama areas (in 1962)
9. Fukuyama and Kasaoka areas. (in 1962)
10. Marginal region of the Bay of Osaka. (in 1962,1963)
11. Kinuura area, Aichi Prefecture. (in 1963)
12. Jōban area, Fukushima Prefecture. (in 1963)
13. Harima area, Hyōgo Prefecture. (in 1963)
14. Coastal area of the Bay of Suruga. (in 1963)

The results of these investigations will be published in Series of Report of the Committee, and the following five reports have been issued.

- Volume 1. Ground in the Northern Part of the Marginal Region of the Bay of Ise. (1962)
2. Ground in the Southern Part of the Marginal Region of the Bay of Ise. (1962)
3. Ground in the Imizu Area, Toyama Prefecture. (1963)
4. Ground in the East-Mikawa, Aichi Prefecture. (1963)
5. Ground in the Hiroshima Area. (1964)

The above volumes were all printed at the Printing Bureau of the Ministry of Finance, and are sold by dealers of the government publications. The Reports of Investigations in the areas other than the above five are now in preparation.

Beside the reports enumerated above, the Ministry of Construction issued the following one.

Outlines of the Ground in the Marginal Region of the Bay of Tokyo. (General Report.) Planning Bureau of the Ministry of Construction, 1962.

Methods of Ground Investigation.

The projects which are usually adopted in the ground investigation are as follows :

- a) Collection and arrangement of the pre-existing materials.
- b) Topographical (micro-topographical) and geological surveys.
- c) Ground geological surveys.
- d) Soil tests.
- e) Designs of the foundation of structure.
- f) Observation of micro-tremors at an ordinary time.
- g) Plan of utilization of ground.

In the following paragraphs, some explanations will be given of these projects.

(1) Collection and arrangement of the pre-existing materials.

In order to pursue the ground investigation effectively in a short time, it is necessary to gather, as many as possible, the materials for the subsoil conditions which have been obtained by borings made in connection with the construction of new railway, highway, canal, electric transmission line, harbour facilities, etc., and the data for deep-well borings are also available. However, as these borings were made specially for various purposes, they do not give us a good reference for our investigation necessarily, because of an unsatisfactory precision and unreliability. Therefore, the Committee decides the positions of the borings which are made by its own hands with a careful consideration so as to become possible to test the subsoil formations roughly determined by means of the pre-existing materials for borings, that is to say, to give the finishing touch to the pre-existing borings.

(2) Topographical (micro-topographical) and Geological surveys.

The methods of the geological survey adopted in this investigation are common in ordinary geological surveys. In some cases, the surveys were made very precisely, for example, in the East Mikawa region³⁾. The soil layers, however, determined by geological surveys do not necessarily agree with those determined by the ground geological surveys, because in the latter surveys, the soil layer are mostly classified in consideration of their physical and mechanical properties, such as, hardness (or the N-value of standard penetration) or the bearing capacity, etc.

In the micro-topographical surveys, the area of investigation is first divided into several number of topographical units, such as plains and mountainous areas usually. Each plain is further divided into lowlands, plateaus and terraces, and their positions are determined. The lowland may be specified into several kinds according to the shape and the process of formation, such as the land reclaimed by drainage, tidal plain, delta, overflow plain, etc. For the marine plain, the process of formation of the shoreline is taken into consideration, that is, transgression and regression.

For the plateau, its process and age of formation are usually taken into consideration.

Generally speaking, through the micro-topographical surveys, we can find out the processes by which was formed the ground at any point in the investigated area. The ground which is specified micro-topographically has the mechanical characteristics which are peculiar to the ground. It is noteworthy

that the result of the micro-topographical survey shows a close relation to the distribution of the Upper Sand-and-gravel layer which will be explained later. In practice, it may be said that the result of micro-topographical survey and the distribution of the superficial soil layer as cited here serve mutually as a complementary method of determining the nature of the soil layer in the ground surface. As the effect of the earthquake upon structures differs remarkably according to the subsoil condition, especially to the nature of the superficial soil. So, we can say, in other words, that the micro-topographical division specifies, or indicates, the degree of the seismic damage.

