Basic Concepts of Photo-geomorphological Analysis of Soft Ground Conditions

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ABSTRACT

The analysis of micro-features of the terrain surface is most important to allow interpretation in geology and soils by using aerial photographs to be accomplished. The basic concepts, methods and techniques used to analyze and interpret engineering soils in Recent alluvial lowlands, above all those forming soft ground conditions, from a systematic analysis of micro-landforms are discussed. A procedure for soft ground investigation by means of photo-geomorphological analysis is presented.

INTRODUCTION

The use of aerial photographs has recently increased in Japan in various fields of land surveys, not only in basic land surveys such as land classification, geological and soil surveys, but also in investigations for engineering purposes and for disaster prevention projects. However, aerial photographs have not been used properly and systematically in previous surveys.

One cannot see soils and geology directly on photographs. The keys of interpretation in soils and geology are characteristics of landforms and tonal characteristics. As mentioned by Tator and others (1960), it is mainly through geomorphology that photo analysis and interpretation realize their service to geology, pedology, soil engineering and other earth sciences. In other words, the analysis and interpretation of soils and geology by photographs can only be conducted through the analysis of the surface features of the terrain by applying geomorphological principles. Therefore, one can answer the question "how much can one infer soils and geology from aerial photographs?" by examining how much the surface features seen on the terrain indicate these. The first key to solve the question is to establish "micro-landform units" and "landform areas" or "landform types" from a systematic analysis of surface features and tonal characteristics. Then, the second key may be obtained by establishing the methods and procedures by which one can correlate the "micro-landform units" and others with soils and geology.

For the purposes, it is necessary to prove the relationships between landforms, soils and geology that were interpreted using information obtained from field investigations and previous source materials. It is also necessary to establish deductive interpretation methods through the accumulation and arrangement of the relationships. Needless to say, the usefulness of aerial photographs for land surveys will be promoted through this work.

In this paper, a discussion of photo-geomorphological methods and techniques used to analyze engineering soils, above all those distributed in soft ground areas, from the above-mentioned viewpoint follows. This study intends to construct a technical base for the applied geomorphological studies on the problems caused by ground characteristics in recent alluvial lowlands, as well as to examine the applicability of geomorphology to engineering soil surveys.

BASIC PROBLEMS

Outline of Landforms and Surface Materials in the Recent Alluvial Lowlands

The land surface of alluvial lowlands, except for landforms having a relatively higher relief and steeper slope such as sand dunes and small alluvial fans, is generally featureless compared to that of mountains and hill-lands. In spite of such featureless forms on the surface of lowlands, one can recognize in a stereo-model of such micro-landforms as natural levees, sand bars, abandoned low water channels, back swamps, etc. which are formed mainly by depositional agents of rivers, sea, wind, etc. However, most of these micro-landforms have a very small relative height of less than 2m., and consist of characteristic materials which vary slightly from place to place according to their topographic locations, the surface slope and other geomorphological elements.

Variations in photographic tone vary in relation to the distribution of micro-landforms. Both elements, micro-geomorphological features and tonal characteristics are closely related and they form the particular pattern seen in a stereo-model. Such patterns, seen on alluvial lowlands composed of recently transported materials are more closely related to the composition of the surface materials of the terrain than those seen on mountains and hill-lands where landforms formed on consolidated rocks and due to erosion prevail. Above all, micro-landforms and their distribution patterns are the most important indicators showing the distribution of surface materials, i.e. the parent materials of engineering soils.

In areas of intensive land utilization and artificially reformed land surfaces such as the alluvial lowlands of Japan, it is usually difficult to infer surface materials or soils from aerial photographs. The land surface of urbanized areas is mostly occupied by agglomeration of structures, and agricultural areas has been modified by land improvement in some cases. In spite of the reformations and modifications of the land surface, one can infer surface materials of such areas from a systematic analysis of the micro-features with the aid of topographic maps surveyed before urbanization and other data. In such areas, it is better to interpret surface materials from systematic analysis of micro-landforms than from the analysis of tonal characteristics alone. The latter should be analyzed in connection with micro-geomorphological features of the lowlands.

Definition of the Term Soft Ground and Problems Caused by Its Conditions

The term soft ground is not a technical term in geomorphology or in geology, but it is in soil engineering. The definition of soft ground is variable according to the kind, size and importance of structures to be constructed and other engineering elements.

In this paper the term soft ground is used to describe areas which consist of such materials having the engineering properties of high water content, high compressibility and small carrying capacity as unconsolidated clayey soils and organic soils. Besides these, well-sorted and loosely bedded fine-grained sands with relatively high water content have caused earthquake damage to heavy-weight structures such as reinforced concrete buildings due to "liquefaction" as noticed in the case of the damage caused by the Niigata Earthquake of 1964. These should be noted as soft ground materials.

The areas of soft ground conditions cause problems during the construction of buildings and civil engineering structures, and also cause difficulties after the construction as uneven settlement occurs. Earthquake damages to structures have frequently resulted in such areas, and ground subsidence due to the taking up of groundwater has occurred in the lowlands, for example in the Tokyo and Osaka deltas, which consist of thick deposits of soft ground layers. Besides these problems, such areas have frequently been striken by flood disasters due to high tidal waves and river floods, as well as due to the stagnation of inland water, because the areas in soft ground conditions usually lie on the topographic lows or on the lowlying lowlands. It is undesirable to urbanize, industrialize areas, to construct transportation or other facilities to the areas in soft ground conditions without reasonable counterplans, from the viewpoint of disaster prevention.

Classification of Soft Ground Materials

Soft ground, which is found in Japan, is composed mainly of soft and unconsolidated sediments deposited during the Recent, i.e. the Recent Deposits or "Alluvial Deposits", and is distributed in the Recent alluvial lowlands. Among the "Alluvial Deposits", organic soils such as peats and muck soils, and such fine-grained materials as clays and silts are typical soft ground materials, as mentioned above.

