Predicting the Areas in Danger from Natural Disasters due to Soft Ground Conditions—An Application of Aerial Photo Analysis

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ABSTRACT

This paper is a study of physical geography of alluvial and deltaic lowlands, by using aerial photographs, for the purpose of disaster prevention and regional development. The methods and procedures for predicting the areas in danger from natural disasters due to soft ground conditions, especially earthquake disasters, are presented and discussed, in case of the Shizuoka-Shimizu Region situated on the Pacific coast of Central Japan.

Both by photo-geomorphological analysis and by regional analysis of geologic and engineering soil data obtained from previous boring investigations, the nature of the ground of the region has been made clear and mapped. The danger areas from earthquake damage as inferred from ground conditions are classified and mapped based on the relationship between ground conditions and earthquake damages occurring in this region and in other regions having similar ground conditions, by assuming magnitude and intensity of a destructive earthquake. As a result of this study, the problems of disaster prevention, in relation to the future development of the region are summarized.

INTRODUCTION

Among land conditions, physical properties of the land can be regarded as the ground which supports man-made structures. As the occupance of the earth's surface by structures is essential for human activities, ground conditions or the nature of the ground should be considered the significant natural environment. Its conditions are also closely related with human activities as causative factors which result in natural disasters such as ground subsidence and earthquake damage.

To the present, in Japan, ground conditions have mainly been studied by soil engineers and engineering seismologists. Considering the significance of ground conditions as an environmental condition, their formations, areal differences, and influences on human activities must be the subject of physical geographical study. Almost all problems due to ground conditions which affect land use, land development, and disaster prevention have resulted in areas with soft and weak ground conditions. In Japan, the areas with such ground conditions consisting of unconsolidated soft sediments are geomorphologically distributed mainly in alluvial and deltaic lowlands (Kadomura, 1967).

On the coastal deltaic and alluvial lowlands in Japan, where rapid regional development is now in progress, many areas are found with such conditions which might result in problems of disaster prevention in relation to development (Kadomura, 1966). Therefore, to examine and forecast the areas in danger from natural disasters due to soft ground conditions are most important to allow reasonable plans for development and prevention of disasters. The methods for eastablishing the areas in danger from natural disasters due to destructive earthquake motions by means of photo-geomorphological analysis of soft ground conditions (Kadomura, 1965/66, 1967, 1968) are discussed in this paper in the case of the Shizuoka-Shimizu Region, Central Japan.

BASIC CONCEPTS AND PROCEDURES

In general, the following two methods are used together in order to forecast the danger from natural disasters in a region.

1) Historical approach - inductive approach: The analysis of the relationship between the aspects of previous disasters that occurred in the region concerned, land conditions and the causative factors.
2) Deductive approach: The application of the general relationship between the damages and their causative factors obtained from other regions having similar land conditions to the region concerned.

Regarding the former, the method to measure the expectancy of the maximum intensity of the causative factors from statistical analysis of the data on previous disasters is used (e. g., Kawasumi, 1951). This method is useful for determining the construction standard of structures.

On the other hand, the method by which one can forecast the danger areas based on analysis of land conditions by assuming a scale of the causative factors is also useful. The author attempts to delineate the areas in danger from earthquake damage based on this point of view by jointly applying the above-mentioned two methods. The methods and procedures for establishing the areas in danger from earthquake damage can be summarized by Fig. 1. The role of aerial photo analysis for the purposes is also presented in this figure.

OUTLINE OF THE REGION STUDIED

The Shizuoka-Shimizu Region is situated on the Pacific coast of Central Japan, and is expected to be developed as a metropolitan area by the conurbation of two cities, Shizuoka and Shimizu. Shizuoka is an administrative centre in Shizuoka Prefecture, while Shimizu is an industrial city which relies on Shimizu Port. Shipbuilding, oil refinery and alumina refining industries which are located on the reclaimed land around Shimizu Port are the main industries. As shown in Fig. 2, the main traffic routes connecting Tokyo and Osaka, namely the Tokaido Line, the New Tokaido Line, The Tokyo-Nagoya Expressway and the National Route 1, pass through this region.

Excepting the built-up areas of Shizuoka and Shimizu, alluvial lowlands are widely used as paddy fields. But, the recent increase of population results in rapid expansion of the built-up areas. Most of the areas which have been used as paddy fields to the present are poorly-drained lowlands with soft ground conditions as in the other coastal lowlands of Japan. It is undesirable to urbanize, to industrialize,