In the micro-topographical survey, air-photos of a scale of 1/10,000 or 1/15,000 (sometime of 1/5,000) are used. Of course, field surveys are made.

(3) Ground geology.

A. General principle of ground geology.

As a principle, the ground is classified from the viewpoint of supporting the structures. As in the marginal region of the Bay of Ise⁴⁾, the coastal areas in various districts of Japan have a common subsoil formation, that is, the upper part of the ground is stratified by the following soil layers, in a direction from top to bottom.

- 1) Upper Sand-and-gravel ; (US)
- 2) Upper Clay ; (UC)
- 3) Lower Sand-and-gravel ; (LS)
- 4) Lower Clay ; (LC)
- 5) Substratum or Bedrock ; (D.T.O.)

The bedrocks are usually of the tertiary age, but in some cases they are of the older diluvium overlying the rocks of old age.

It is necessary to make us easy to see through the thicknesses and the shapes of the lower boundaries of these constituent layers, and also to classify the ground according to the state of combination of these layers, and determine the types of the ground. From these types of ground, we can find out the depth of the soil layer safely supportable of the structure, or the thickness of the alluvial deposits which possibly cause the damage of subsidence.

In the following paragraphs, brief explanations will be given of the general characters of these constituent layers.

B. General character of constituent soil layer.

I. Alluvial layers.

1) Upper Sand-and-gravel layer ; (US)

Layer (US) contains or intervenes silt and clay sometime. In this case, it is necessary to make clear the positions (depths) of these silty and clayey parts. If the thickness of the sand-and-gravel, or of the sand, is greater than 3 m, excluding the silty and clayey parts, and the compaction of the layer is in such a degree that the N-value of the standard penetration

is greater than 10 throughout a depth of more than 3 m, then, layer (US) may be judged as fully bearable of the light-weight structures. But, the layer may not be so, if the N-value is less than 10 and the weak and soft Upper Clay layer (UC) underlies layer (US), even though the thickness of the latter layer is greater than 3 m. It is needed to point out such a dangerous type of ground to which we must pay attention at the time of the design or construction of structures.

2) Upper Clay layer ; (UC)

For this layer, it is important to show the areal distribution and the thickness. The physical and mechanical properties of this layer must be made clear as possible by the soil tests. Usually, by the soil tests, we determine the uniaxial compressional strength, preloading, cohesion, compression index, angle of internal friction, degree of over-consolidation, etc.

It has been found that there is a close relation between the mechanical properties of the clay and the depth of the upper boundary of layer (UC). Actually, the contours in the map drawn for equal values of cohesion, angle of internal friction and over-consolidation almost agree with the contours showing the depths of the upper boundary of layer (UC).

As layer (UC) is mainly consisted of soft silt and clay, the layer is not reliable for supporting the structure. The layer is easily consolidated even by the load of light-weight structure, and the consolidation of this layer becomes the principal cause of the settlement of the ground in a wide area.

At the point where the lower boundary of layer (UC) is steeply inclined, or the sandy soil exists in the upper part or lower part of layer (UC), or this kind of soil is intervened in the layer, there is a possibility of an unequal settling of the structure, because in such points, the thickness of the clayey soil changes very locally.

II. Younger diluvial layers.

1) Lower Sand-and-gravel layer ; (LS)

Some of the lower sand-and-gravel layers may be classified into several parts from the stratigraphical point of view, but, in our ground geology, we meet many cases in which there is no difference of strength (or bearing power) between these parts and thus may be treated as a single layer.

There are two cases of the layer, that is, the layer is mostly constituted of sand, and of sand-and-gravel. Generally, the N-value of the standard penetration is smaller in the former case as compared with that in the latter case. For example, $N = 10 \sim 30$ in the former, and $N = 20 \sim 40$ in the latter case. It must be added that the thickness of layer (LS) must be sufficiently large, if the structure is supported by this layer. In the East Mikawa region this thickness is $4 \sim 6$ m.