The soft and unconsolidated layers distributed in lowlands along the coastal regions of Japan are classified into two categories: Upper Muddy Layer (Um) and Lower Muddy Layer (Lm). Their distribution in depth from the ground surface and their relative foundation bearing strengths of structures must be considered (Table 1). Um consists mainly of marshy and lagoonal deposits, which has been deposited in the latest Recent and is

Table 1 Classification of "Alluvial Deposits" and soft ground layers by engineering geology in case of coastal lowlands of Japan

Classification of Unit Layer				Engineering Properties			Types of Soft Ground Layer
				N-Value	Wn (%)	qu(kg/cm^2)	
"Alluvial Deposits"	Upper	Upper Muddy (Um)	Peat & Organic Soil	0 -2	100-1000	0.05-0.5	Surface Layer Type
			Clay & Silt	0-5	40-80	0.5-1.0	
		Upper Sand-and-Gravel (Usg)	Sandy Soil (Us)	5-15			
			Gravelly Soil	20-30+			
	Middle	Middle Sand (Ms)		5-20			
	Lower	Lower Muddy (Lm)		0-20	30-50		Deep Layer Type
		Lower Sand-and-Gravel (Lsg)	Sandy Soil (Ls)	20-30+			
			Gravelly Soil	50+			
Basement Layer		Pleistocene, Tertiary and other older rocks					

Um: Alluvial, Paludal, lagoonal and deltaic deposits.
Usg: Alluvial and beach deposits.
Us: Channel fillings, beach and deltaic deposits. Usually loosely bedded.
Ms: Beach and deltaic deposits.
Lm: Mainly marine deposits with some lagoonal deposits.
Lsg: Alluvial deposits.
N-Value: The N-value of standard penetration-test.
Wn: Natural water content.
qu: Unconfined compression strength.

usually rich in organic soils. The N-value of the standard penetration-test of this layer is generally less than 5 and the foundation bearing strength is not enough to carry even light-weight structures. On the contrary, Lm consists mainly of clayey deposits accumulated on the shallow sea bottom during the rising-sea-level stage in the early Recent. Although this layer has an N-value between 5 and 20, the foundation bearing capacity for heavy-weight structures is not sufficient.

The author suggests the name "surface layer type soft ground" for the Um layer and "deep layer type soft ground" for the Lm layer as shown in table 1. In this table the classification of the "Alluvial Deposits", including that of the soft ground layers, by engineering geology is arranged for comparison with the geological classification. Needless to say, the layers that form the micro-landforms seen on the present terrain surface are the uppermost parts of the Um and Usg. The outline of soil engineering properties of each layer, which has been obtained from previous geologic and soil investigations, are shown in the last three columns is this table.

METHODS AND TECHNIQUES OF SYSTEMATIC CLASSIFICATION OF MICRO-LANDFORMS

Basic Concepts

The methods and techniques of micro-geomorphological analysis are one of the most important parts of interpretation procedure in geological and soil surveys as mentioned above. However, one is not satisfied to know the types of landforms alone. In order to interpret engineering soils, including soft ground materials, it is necessary to classify systematically "micro-landform units" which should be closely related with the physical properties of the soils. In other words, the first step to analyze engineering soils is a systematic classification of "micro-landform units", and the second step is the correlation of these units with engineering soil units.

For the purpose of establishing the "micro-landform units" systematically, the principles and techniques of "landform type" analysis on photographs which have been developed and systematized by Nakano (1962) and his collaborators (e.g. Takasaki et al, 1966) can be applied. This method is based on a systematic micro-landform classification of genetic classification of landforms and has been widely applied to the various fields of land surveys not only fundamental land classification surveys regulated by the Land Survey Law, but also investigations for prevention of disaters due to flood, earthquake, snow avalanches and other natural hazards (Nakano et al, 1966, Takasaki et al, 1966). To set up the unit landforms having a characteristic, terrain surface should be classified depending upon the following four geomorphological criteria: ages, shapes, geneses and compositions of landforms. Such units can be recognized on photographs by analyzing their micro-features, topographic locations and distribution patterns and by delimiting the kinds of units and boundaries between the units. The analysis and interpretation should be accomplished repeatedly in stereo-models.

As for as soil surveys, although this method is useful for agricultural soil surveys, particularly those based on the genetic classification of soils, there are some problems in applying this to engineering soil surveys. The main problems are as follows:

1. It is already clarified through previous agricultural soil surveys that the micro-landform units properly correlate with the physical properties of soils lying within 1 to 2m depth from the surface, but it is not known how much "micro-landform units" correlate with soils lying at deeper in ground.

2. There are very little data available for the relationship between those two terms, especially in the case of the ground composition to the depth of 20 to 30m or more from the surface.

Classification of "Micro-Landform Units"

"Micro-landform units", which are used to interpret engineering soils and distributed in the Recent alluvial lowlands of Japan, by using aerial photographs are arranged in Table 2. These units are thought to be suited for inferred engineering soil mapping on the scale of 1:20,000 – 1:50,000, as the mapping units. The units shown in this table can be identified without much difficulty in a stereo-model on the scale of 1:10,000 – 1:40,000, to analyze the micro-features of the terrain based on the above-mentioned concepts and techniques. Because these units are classified by their genesis, they correlate with the occurrence of the materials composing landforms. The photographic characteristics of each unit shown in this table are generalized and have been obtained from previous research in Japan by the author. The correlation of the units to soils is also generalized. Therefore, photographic characteristics and materials in each unit differ somewhat in every area and in every photograph used for interpretation.