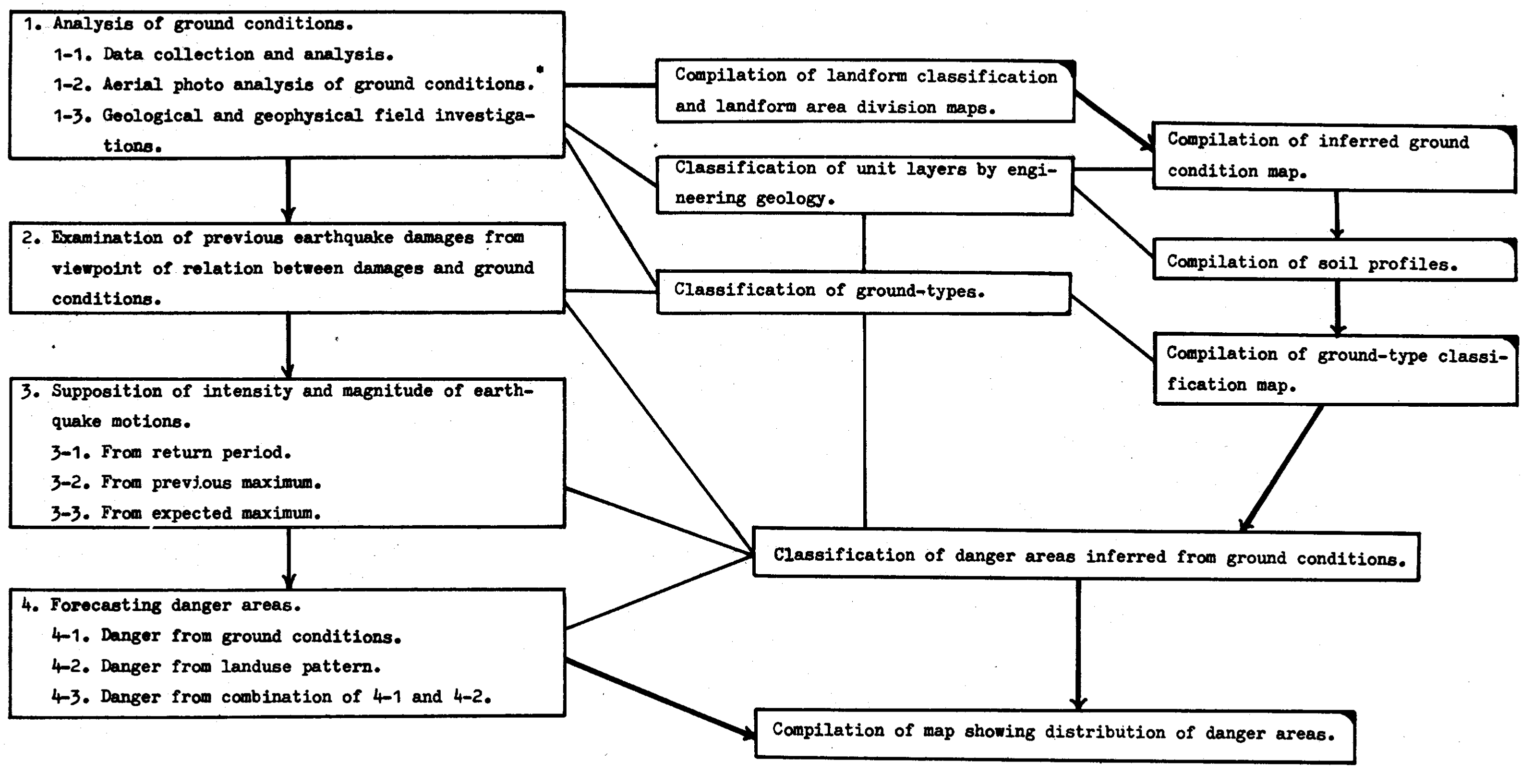


Fig. 1 Procedure for delineating the areas in danger from earthquake damage and the role of aerial photographs.

* Procedure for soft ground investigation (Kadomura, 1967) can be applied.

ϯ Aerial photographs may be used for the purpose.