Generally speaking, layer (LS) is a good substratum for the structures. But, when the soft lower clay layer (LC) underlies this layer and the thickness of layer (LS) is small, layer (LS) may not be used as the stratum which supports the heavy-weight structure or special structure.

2) Lower Clay layer ; (LC)

Layer (LC) is also consisted of silt , clay and loam. The mechanical properties of the soil have a close relation with the depth of the upper boundary of layer (LC). Usually, the soil tests are made to determine cohesion, angle of internal friction ,degree of over-consolidation, etc.

As this layer is compacted fairly well, it may be used as the supporting stratum for light-weight structure. But for a heavy-weight structure or a special structure which requires a high precision of level, the layer becomes questionable to be so.

III. Bedrock (Substratum).

As the bearing capacity is large,there is no special problem of supporting the structure, if the bedrocks lie at a depth smaller than 30 m. Beyond this depth, the foundation of the structure becomes difficult both technically and economically.

C. Local characteristics of the ground geology.

Generally, the constituent layers of the ground geology may be divided into two kinds from the viewpoint of the bearing capacity for structures, i.e.,

- I. Layers capable of supporting the structures.
- II. Layers unbearable of the load of structure, and cause subsidence due to consolidation.

In case I, the bearing capacity decreases generally in the following order.

- a) Rocks of old age, substratum of middle and older diluvium.
- b) Lower Sand-and-gravel layer ; (IS).
- c) Upper Sand-and-gravel layer excluding the silty and clayey parts ; (US).

In a), the bearing capacity is generally so large that there will be no question of supporting any kind of structure; in b), the capacity is expectable to be greater than 30 ton/m², while in c), the capacity of 15 ~ 30 ton/m² is expectable, and the direct foundation or friction-pile foundation may be used for ordinary structures.

In case II, the following four layers are included.

- a) Clayey part of layer (US).
- b) Layer (UC).
- c) Layer (LC).
- d) Humus.

The majority of layers in a) and b) are so weak and soft that they undergo rapid subsidence due to consolidation by the action of load. Layers in c), layers in d) which lies in the surface of terrace and some of the compacted parts in a) which are mixed with sand , have generally a bearing capacity of more or less than 15 ton/m². Therefore, ordinary structures may be supported by them, but, a full examination of the ground must be made when the heavy-weight structure is built.

D. Distribution of types of ground.

In general, a map is constructed which shows the distribution of various types of ground. These types are determined from the nature of the constituent soil layers and their thicknesses. For example, in the East Mikawa region, the types of the ground have been classified as in the following table. See, also Fig. 1.

Table 1. Types of ground in the Mikawa District.

Type	Thickness of constituent layer				Layer for supporting structure	
	(US)	(UC)	(LS)	(LC)	Light-weight (Direct foundation)	Heavy-weight, or requiring precise level
	m	m	m	m		
H	-	-	-	-	Mid. and old diluv.	Mid. and old diluv.
L ₁	-	-	3 - 20	5	(LS)	" " " and (LS)
L ₂	-	-	3 - 10	5 - 10	(LS)	Mid. and old diluv.
A ₁	3 - 15	0 - 3	0 - 3	0 - 5	(US), (LS), M.O. diluv.	" " " and (LS)
A ₂	3 - 15	3 - 5	3 - 10	0 - 5	(US)	ditto
A ₃	3 - 15	3 - 5	3 - 10	5 - 10	(US)	"
B ₁	3 - 15	5 - 20	3 - 10	0 - 5	(US)	ditto
B ₂	0 - 3	5 - 20	3 - 5	5 - 10	----	"
X	-	3 - 20	3 - 10	0 - 10	----	"

In the ground which belongs to type-H, type-L₁ or type-L₂, the upper layers (US and UC) are absent, therefore, there is no question of supporting the structures, excepting the heavy-weight structure. For heavy structure, the foundation must be laid down to the middle and older diluvial layer, and if the structure is of extraordinary heavy weight, the foundation must be seated at a greater depth than 30 m.