Correlation of Micro-Features to Soils

The correlations of the micro-geomorphological features to soils in Recent alluvial lowlands which have been clarified in Japan and in other countries by previous works are summarized as follows:

1. The areas of slight elevation are usually composed of relatively

Table 2 Classification of "micro-landform units" for inferred engineering soil mapping (Scale 1:10,000−50,000), photographic characteristics and relationship to soils in Recent alluvial lowlands of Japan

Locations	Agents or Environments	"Micro-Landform Units"	Main Land Use	Main Soils**	Drainage Conditions
Piedmont	Gravio-Fluvial	Talus (Ts)	Forest or upland field	PG	Very good
		Colluvium (Cl)			
		Alluvial cone (Ac)	do.		
Small valley flat	Fluvial	Gravelly valley flat (Gvf)	do.	PG-WSG	Good
		Muddy valley flat (Gmf)	Paddy field	Si, C, O, P	Poor−Very poor
Large alluvial and deltaic lowlands: Well-drained landforms with slight elevations	Fluvial	Alluvial fan (F)*	Upland field	WS/PG	Good
		Abandoned channel bar (Acb)	Upland field & hamlet	do.	Good
		Interchannel flat (If)	do.	do.	Good
		Natural levee (Nl)	do.	S, Si	Good−Fair
		Point bar (Pb)	do.	do.	Good−Fair
	Littoral	Shingle bar (Shb)	do. & forest	WSG	Good
		Sand bar & Sand bank (Sb)	do.	WS	Good−Fair
	Aeolian	Sand dune (Sd)	do.	WS	Good
Large alluvial and deltaic lowlands: Poorly-drained lowlying lowlands	Fluvial-Paludal	Back swamp (Bs)	Paddy field	C, Si, O	Very poor
	Fluvio-Marine	Delta (D)*	do.	C, Si, S, O	Poor−Very poor
	Lagoonal-Paludal	Lagoonal lowland (L1)	do. or marsh	P, O, Si, C	Very poor
	Paludal	Interbarnal slough (Is)	do.	do.	Very poor
	Littoral-Paludal	Tidal flat (Tf)	Marsh	O, Si, C, S	Poor−Fair
	Fluvial	Abandoned low-water channel (Alc)	Paddy field or marsh	Si, C, O/WSG-WS	Very poor
	Biogenetic-(Paludal)	Peat bog (P)	do.	P	Very poor
		Marsh (M)	do.	P, O, C, Si	Very poor
		Area with numerous drainage ditches (Ad)	do.	C, Si, O, P	Very poor
Anthropogenetic		Reclaimed land (Rl)	Paddy field	WS, Si, C, O	Poor−Very poor
		Filled-up land (Fl)	Industrial area	Filled-up soils	
		Modified land (Ml)	Built-up area	Banked & filled-up soils	

* Small size landforms which cannot be classified into other units
**P: Poorly-sorted, W: Well-sorted, G: Gravel, S: Sand, SG: Sand-and-gravel, Si: Silt, C: Clay, O: Organic soils, P: Peat, WS/PG: Poorly-sorted gravel overlain by well-sorted sand.

coarser materials than the adjacent lower elevations, and one can expect that fine-grained soils comprising soft ground, especially surface layer type are distributed in the lower elevations.

2. For instance, in fluvial lowlands, such micro-landform units of slight elevation as abandoned channel bars, natural levees, point bars, etc. are composed mainly of coarser materials than back swamps stretched among or behind them, as they have been formed in the characteristic environments in the floodplains, respectively.

3. In the areas where river channels have been stable and natural levees have been formed in a limited site, the thickness of the soft ground materials deposited in back swamps, including organic soils, is expected to be considerably great as a general tendency.

4. In the areas where abandoned low water channels of braided pattern with shallow scores are distributed densely, one can expect that the main deposits composing such areas should be sands and gravels.

5. In the middle and lower courses of river floodplains where the terrain surface is extremely featureless because of the lack or scantiness of such micro-landforms having elevations as natural levees, abandoned channels, etc., the greater parts of the materials transported by rivers are fine-grained, and most parts of the floodplains may be composed of thick deposits of fine-grained materials such as clay and silt.

6. It is in the deltaic lowland showing such geomorphological features that the above-mentioned deep layer type of soft ground is found, which consists mainly of marine clayey sediments and is overlain by a thick surface layer of soft materials.

7. The relative stability of river channels is an important indicator showing the distribution of soils, because the behavior of river channels has been influenced by grain size and plasticity of adjacent sediments.

8. Sand and gravel offer little resistance to river scouring and migration, and channels shift rapidly. Channels are wider and more shallow than those in finer grained soils. In the low-water stage, braided stream patterns can be seen on the river beds. Such stream patterns can also be seen on the floodplains in which sand and gravel compose the upper part of ground as mentioned above.

9. Silt and clay are more cohesive than sand and offer more resistance to river migration, so that channels become comparatively stable. Above all, clay with high plasticity offers maximum resistance to river migration. Channels in such clayey deposits are extremely stable, narrow and deep (Turbull et al, 1950). The similar behavior of rivers is also seen in peat bogs in Hokkaido, northern Japan.

10. However, when one intends to interpret soils distributed in fluvial lowlands from the analysis of present river channels, it should be noted that most rivers in Japan have been re-formed or stabilized artificially by engineering work. In such a case, it is recommended that one should interpret soils by the geomorphological analysis of abandoned channels.

11. In a fluvial lowland, the grain size of the materials which compose the upper parts of the ground is generally decreasing downward with de-

creasing of surface slope, and accompanying the distribution density of sandy and gravelly micro-landforms having a slight elevation is also decreasing (Kadomura 1965-66).

12. The grain size of materials, which compose sand bars and beach ridges vary according to the grain size of materials supplied to the shoreline, but such materials are usually coarser and more well-sorted as compared to those forming natural levees which are distributed on the coastal regions.