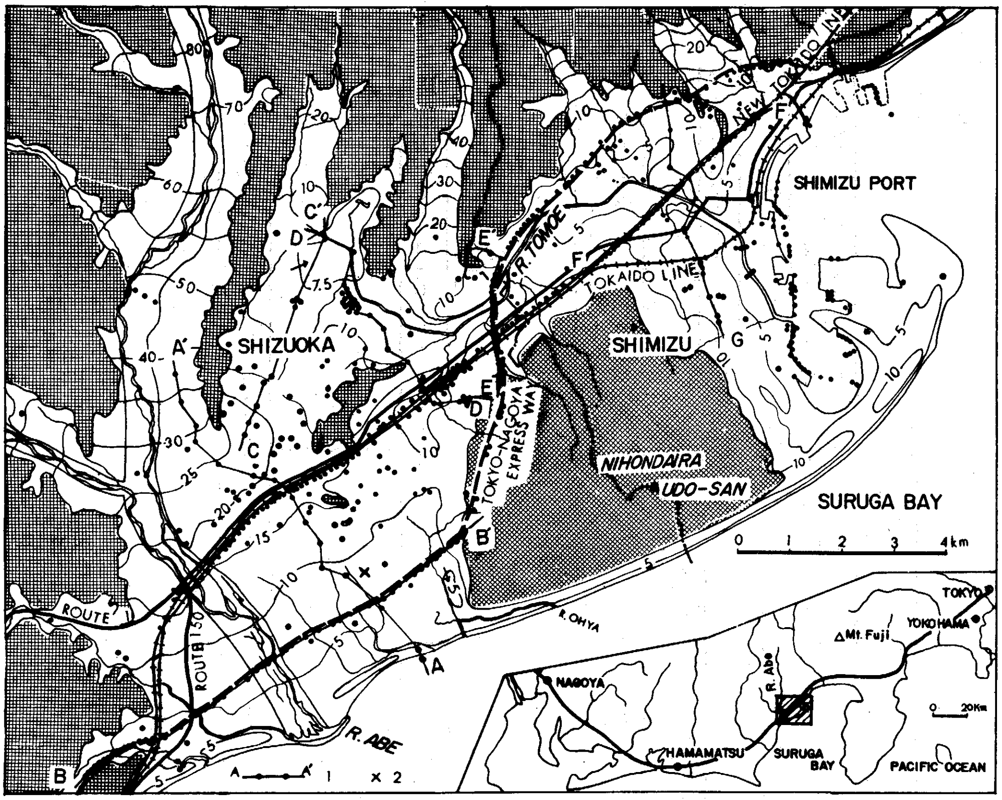


Fig. 2 Map showing the general geographical conditions of the Shizuoka-Shimizu Region.

Hatched areas indicate mountains and hill-lands.
Contour-lines in lowland areas show elevation in metres.
1: Bore hole sites, A-A' denotes location of geological sections shown in Fig. 5. 2: Toro Remains.

and to construct transportation and other facilities in such areas without reasonable counterplans.

GEOMORPHOLOGY AND GEOLOGY

The Shizuoka-Shimizu Lowland is bounded by the Tertiary mountains to the north and Suruga Bay to the south. The primary rivers forming the main body of this lowland are the Rivers Abe and Tomoe (Table 1). The R. Abe which flows from the southern part of the Southern Japan Alps, and has a great landslide area on its uppermost reaches, Ohya-kuzure Landslide (Machida, 1959), forms an alluvial fan in the western part of this region. On the other hand, the R. Tomoe which rises in the Tertiary mountains and supplies a small amount of sediments has built up a deltaic lowland in the eastern part. The Udo-san Hill Lands composed mainly of Pleistocene gravel layers are located in the middle part of the region. The two stepped-terraces which have been deformed due to crustal movement are developed on the top and northwestern foot slopes of these hill-lands (Tsuchi; 1959). Sand banks and shingle

Table 1 Comparison of the River Abe and the River Tomoe

	Catchment Area			Length of Main River	Expected Max. Discharge at Mouth	Geomorphological & Geological Conditions		
	Mountains	Lowlands	Total			Geomorphology	Geology	Landslide, etc.
River Abe	504.1 km^2	37.9 km^2	542.0 km^2	51.3 km	5,500 m^3	High relief mountains of 1000-2000 m in elevation	Paleo-gene	A great land-slide on upper reaches & great debris supply *
River Tomoe	50.22	41.32	91.54	20±	318	Moderate relief mountains of 300-1000 m in elevation	Neo-gene	Small debris supply

* Ohya-kuzure Landslide, one of the greatest landslides in Japan having an area of 180 ha (Machida 1959).

bars are continuously developing on the coast, characterizing coastal landforms.

The distribution of landforms and geologic materials of the Shizuoka-Shimizu Region is outlined in Fig. 3, which was compiled mainly by aerial photo analysis and interpretations. As micro-landform units shown in this detailed landform classification map are classified systematically by origin and composition, they can be expected to correlate properly with the geologic materials and the composition of the upper part of the ground. From this map, the Shizuoka-Shimizu Lowland is divided into the landform areas as shown in Table 2 and Fig. 4, depending on the distribution pattern of micro-landform units, the geomorphological agents, their topographic locations and other criteria. These areas are thought to correlate somewhat with the composition of the ground to the deeper part because such areas are classified from the similarity of geomorphological development (Kadomura, 1967). The outline of land use of each landform area is demonstrated in the last column of Table 2.

Landforms, such as deltaic lowlands, back swamps, valley flats originated from drowned valleys etc., which indicate that soft ground areas are found behind or between the sandy or gravelly landforms. It seems probable that during the formation of those poorly-drained lowlands as well as the formation of soft ground areas, the rapid expansion of the R. Abe Fan and the development of coastal barriers which formed before the construction of muddy lowlands played an important role (Iseki, 1952).

LAYERS COMPOSING SOFT GROUND CONDITIONS

More than five hundred boring data with soil test data are available for the investigation of ground conditions of this region (Fig. 2). From an analysis of geologic and engineering soil data, the layers consisting of the ground in the region and surrounding mountain lands are divided into unit layers as in the other coastal lowlands of Japan as shown in Table 3, for comparison of their relative foundation bearing strengths.