In the ground type-A, the Upper and Lower Clay layers are comparatively thin or non-existent, and therefore, in type-A₁, most of the ordinary structures may be supported by the foundations shallower than 10 m, and in type-A₂, the depth of the foundation may be less than 15 m, whereas this depth must exceed 15 m in type-A₃.

By means of a square footing foundation of a side of 4 m, a bearing capacity of 3 ~ 32 ton/m² can be obtained. The sinking will not exceed the allowable limit so long as the load is in a range between 47 and 100 tons acting on a pedestal pile of a diameter of 50 cm, generally in ground type-A. Especially, in types-A₁ and A₂, the sinking will never exceed the allowable limit even for a load of 90 ton/m².

In the ground type-B, the upper clay (UC) layer develops with a thickness larger than 5 m, therefore, the foundation of the structure must be seated in

the lower sand-and-gravel (LS) layer or the middle and older diluvial layer.

In type-B₁, layer (LC) is thinner than 5 m, or otherwise non-existent, therefore, there will be no serious question of supporting the structure. In type-B₂, however, layer (LS) is comparatively thin and underlying layer (LC) is thick. Therefore, the depth of the foundation of an extraordinary heavy-weight structure must be seated at a depth greater than 30 m, and thus it becomes difficult to construct such a deep foundation economically.

By means of a square footing of the 4m side, a bearing capacity of more than 3 ~ 32 ton/m² is obtainable, but, according to the place, the amount of sinking exceeds the allowable limit as the result of consolidation of underlying clayey soil. A bearing capacity of 18 ~ 100 tons can be obtained by a single pedestal pile of a diameter of 50 cm. So long as the load intensity does not exceed 60 ton/m², the subsidence due to the consolidation of underlying clayey soils may be negligibly small. However, if the load intensity becomes large, such as 90 ton/m², the subsidence will exceed the allowable limit.

In the ground type-X, layer (US) is entirely absent, or the sand which is compacted mediately does not continue through a depth greater than 3 m.

In general, a bearing capacity of 16 ~ 47 ton/m² or more can be expected by means of a square footing foundation of a side of 4 m, and a load of 37 ~ 100 tons can be supported by a single pedestal pile of a diameter of 50 cm. So long as the load on a unit area (1 m²) does not exceed 60 tons, the subsidence will be within the allowable limit. If the load intensity becomes as large as 90 ton/m², the subsidence will exceed this limit, when the supporting substratum is chosen in layer (LS).

Allowable limit of subsidence of structures

As a reference, the limit of subsidence will be shown in the following table.

Table 2. Allowable limit of subsidence of structures.

Foundation	Allowable amount of sinking	
	Standard	Maximum
Mat	15 cm	30 cm
Footing	5	10

E. Distribution of substratum having N-value greater than 30 and 50

In practice, it is convenient to show the distribution of the layers of which N-value exceeds 30 and 50. These layers are reliable for supporting the heavy-weight and extraordinary heavy weight structures respectively. Strictly speaking, in the map of N-value, the contours are drawn for the depths of the upper boundaries of the layers which have the N-values above given and the thickness of greater than 3 m. In most of the cases, the upper boundary of the layer of N ≥ 30 coincides with the upper boundary of layer (LS), or with

that of the middle and older diluvial layer.

For the layers of $N \approx 50$, the same things may be said, but, in this case, the boundary of such layers lies sometime at an especially hard part of the rocks contained in layer (LS). An example of N-value map is shown in Fig.2.

(4) Micro-tremors.

As has been cited in our previous paper⁵⁾, the ground motion at the time of the earthquake differs according to the physical nature of the ground. The vibrational characteristics of the ground can be detected fairly in detail in the micro-tremors at an ordinary time. As one of the characteristics, we can point out the predominant period of the tremors. It may be said roughly, that the periods which range between 0.5 and 0.7 second predominate in number in the plain; those ranging between 0.2 and 0.4 second do so in the terrace or plateau, while rather long periods, say, 0.8 ~ 1.0 second are somewhat predominant, with comparatively short periods such as 0.05 - 0.2 second in the mountainous area.

The observation of micro-tremors is indispensable in the ground investigation, because it is a unique method of determining the dynamical property of the ground at present.