13. In order to classify micro-landforms, which are distributed on coastal regions, from genesis, it is better to analyze not only the micro-geomorphological features, but also their distribution pattern as a whole.

14. Sand dunes formed by aeolian action generally consist of well-sorted, fine-grained sandy soils, and overlie the abandoned beach ridges or natural levees.

15. Peat and peaty soils composing most unstable soft ground are found in the poorly-drained and lowlying lowlands even in southwestern Japan, for example in the Tokaido region and Kyushu. These soils comprise the upper part of ground with a considerable thickness of such limited landforms as those originated from lagoons, small valley bottoms not only of the blockaded types but also in hill-lands and pleateaus composed of uncosolidated fine-grained layers such as mudstones and volcanic ash layers, the central parts of back swamps and marginal parts of floodplains.

Correlation of Tonal Characteristics to Micro-Features and Soils

The relationships between photographic tone and micro-geomorphological features in the Recent alluvial lowlands and between tonal characteristics and soils which have been evidenced by previous investigations are summarized as follows:

1. Darker tones seen on the topographic lows represent the existence of the finer grained materials in moist conditions and are rich in organic materials.

2. The areas of slight elevation, where brighter tones are seen, are composed of coarser grained materials in well-drained conditions (e.g. Tator et al, 1960; Belcher et al, 1960).

3. In order to identify abandoned channels either meandering or braided, it is more profitable to analyze tones in connection with micro-features than to analyze micro-features alone, because a slight difference in elevation is usually revealed as the difference in the amount of water contained in the materials, i.e. the difference in tones. In the areas that are utilized as paddy fields, the allotment patterns of fields which clearly mark former channels, should be used as a clue.

4. Peat and organic soils are generally characterized by darker tones on photographs because of their blackish colours and very high water content. These soils have a higher water content than clay, silt and other

soft ground materials, so that the areas where they are distributed on or near the surface are usually marked by their quite dark tones, though used as paddy fields. In general, water content of peat is between 200% and 600%, and that of soft clay is 60 to 100%.

5. Although the tonal characteristics may vary in each photograph according to the photographing conditions, development processes, etc., the darker tone seen on back swamps, lagoonal lowlands, blockaded small valley bottoms and other topographic lowlands should be noted as areas where highly compressive soft ground materials such as peat and other organic soils comprise the upper part of ground.

6. However, the interpreter must pay careful attention to the date of the photograph, whether it was during the irrigation season or not, because the alluvial lowlands of Japan are mostly used as paddy fields. Tonal patterns even of the same objects may reverse by the effect of irrigated water. Needley to say, the photographs taken out of irrigation season are better suited for interpretation of soils.

DISTRIBUTION PATTERN OF "MICRO-LANDFORM UNITS" AND "LANDFORM AREAS"

The term "Landform area" used here means a complex landform, while "micro-landform unit" is a unit landform. The distribution pattern of "micro-landform units", which are composed of the combination of such micro-landforms having a slight elevation as natural levees, abandoned channel bars, sand bars, etc., as well as abandoned low water channels, forms the geomorphological framework of the surface of alluvial lowlands.

The author proved in his previous paper (1965-66) that a "landform area" depending upon the distribution pattern of "micro-landform units" can be used to interpret the geological composition of the upper parts of the ground. Namely, to set up "landform areas" by grouping "micro-landform units" is the second step to interpret the types and the occurrence of soft ground in a certain area, to consider the geomorphological development or the sedimentary environment over the areas in the recent years. Not only the distribution pattern of unit landforms but also the geomorphological environments, geomorphological agents and surface slopes of the areas are used as the criteria to delineate such areas. The criteria differ somewhat in every "landform area" as classified by such main geomorphological agents as fluvial, marine, aeolian, lagoonal, biogenetic, etc. Among those areas classified by their genesis, fluvial lowlands show the most complicated micro-geomorphological features, and it is usually difficult to infer materials composing landforms. While in the other areas, it is relatively simple to infer materials through the examination of the geomorphological development process, as "micro-landform units" which appear in such areas are limited in kinds and are almost always situated in the limited topographic locations, for instance, along the coasts and around bogs, showing a monotonous pattern.

The geomorphological characteristics and the occurrence of materials composing landforms vary greatly in every fluvial lowland formed by every river, because of the difference of the size, geomorphological and geological conditions, and hydrological conditions of the catchment areas. Even in a fluvial lowland formed by a single river, the kinds of "micro-landform units" and their distribution patterns are changing from the upstream parts to the downstream parts. However, such complicated geomorphological and geological conditions are seen in fluvial lowlands, the following classification of "landform areas" may be used as the unit areas to infer materials over the areas

Fluvial lowlands in Japan are generally classified into three kinds of "landform areas": fan, natural levee zone and deltaic areas in this order from the upstream to the downstream parts depending on their geomorphological characteristics. Such areas not always lie in the above-mentioned order, because of the modified "landform areas".

Table 3 shows the "landform areas", which can be expected in alluvial lowlands of Japan, in correspondence to "micro-landform units" which make up the areas and the occurrence of soft ground. In this table, the "landform areas" classified by their geomorphological agents are called "major landform areas", while such areas as fan, delta and other areas mentioned above are called "minor landform areas". One can expect that every "landform area" consists of distinct materials as the characteristic pattern of micro-geomorphological features.

GENERAL RELATIONSHIP BETWEEN "LANDFORM TYPES" AND SOFT GROUND MATERIALS

Soft ground, as mentioned above, is found in the limited "landform areas" and "micro-landform units" in the Recent alluvial lowlands, and consists of such characteristic materials as peaty and clayey soils which have been deposited in the particular sedimentary and geomorphological environments. The most favorable environments for the formation of such materials are as follows: calm embayments, estuarine deltas, lakes, lagoons, marshes, back swamps, small valley bottoms blockaded by sand bars or the deposits of larger rivers at their mouths and other topographic lowlands. If one can mark out these landforms and those originated from such conditions from the analysis of aerial photographs, he can map the areas in soft ground conditions with high accuracy.