Among unit layers, the Upper Muddy Layer (Um) the Lower Muddy Layer (Lm)

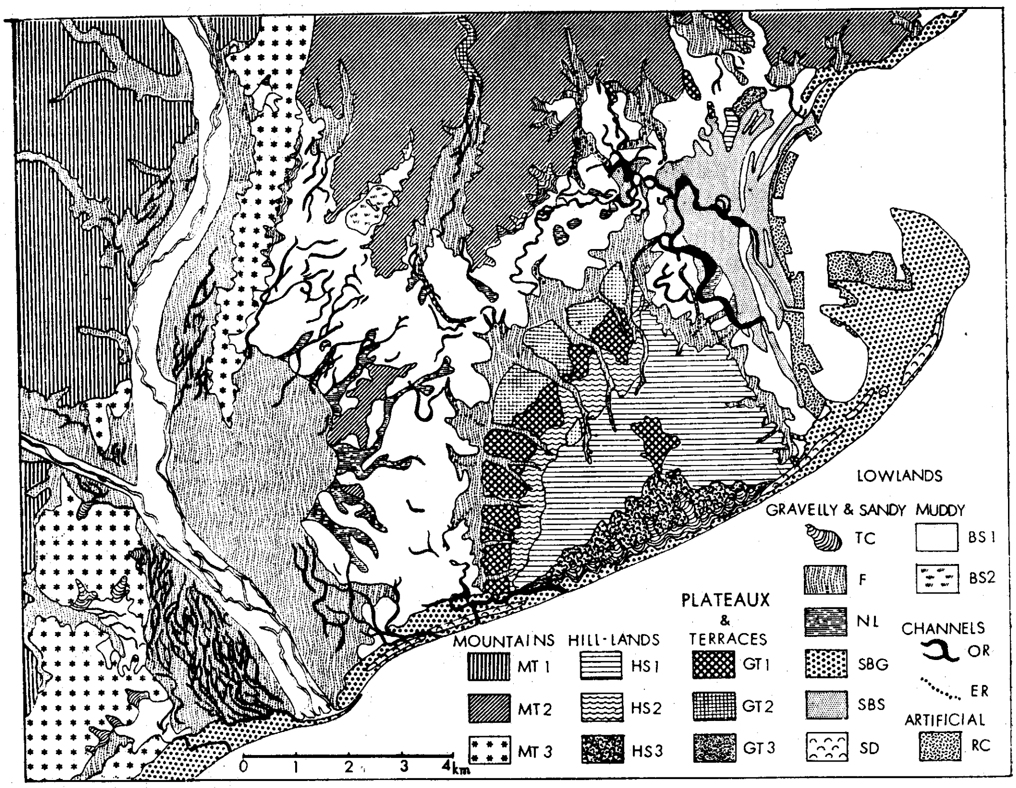


Fig. 3 Landform classification and surface geological map compiled mainly by aerial photo analysis and interpretation.

Mountains MT 1 : Paleogene Tertiary mountain lands. MT 2 : Neogene Tertiary mountain lands. MT 3 : Alkali basaltic rocks mountain lands.
Hill-lands HS 1 : Hillslopes of Pleistocene gravelly layers. HS 2 : Hillslopes of Pleistocene muddy layers. HS 3 : Hillslopes of severely eroded. (Pleistocene gravelly layers and Pliocene mudstones).
Plateaux & Terraces GT 1 : Gravelly, Upper. (Nihondaira and Ojika Surface*). GT 2 : Gravelly, Middle. (Kuniyoshida Surface*). GT 3 : Gravelly, Lower. (Terrace-like).
Lowlands Gravelly & Sandy —TC : Talus and cone. F : Alluvial fan and gravelly valley bottom lowland. NL : Natural levee and former channel bar. SBG : Shingle bar. SBS : Sand bank. SD : Sand dune. Muddy—BS 1 : Back swamp, deltaic lowland, lagoonal lowland and slough. BS 2 : Area of the Asahata-numa Marsh in the 19 th C. Channels—OR : Abandoned low water channel. ER : Elevated river bed by embankment. Artificial—RC : Reclaimed land (Areas of industry and harbour facilities)

* After Tsuchi (1959). These landform surfaces have been inclined due to crustal movement and show gentle slopes with the slope of 5-10 %.

and a part of the Upper Sand-and-Gravel Layer composed of loosely bedded sandy soils (Us) should be noted as soft ground layers. In order to make clear the composition and the distribution of soft ground, geological sections are compiled based on this unit layer classification (Fig. 5). The outline of soil engineering properties of unit layers is presented in Table 3.

The Um Layer consists of clayey soils deposited in the lagoons and marshy environments in the later half of the Recent era. This layer is rich in organic soils, such as peat and muck, and composes compressive and unstable ground conditions. The N-value of the standard penetration-test of this layer is generally less than 5. In the case of organic soils, the N-value is less than 2 and the water content is between 300 and 600%. The total thickness of this layer is generally 3 to 10m., but exceptions are found in the Osaka and the Asahata areas where the thickness exceeds 10m.