It has been proved that the micro-tremors have a close relation between the type of the ground. For example, the following facts have been found in the East Mikawa region.

- a) Predominant period of about 0.2 sec. can be seen on terraces in ground type-H and -L.
- b) Predominant periods of 0.3 ~ 0.4 sec. are common in low coastal areas. At the places where these values of the predominant periods are obtained, there lies a thick weathered soil layer.
- c) Predominant periods of 0.4 ~ 0.5 sec are common also in coastal areas, but in many cases, a clay layer is intervened in the lower part of the ground.
- d) In the case of the predominant period which cannot be determined definitely, the ground is situated in the terrace covered by a weathered granite. However, a similar result is obtained for the predominant period in the low beach area. But, at any place in the terrace area, the maximum amplitude of the tremor is not large. The fact suggests that there lies a hard substratum immediately beneath the weathered surface. On the other hand, in a low soft ground, the maximum amplitude of the tremor is usually large as compared with those in the terrace area. Thus, the difference of the maximum amplitude indicates the difference of the type of ground, when the predominant period cannot be determined definitely.

Generally speaking, if the ground formation is simple, the frequency curve (curve showing the frequency of occurrence of various periods) is also simple, such as the one having a single peak, suggesting that the tremors have nearly equal periods. In this case, if the predominant period is short, the ground is of sand, or of sand-and-gravel, and if the period is long, the ground is of silt. When the period is longer, say 0.4 ~ 0.5 sec, and the period of 0.2 ~ 0.3 sec. cannot be observed, the alluvial layer is generally thick. If the period begins with a value of 0.2 ~ 0.3 sec. and predominates at 0.4 ~ 0.5 sec., a firm stratum may be expected at a comparatively shallow place.

(5) Construction of maps.

In the ground investigation in city-area so far mentioned, the main purpose lies in the application of the result in the design of foundation of structure and the plan of utilization of the ground, in consideration of the ground condition. Here, the structures are tentatively divided into three kinds; ordinary, heavy-weight and extraordinary heavy-weight structures. The ground must have a sufficient bearing capacity for supporting such a structure. Therefore, in this investigation, it is most important to indicate the depths of the soil layers which are available for supporting the structure. For this purpose, the following maps are recommended to be prepared.

- a) Map showing the ground geological profiles.
(Example, Fig. 3.)
- b) Map showing the lower boundary of layer (US).
(It will be convenient to show the micro-topographical division together in this map, if possible. Example of boundary map, Fig. 4.)
- c) Map showing the lower boundary of layer (UC), that is, the upper boundary of layer (LS) (See, Fig. 4.)
- d) Map showing the lower boundary of layer (LS). (Fig. 5.)
- e) Map showing the lower boundary of layer (LC), that is, the depth of the bedrock. (Fig. 5)
- f) Map showing the general distribution of the types of ground
(Example, Fig. 1, already cited.)

As auxiliaries, more detailed maps are also recommendable, such as those showing the following matters.

- a) Level (altitude) of ground.
- b) Topography of sea bottom.
- c) Boundary of existence and thickness of sandy soil in layer (US).
Boundary of existence of clayey soil in layer (US).
- d) Boundary of existence and thickness of sandy soil in layer (LS).
Boundary of existence of clayey soil in layer (LS)
- e) Boundary of existence and thickness of clayey soil in layer (LC).
Boundary of existence and thickness of sandy soil in layer (LS).

From the results of the soil tests, maps are prepared to show the distributions of the following matters.

- a) Degree of over-consolidation in layer (UC).
- b) Cohesion of soil in layer (UC).
- c) Angle of internal friction in layer (UC).
- d) Degree of over-consolidation in layer (LC)
- e) Cohesion of soil in layer (LC).
- f) Angle of internal friction in layer (LC).

From the observation of micro-tremors, a map is prepared which shows the classification of the ground into the following kinds. These kinds of ground

are equivalent in their physical properties (hardness, bearing capacity, etc.,) to the ground as specified below.