As sedimentary environments and soil forming processes, not only in recent years but also in the special cases ever since the Recent, can roughly be inferred from the geometric characteristics of the present landforms, the outline of the occurrence and the engineering properties of soils can be interpreted. The main clues for the interpretation are types, geomorphological environments and boundary characteristics of "landform areas", kinds and distribution pattern of "micro-landform units", and such morphometric data as elevation, surface slope and "Micro-Relief Ratio" (Kadomura 1965-66). For interpretation, it is most important to consider the processes of the geomorphologic development in the landform areas since the Recent. In the coastal regions, for example, the composition of the ground or the formation of soils has been governed by the relationship between the mode of sea-level change and the amount of materials transported by rivers. Hence, the mode of sea-level change since the end of the Pleistocene is necessary to interpret geomorphologic development as well as the soil forming process in the coastal regions. The observations of geomorphology and geologic compositions of the catchment area of a river which has formed a lowland by means of photographic interpretation with the aid of previous source materials are also necessary, because they played an important role in the formation of soils

Table 3 "Landform areas" and occurrence of soft ground in Recent alluvial lowlands of Japan

"Landform Area"		Main "Micro-Landform Units" Comprising "Landform Areas"	Types of Soft Ground Layers	
Major Division by Agents	Minor Division		Surface Layer Type	Deep Layer Type
1. Fluvial	a. Gravelly valley bottom lowland	Gravelly valley flat	*	
	b. Muddy valley bottom lowland	Muddy valley flat	***	*
	b'. do., blockaded type	do.	***	*
	c. Fan	Abandoned channel bar, interchannel flat and abandoned braided channel	*	*
	c'. Fan-like			
	d. Natural levee zone	Natural levee, point bar and back swamp	***	***
	d'. Natural levee zone-like		***	*
2. Fluvio-Marine (Lacustrine) complex	a. Delta and deltaic lowland	do. and tidal flat	***	***
	b. Delta-fan	Abandoned channel bar interchannel flat, natural levee and back swamp	**	*
3. Fluvio-Lagoonal complex	a. Lagoonal delta	Lagoonal lowland and back swamp	***	***
4. Lagoonal	a. Lagoonal lowland	Lagoonal lowland	***	***
5. Lagoonal-Marine complex	a. Drowned valley bottom lowland	Muddy valley flat	***	***
	a'. do., blockaded type			
6. Littoral	a. Coastal barrier	Sand or shingle bar		**
7. Marine or Lacustrine	a. Coastal lowland	Sand bar, beach ridge and slough	***	**
8. Aeolian	a. Sand dune	Sand dune		*
9. Biogenetic	a. Peat bog	Peat bog	***	**
10. Anthropogenetic	a. Reclaimed land	Reclaimed land	***	***
	b. Filled-up land	Filled-up land	***	***
	c. Modified land	Modified land	**	*

*** Usually, ** Occasionally, * Rarely

in an area.

The basic "landform types", which are expected in soft ground conditions and are classified from their origins, are tabulated in table 4. Each landform type is thought to be composed of an individual composition of soft ground materials as shown in this table. Fig. 1 is a schematic map showing the distribution of these landform types and is prepared to be used as a key for identifying such types on aerial photographs and topographic maps. The representative columnar sections of some types with the basic engineering properties, which are obtained from the results of the investigations for the construction of cross country express ways: Tokyo-Nagoya and Nagoya-Kobe Express Ways, are shown in Fig. 2. Fig. 3 represents the generalized soil profiles of the landform types shown in Table 4 and Fig. 1.

From these illustrations, it is natural to consider that each landform type is expected to be composed of the characteristic soft ground materials, because each landform type has been formed through a particular geomorphic history.

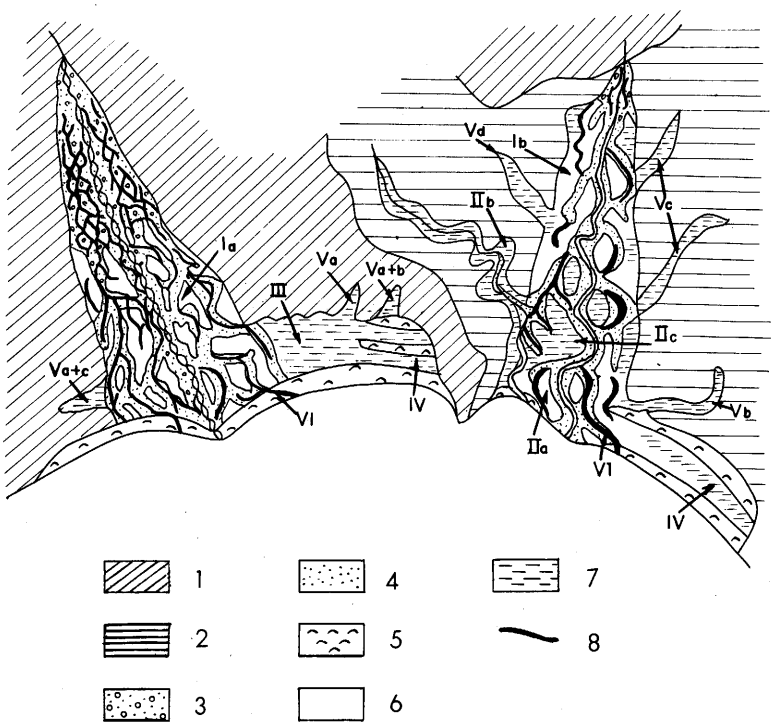
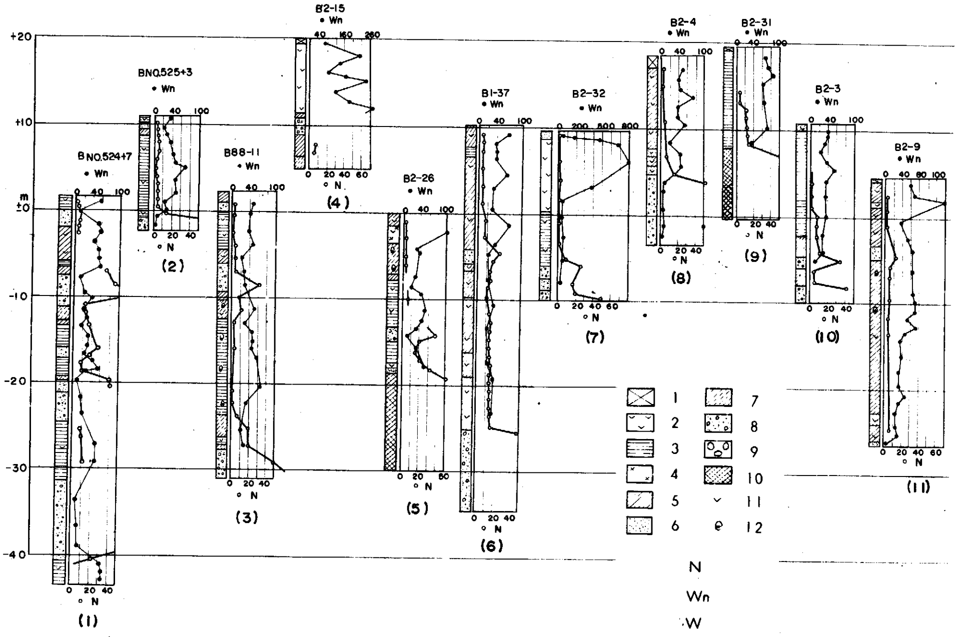