The Lm Layer consists mainly of silts and clays accumulated on the bottom of shallow embayments during the rising-sea-level stage in the early Recent era, and includes some lagoonal sediments. This layer is thickly bedded in deep entrenched valleys that were formed during the lowest sea-level stage in the last glacial age as in the other coastal lowlands of Japan. But, the R. Abe Fan area is formed of thick gravelly deposits with some lenticular clayey layers of fluvial origin, and the actual transgression of the sea during the rising-sea-level stage cannot be recognized in this area. The N-value of this layer is between 5 and 20, and increases toward the deeper parts. The water content is 30 to 40% throughout the layer. The engineering properties of this layer are better than those of the Um Layer, but the foundation bearing strength is not enough to carry heavy structures. The total thickness of this layer is 20 to 30m. in the lower part of the R. Tomoe Lowland, the Asahata and the Osaka areas, and exceeds 30m. in some places. The Middle Sand Layer (Ms) which was formed as sand bar deposits or foreset bed deposits of delta is frequently found in this layer.

The Shimizu Sand Bank consists of sandy soils, that is, the Us Layer. As shown in section F-F' (Fig. 5), this sandy layer overlies the Lm layer filling the entrenched valley of the R. Tomoe, and blockades the R. Tomoe Lowland. The most common materials comprising this layer are fine-grained sands. Although this layer has an N-value between 5 and 20, sandy materials are loosely bedded in the upper and the marginal parts of the banks, because of the higher groundwater table. Such loosely bedded sandy soils are also distributed on abandoned channels situated in poorly-drained lowlying coastal lowlands. The thickness of the sandy layer composing the Shimizu Sand Bank is 3 to 10m.

CLASSIFICATION OF GROUND-TYPES

In order to delineate the basic terrain units used to examine and forecast the danger from natural disasters due to ground conditions, the ground in this region is classified into six kinds of major ground-types and fifteen kinds of minor ground-types as shown in Table 4. The criteria of the classification include the engineering properties, kinds, thicknesses and the compositions of unit layers. For the purposes of classifying the ground-types, the relationships between ground conditions, earthquake damage and ground subsidence, as well as the handicaps for construction are taken into consideration. As for earthquake damage, previous studies on the relationships to ground conditions carried out by geomorphologists and engineering seismologists in Japan are introduced. However, the degree of earthquake damage may differ according to the magnitude, distance from the epicentre and other elements; the following can be pointed out in relation to ground conditions.

1) The main causes of earthquake damage to structures can be classified into three categories: a) due to ground vibration, b) due to land deformations such as cracks, uplift, etc., and c) due to liquefaction of sandy soils resulting in complete loss of bearing capacity.
2) The damage percentage of old-Japanese-style wooden houses due to a) increases rapidly with increasing thickness of soft ground layers, and

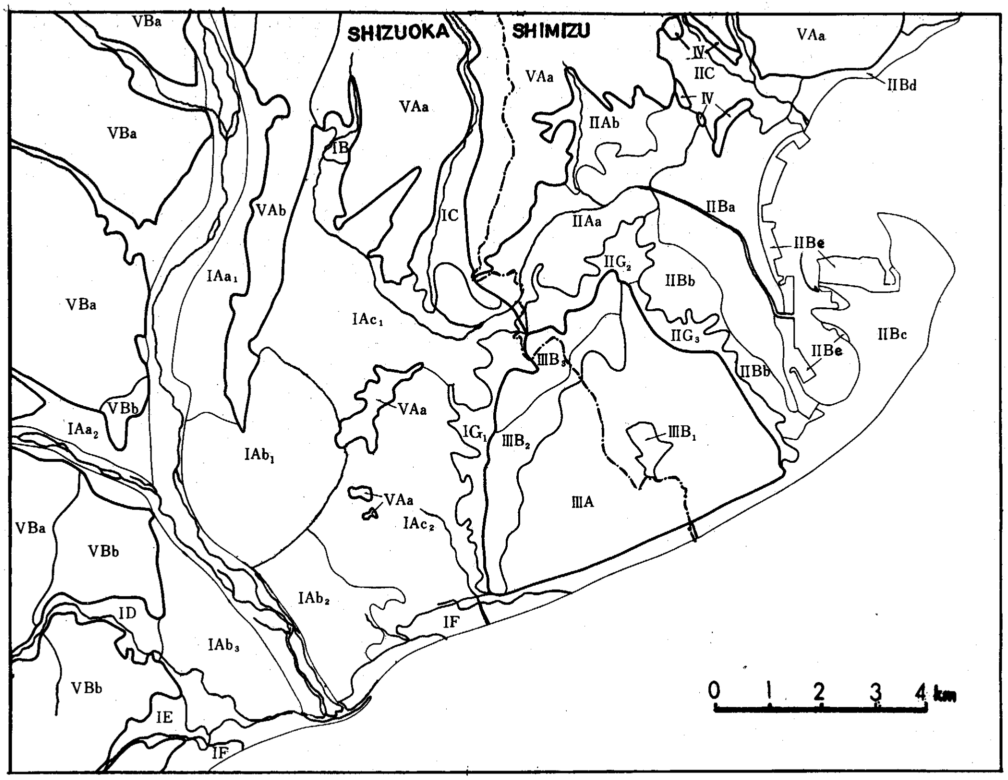


Fig. 4 Division of landform areas. See Table 2 for symbols.

exceeds 50% in areas where the thickness of soft ground layers is more than 30m.