- Kind I ; Tertiary or other very hard ground.
- Kind II ; Ground mainly of diluvium, or ground with gravel layer 5 m or more in thickness.
- Kind III ; Alluvial ground 5 m or more in thickness.
- Kind IV ; Alluvial ground 30 m or more in thickness, and reclaimed ground. An exception is made for such thick alluvial ground where a firm gravel layer lies near the ground-surface, this ground is classified as Kind III.

In the cases of Kind I and II, the design seismic coefficient of horizontal force may be reduced down to the values which are fixed in the Ministry of Construction Notification No.1074, July, 1952.

The maps which show the classification of ground basing on the observation of micro-tremors have already been inserted so many in various reports⁶⁾ or publications that there will be no need to illustrate them particularly.

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- 4) See, 1) and also Report Ground. Inv.Comm. Vol.1, 1962.
- 5) See, 1).
- 6) For example, Fig.5 in paper referred in 1).

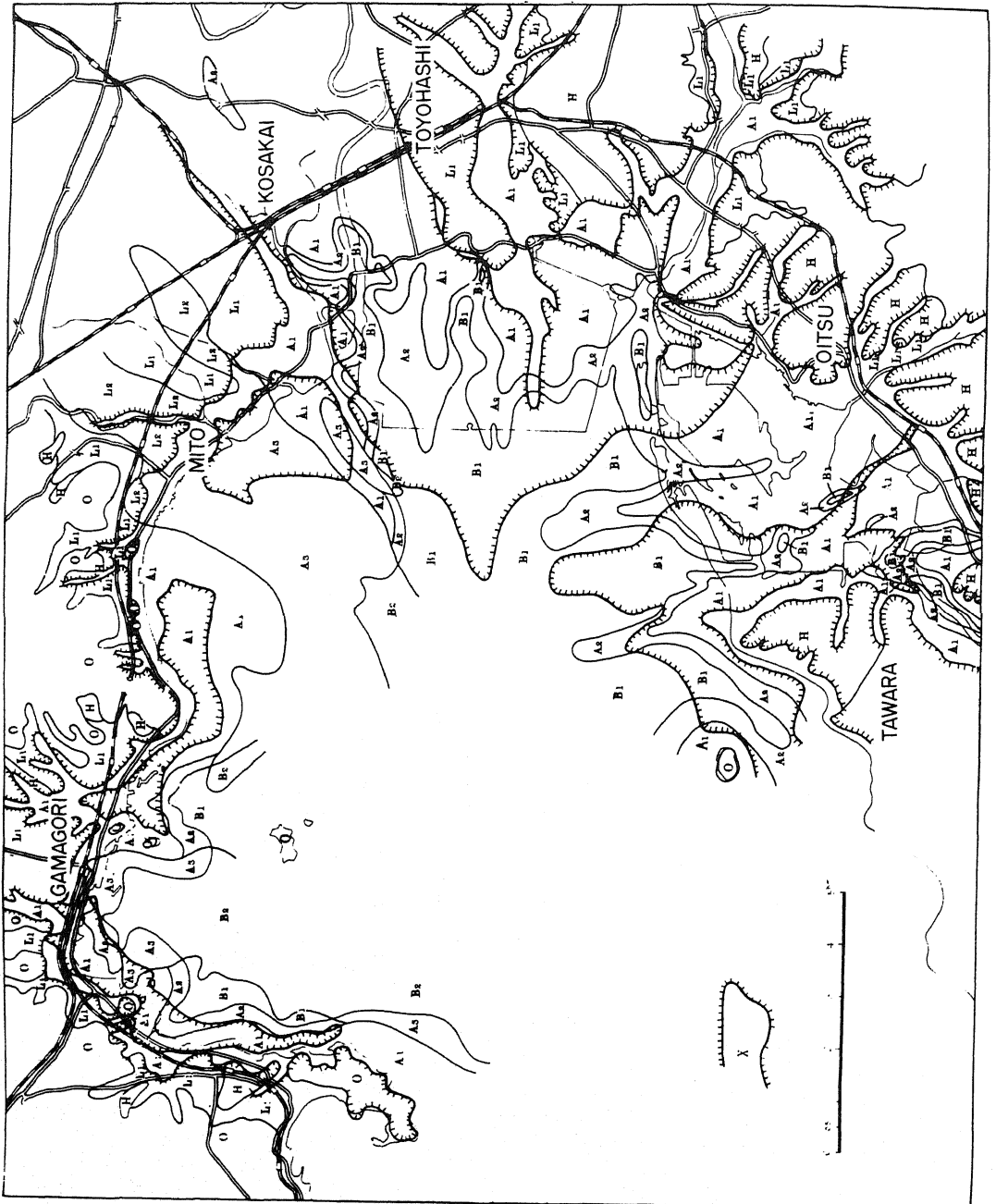


Fig.1. Distribution of type of ground in the East Mikawa region.

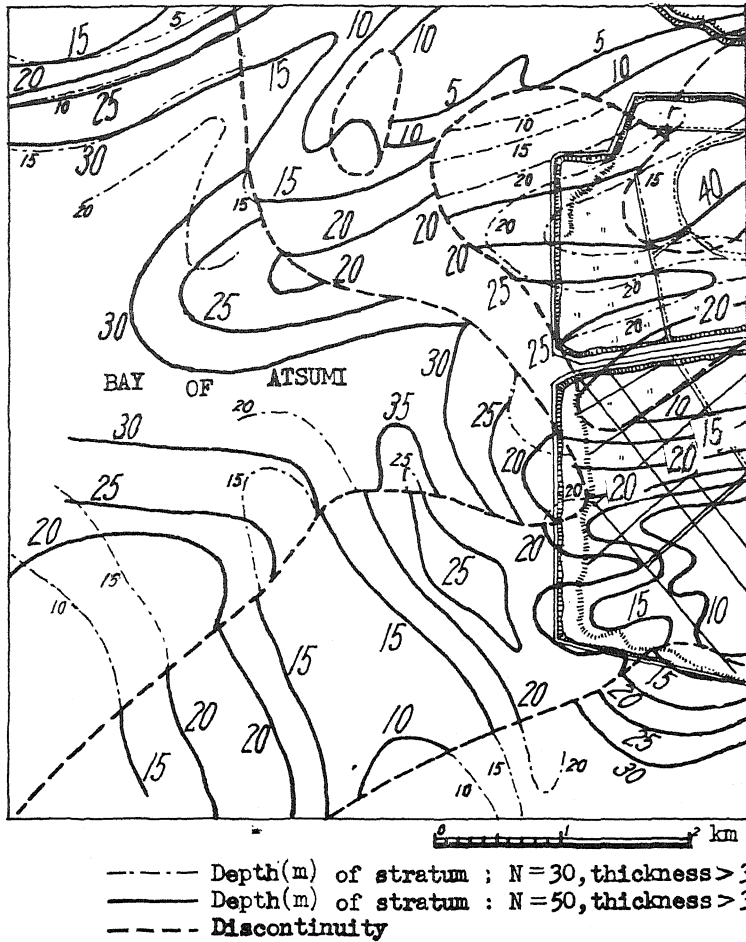


Fig.2. A portion of map showing depths of strata, N = 30 and 50.

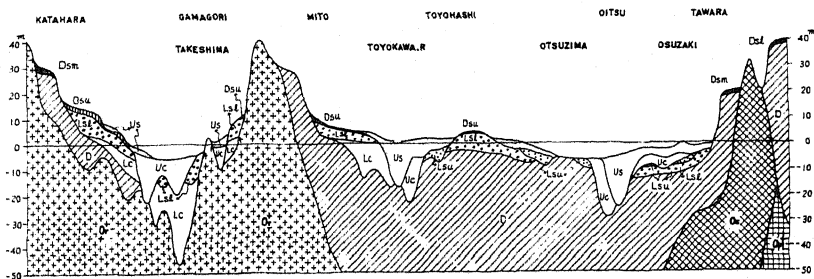


Fig.3. Example of map showing ground geological profile.