Fig. 1 Schematic map showing the distribution of "landform types" expected in soft ground areas. Modified from Ikeda, 1964.
1: Mountains, 2: Hill-lands and plateaus, 3: Alluvial fan and abandoned channel bar, 4: Natural levee, 5: Sand bar and sand dune, 6: Back swamp, 7: Peat bog, 8: Abandoned channel, I-VI: see Table 4

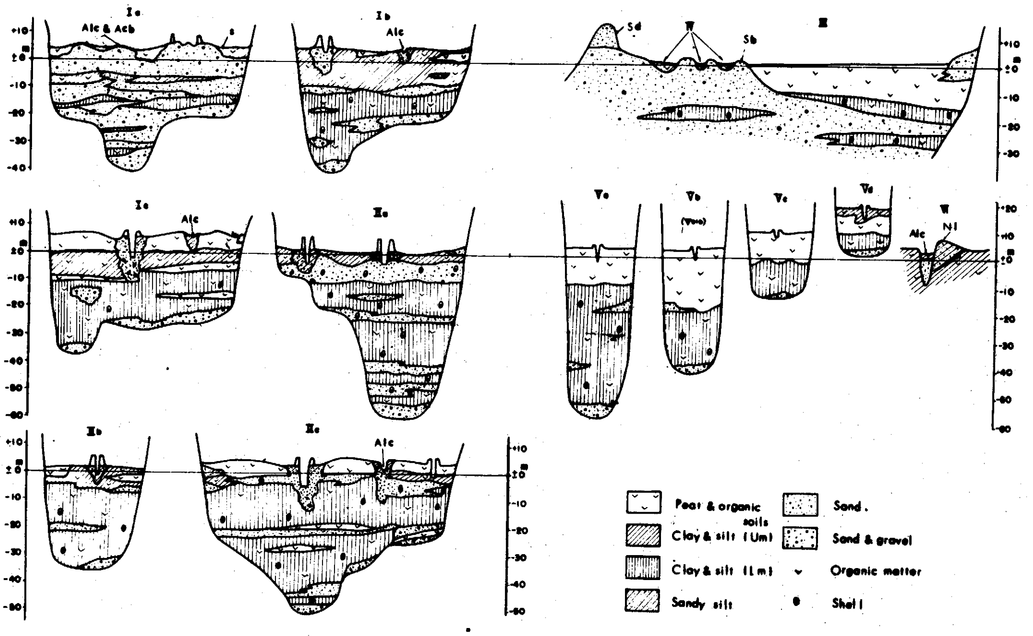
Table 4 "Landform Types" expected in soft ground conditions in Japan

"Landform Types"		Composition of Soft Ground			
		Surface Layer Type		Deep Layer Type	
Major Classification	Minor Classification	Soil	Thickness	Soil	Thickness
I. Flood basin or back swamp in floodplain	Ia. Floodplain formed by river transporting large load	Clay, silt	Less than 5m.	Clay, silt	Thin or lack
	Ib. Floodplain formed by river transporting small load	Clay, silt, organic soil	5-15	Clay, silt	10-30m.
	Ic. Floodplain in Northern Japan	Peat	3-5	Clay, silt	10-30
II. Deltaic lowland	IIa. Delta formed by river transporting large load	Clay, silt	2-3	Clay, silt	10-50
	IIb. Delta formed by river transporting small load	Organic clay	3-5	Clay, silt	10-40
	IIc. Delta in Northern Japan	Peat	3-5	Clay, silt	10-40
III. Lacustrine and lagoonal lowland		Peat, organic clay	5-10	Clay, silt Organic clay	10-30
IV. Interbarnal lowland		Peat, organic clay	2-5	Clay, silt Organic clay	Thin or lack
V. Small valley bottom lowland within small catchment area	Va. Drowned valley	Organic clay	5-10	Organic clay	5-50
	Vb. do., blockaded by sand bar	Peat, organic clay	5-20	Organic clay	5-40
	Vc. Small valley bottom blockaded by deposits of main river	Peat, organic clay	5-15	Organic clay	Thin or lack
	Vd. Other small valley bottoms in plateaus and hill-lands	Clay, silt, organic clay	3-10	Clay, silt, organic clay	Lack
VI. Abandoned low water channel, especially destributed in Types-Ib, Ic, IIa, IIb & IIc.		Organic clay underlain by loose sandy soil	Less than 5m.		