3) The damage to structures due to b) is liable to occur in the recently formed lands, and in such reclaimed lands as filled-up areas and banks. The damage in the northern Tohoku District caused by the Tokachioki Earthquake of May 16th, 1968, was characterized by the destruction of such earth structures as banks and dams.

4) The damage to structures due to c) occurs mostly in the areas where the upper part of the ground is composed of loosely bedded sandy soils having an N-value of less than 5 and with groundwater level very close to the surface. The damage caused by the Niigata Earthquake of 1964 was characterized by damage to reinforced concrete buildings on sandy ground of recently abandoned channels (Building Res. Inst., 1965; Osaki, 1966).

5) The main cause of the earthquake damage to old-Japanese-style wooden houses is the synchronization of the natural period of houses with the predominant period of destructive earthquake motions, and maximum damage ratio appears on soft ground areas where the predominant period of microtremors is 0.4 seconds (Kanai et al., 1966).

6) The composition of the upper part of the ground within 5 to 10m. from the surface is the most important factor determining the extent of earthquake damage (e.g.,Kanai et al., 1963; Osaki, 1966; Sato, 1966).

Table 2 Division of Landform areas in the Shizuoka-Shimizu Region. Location of landform areas is shown in Fig. 3.

Landform Areas					Main Land Use
Shizuoka-Shimizu Lowland	I. Shizuoka Lowland	IA. R. Abe Lowland	a. R. Abe V. L	1. Main River V. L 2. R. Warashina V. L	Paddy field
			b. R. Abe Fan	1. Fan Proper	Built-up area
				2. Marginal Area, Left Bank	Paddy field
				3. do., Right Bank	do.
			c. Eastern Deltaic Lowland	1. Asahata Area	do.
				2. Naganuma-Takamatsu Area	do.
		IB. Upper part of R. Tomoe Lowland			Upland field
		IC. R. Nagao Lowland			do.
		ID. Mariko Area			Paddy field
		IE. Osaka Area			do.
		IF. Mochimune-Oya Shingle Bar			Built-up area
		IG. Small Fans at the foot of Udo-San Hill-lands		1. Katayama Area (IG1) 2. Kusanagi Area (IIG2) 3. Komagoe Area (IIG3)	Built-up area & Paddy field
	II. Shimizu Lowland	IIA. R. Tomoe Lowland	a. Lower part of R. Tomoe Lowland		Paddy field
			b. R. Shiota Lowland		do.
		IIB. Lowlands around Shimizu Port	a. Shimizu Sand Bank		Built-up area
			b. Yabe-Komagoe Coastal Lowland		Paddy field
			c. Miho Shingle Bar		Built-up area
			d. Okitsu Shingle Bar		do.
			e. Shimizu Reclaimed Land		Industry
		IIC. R. Ihara Lowland			Upland field

III: Udo-San Hill-lands, A: Area of steep slopes. B1: Nihondaira Area, B2: Ojika Area, B3: Kuniyoshida Area. IV: Mine-Ihara Plateau & Hill-lands. V: Marginal Mountain Lands, Aa: Ihara Mts. Ab: Shizuhatayama Mts., Ba: Abe Mts., Bb: Takakusayama Mts.
V.L.: Valley bottom Lowland

DISTRIBUTION OF GROUND-TYPES

Fig. 6 shows the distribution of ground-types in the Shizuoka-Shimizu Region. This map has been compiled by the following processes.

Step 1 -- The examination of the ground composition of micro-landform units and landform areas by boring data and geological sections.

Step 2 -- The delineation of ground-types by an analysis of micro-landforms using aerial photographs, and information obtained from Step 1.

Comparing the landform classification map (Fig. 2) and the ground-type classification map, it can be said that the boundaries of micro-landform units and landform areas coincide with those of ground-types to a considerable degree. This is a natural result because the primary ground-type classification is conducted by composition of the upper part of the ground. This is an example exhibiting the usefulness of the micro-landform analysis by aerial photographs. As earthquake damage occurs in close relation to the composition of the upper part of the ground, the micro-landform analysis on aerial photographs can be said to be a significant technique for pointing out danger areas from earthquake damage. The usefulness of this method was proved by the investigation of earthquake damage due to the Niigata Earthquake of 1964 (Takasaki et al., 1966; Nakano, 1966).

Table 3 Classification of unit layers by engineering geology and their engineering properties in the Shizuoka-Shimizu Region.