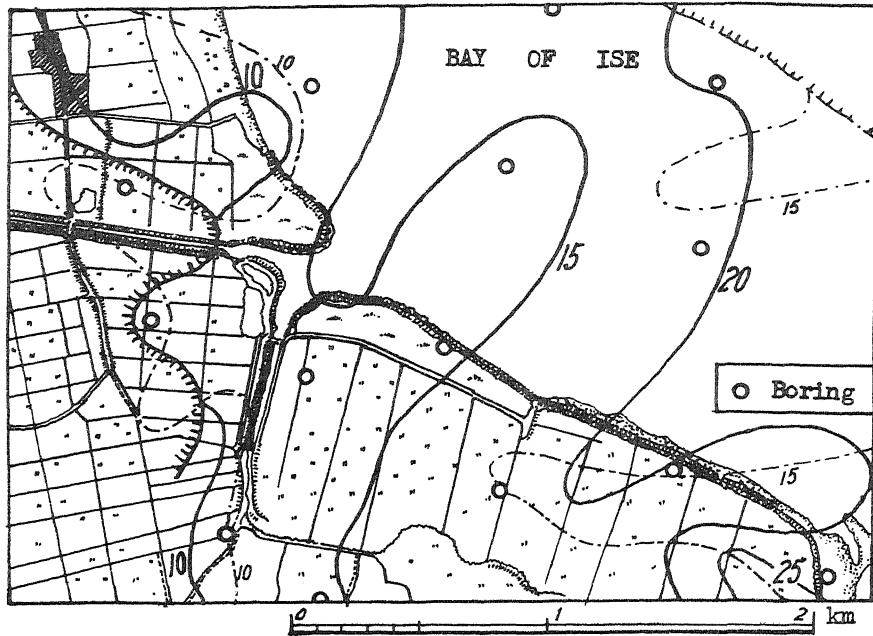


Fig.4. (Portion of map.)

- Depth(m) of lower boundary of layer (US)
- ||||| Boundary of non-existence of layer (US)
- Depth(m) of lower boundary of layer (UC)
- ||||| Boundary of non-existence of layer (UC)

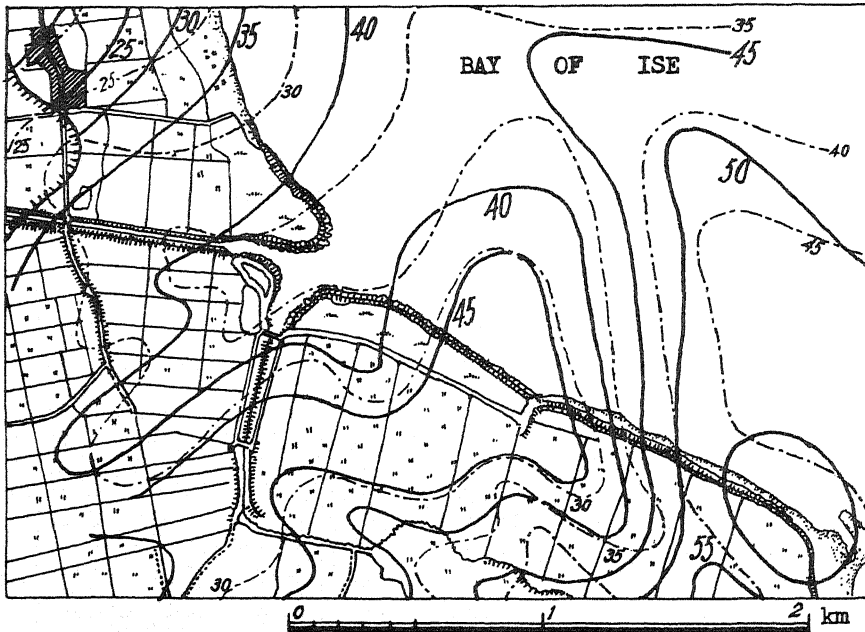


Fig.5. (Portion of map.)

- Depth(m) of lower boundary of layer (LS)
- Depth(m) of lower boundary of layer (LC)
- ||||| Boundary of non-existence of layer (LC)