1) Natural levees distributed in Types-Ib, Ic, IIa, IIb and IIc are composed of thinly bedded silty or clayey fine sands, and their foundation bearing strengths are small.
2) In Type-V complex types such as Va+c, Vb+c, etc. may appear.



NAGOYA-KOBE EXPRESS WAY ←——→ TOKYO-NAGOYA EXPRESS WAY



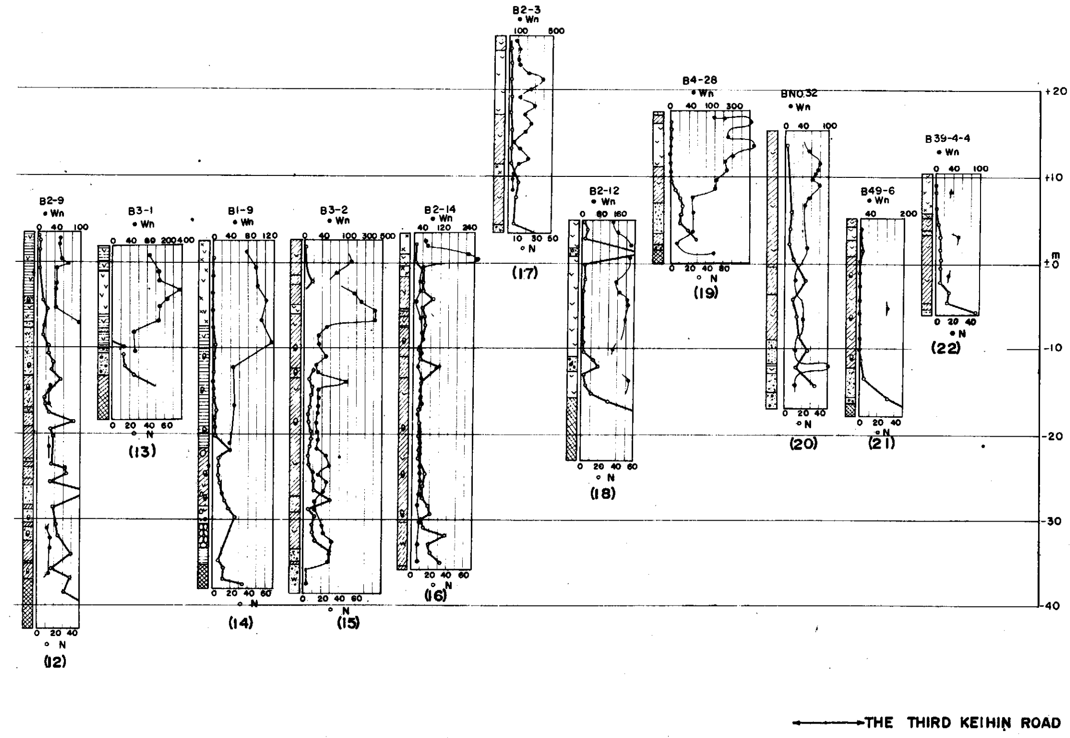


Fig. 2 Representative columnar sections of soft ground areas along Nagoya-Kobe Express Way, Tokyo-Nagoya Express Way and The Third Keihin Road
(1): Amagasaki, western part of the Osaka Lowland (Type-IIb), (2): Otokuni, middle part of the Kyoto Basin (Type-Ib), (3): Ogaki, western part of the Nobi Lowland (Type-IIb), (4): Kamigo, upper part of the R. Yahagi Lowland (marginal part of Type-Ia), (5): Sakume, Lake Hamana (lake bottom), (6): Otagawa, the R. Ota Lowland (Type-Ib), (7): Fukuroi, the R. Ota Lowland (Type-Vc), (8): Haranoyagawa, the R. Haranoya Lowland (Type-Ib), (9): Kikugawa, the R. Kiku Lowland (Type-Ib), (10): Katsumada, Makinohara Region (Type-Ib+Vb), (11): Saguchiya: Makinohara Region, (Type-Vb), (12): Yaizu, northeastern part of the R. Oi Lowland (Type-IIb, blockaded by sand bar), (13): Northeastern part of the R. Oi Lowland (Type-Va+b and c), (14): Takasaki, northeastern part of the R. Oi lowland (Type-Va+b), (15): Osaka, western part of the Shizuoka-Shimizu Lowland (Type-Va+c), (16): Tomoegawa, eastern part of the Shizuoka-Shimizu Lowland (Type-IIa+Vb), (17): Iwabuchi, west bank of the R. Fuji (Type-Vd, on terrace-like topography), (18): Eno-o, at the foot of Ashitaka Volcano (Type-Vd in piedmont slopes covered by a thick deposits of volcanic ash layer), (19): Aiko, west of the R. Sagami Lowland (Type-Vd in plateaus covered by a thick deposits of volcanic ash layer), (20): Atsugi, middle part of the R. Sagami Lowland (Type-Ib), (21): Kohoku Interchange, the R. Tsurumi Lowland (Type-IIb in hill-lands and plateaus covered by a thick deposits of volcanic ash layer), (22): Kawasaki Interchange, middle part of the R. Tama Lowland (Type-Ia)
1: Banked and filled-up soils, 2: Peat and organic soils, 3: Clay, 4: Silt, 5: Clayey soil, 6: Sand, 7: Sandy soil, 8: Sand-and-gravel, 9: Talus detritus, 10: Basement layer, 11: With organic matter, 12: With shells. N: N-value of the standard penetration-test, Wn: Natural water content (%), W: Weathered rock