Classification of Unit Layers by Engineering Geology				N-Value	Wn(%)	WL(%)	qu (kg/cm^2)
"Alluvial Deposits"	Upper	Upper Muddy Layer (Um)	Organic Soils (Pt & OH)	0- 2	100-600	80-200	0.3-0.7
			Inorganic Soils	0- 5	40- 80	40±	0.8-1.0
		Upper Sand-and-Gravel Layer (Usg)	Sandy (Us)	5-20			
			Gravelly (Usg)	30+			
	Middle	Middle Sandy Layer (Ms)		10-20			
	Lower	Lower Muddy Layer (Lm)		5-20	30- 40	20- 35	1.0-1.5
		Lower Sand-and Gravel Layer (Lsg)	Sandy	20-30			
			Clayey Gravel	25-40			
			Gravelly	50+			
Soils on Plateaux & Terraces		Black Humus Soils (Bm) Yellowish Brown Clayey Soils (Ym)		3-10	30- 50	60- 80	
Diluvium		Sand-and-Gravel Layer beneath the Ground (Dsgl)		50+			
		Sand-and-Gravel Layer of Plateaux & Terraces (Dsg2)		50+			
		Muddy Layer (Dm)		20-50	20- 30	30- 45	1.3-3.0
		Sand-and-Gravel Layer of Hill-lands (Dsg 3)		50+			
Basement Layer		Neogene Tertiary Rocks (Tr 1)		50+			
		Alkali Basaltic Rocks (Ab)		50+			
		Paleogene Tertiary Rocks (Tr 2)		50+			

N-Value : The value of N of the Standard Penetration-Test.
Wn : Natural water content relative to dry weight.
WL : Liquid limit.
qu : Unconfined compressive strength.

The areas with soft ground conditions, which consist of organic soils and soft clayey soils, are situated on the valley flats originating from drowned valleys adjacent to the R. Abe Fan (the Osaka (IE) and Mariko (ID) areas), the Asahata-Naganuma-Takamatsu (IAc1 & IAc2) area adjacent to the R. Abe Fan, and in the lower part of the R. Tomoe Lowland (IIAa). Within these soft ground areas, in the Osaka area, in the lower part of the R. Tomoe Lowland, and in a part of the Asahata area, the total thickness of the Um and the Lm Layers exceeds 30m. Consequently, the greater part of the "Alluvial Deposits" in such areas consists of soft and weak muddy layers, forming the types-M_3, M_4 and M_5 soft ground areas where the depth of layers having an N-value of more than 50 and bearing the foundation of heavy-weight structures may also be greater than 30m.

The type-SGM belongs to semi-soft ground, and is distributed in small fans at the foot of the Udo-san Hill-Lands (IG). It is composed of the alternation of thinly bedded gravels, sands and clays. It should be noted that the ground composition of the alluvial fans with a relatively steep slope consists of such kinds of geologic materials. The foundation bearing strength of this type is small. The wooden houses on this ground-type were destroyed by the earthquake of 1935 (Fig. 7).

The sandy ground-types (S_1 and S_2) lie in the Shimizu Sand Bank area (IIBa), among which type-S_2 distributed along the west bank area of the R. Tomoe is composed of sandy soils of 3 to 10m. in thickness underlain by marine clayey sediments of 20 to 30m. in thickness. Earthquake damages have occurred on this ground-type from the earthquakes of 1935 and 1944. Type-OR is the sandy ground of the recently abandoned channels by engineering work, and includes naturally abandoned channels which are distributed in poorly-drained lowlands and on the coast. Sandy soils of this ground-type are loosely bedded and saturated with groundwater. Great damages occurred on and around type-OR crossing the coastal shingle bar at Ohya in 1935 (Hagiwara, 1935). The type-Reclaimed Lands are the reclaimed areas from the sea around Shimizu Port (IIBe), and are used for industry and harbor facilities. This ground-type has frequently resulted in earthquake damages, for instance, due to the earthquakes of 1917, 1930, 1935, 1944 and 1965.