Fig. 3 Generalized soil profiles of "landform types" expected in soft ground areas
Alc: Abandoned low-water channel, Acb: Abandoned channel bar, Nl: Natural levee, Sb: Sand bar, Sd: Sand dune, I-VI: see Table 4

PROCEDURE FOR ENGINEERING SOIL SURVEYS AND SOFT GROUND INVESTIGATIONS USING AERIAL PHOTOGRAPHS

Fig. 4 is a chart showing the proposed procedure for engineering soil surveys and soft ground investigations in cases of highway engineering using aerial photographs. In this chart, the procedure for the compilation of reconnaissance soil maps is shown in detail, but the results of the photo analysis and interpretation can be applied to determine the locations and depths of bore holes in field investigations. Even after completing field investigations, the methods of the systematic analysis of landforms can also be applied to the compilation of the final ground condition maps and soil profiles, developing the geological data obtained at the points of bore holes in plane and in three dimensions. This procedure should be used wholly or partly for route location and preliminary investigation, as well as detailed investigation.

CONCLUSION

Although the detailed composition and engineering properties of soft ground materials can only be ascertained by boring investigations with soil tests, photo-geomorphological principles and techniques discussed in this paper are useful for engineering soil surveys in the reconnaissance stage. At this stage, they can be applied effectively to draw inferred soil maps and to mark out the areas, where soft ground materials are distributed and the precise investigations should be made, as well as even to determine the locations of bore holes. It should be mentioned that they can also be applied to forecast the areas in danger from earthquake damage and to plan regional development (Nakano and Kadomura 1966). A detailed study on the relation of landforms to soils will be discussed in the next paper.

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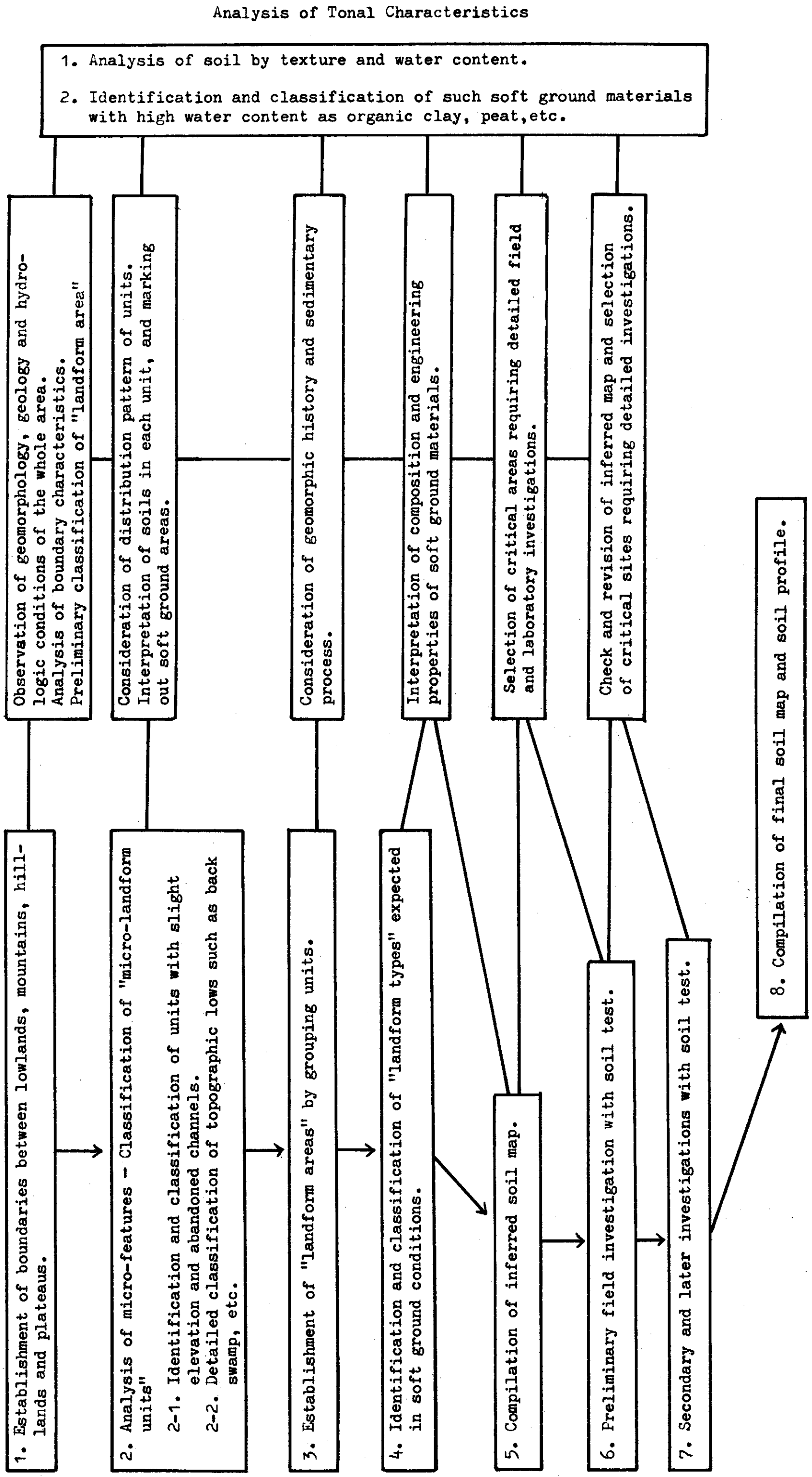

Fig. 4 Procedure for soft ground investigation by means of photo-geomorphological analysis, with reference to highway engineering

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