PREDICTING THE AREAS IN DANGER FROM EARTHQUAKE DAMAGE

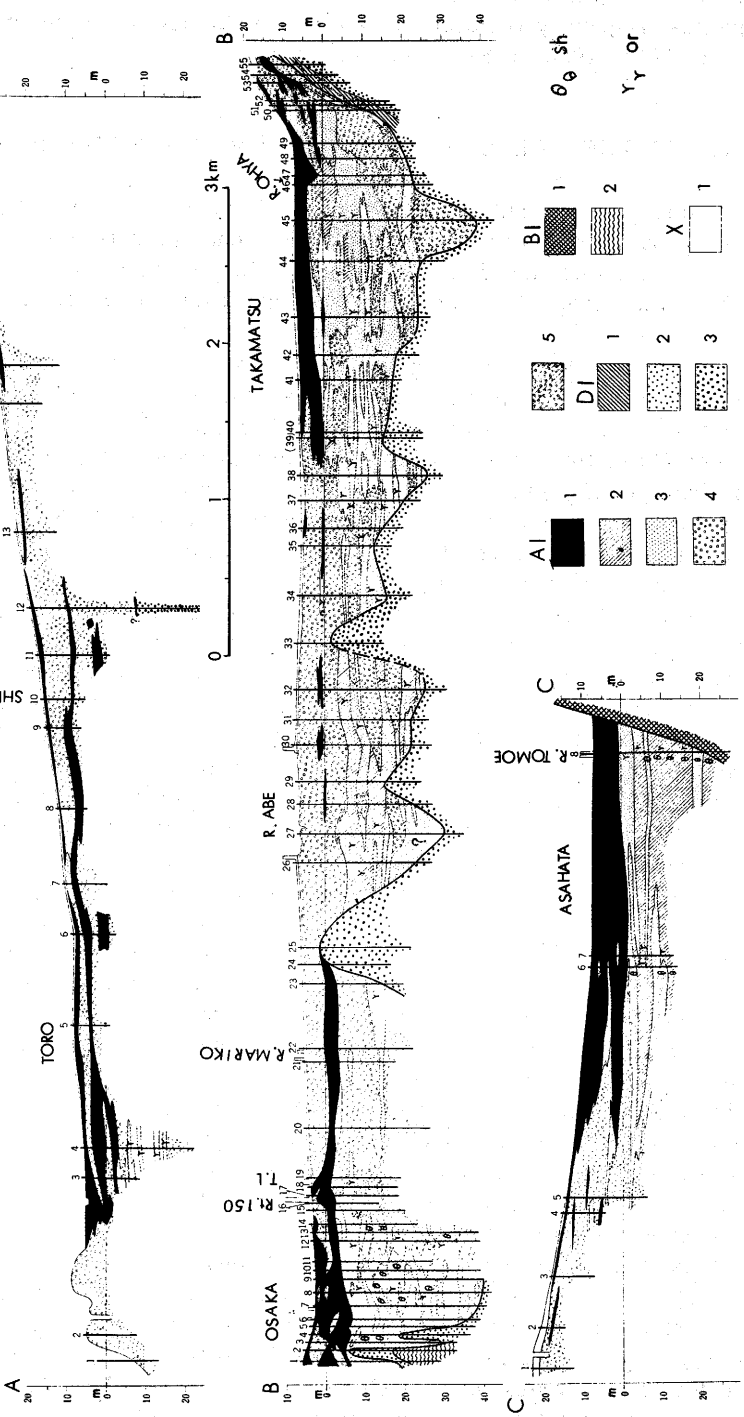
By examining the ground conditions of the above-mentioned soft ground, semi-soft ground and poor ground through general relationships between earthquake damage and ground conditions and the distribution of previous earthquake damages in this region studied, the areas with such conditions may cause disasters due to destructive earthquake motions.

Supposing that a destructive, great earthquake having a magnitude of more than 8.0 occurred in Suruga Bay or Enshu-nada, within 100km. of the region studied and the scale of seismic intensity was greater than Class VI on the Japan Meteorological Agency Classification recorded at the Meteorological Observatory of Shizuoka, situated on the type-SG_2 ground, a great disaster can be expected to occur in the above-mentioned soft ground areas. According to Kawasumi (1951), the probability of the occurrence of such destructive earthquake motions in this region may be approximately once every hundred years.

If the degree of danger from earthquake disasters due to such destructive earthquake motions is classified as A, B, C, D and E in descending order the relation to the ground-types are thought to be as shown in Table 5. In this table, the damage percentage of wooden houses is used to indicate the extent of damage, because most structures in this region in the near future may be wooden houses. The damage percentages shown in this table are based on the relationships between those caused by the Tonankai Earthquake of 1944 and ground conditions in the R. Ota and R. Kiku Lowlands, western Shizuoka Prefecture, which were demonstrated by Miyamura (1946), Tada et al. (1951) and Oba (1957). Damage percentages must be re-examined because of the recent progress in earthquake-proof building techniques of wooden houses; however, the most severe case is assumed here.

The distribution of the danger areas inferred from ground conditions can be mapped as shown in Fig. 8. The areas where the damages due to previous earthquakes have occurred are estimated as A or B according to the extent of damages. In types-M_4 and M_5, where the ground conditions are the weakest in this region, little damages to structures are known to have occurred, because few settlements stood on these ground-types in the past. Such ground-types should be ranked A, because maximum damage percentage has always appeared in such ground conditions consisting of thick soft ground layers as evidenced in the downtown areas of Tokyo and Yokohama due to the Great Kanto Earthquake of 1923, and in the R. Ota Lowland due to the Tonankai Earthquake of 1944, etc.

The areas which might result in damage to heavy structures such as reinforced concrete buildings without suitable foundations are abandoned channels distributed in the deltaic lowlands and coastal areas (type-OR), and the marginal part of the Shimizu Sand Bank (type-S_2), where loosely bedded sandy soils compose the upper part of the ground and the ground-water table is close to the surface. The above-mentioned is just supposition of the extent of damage from ground conditions, so that if land use in this region was taken into consideration, danger from earthquake damage will be



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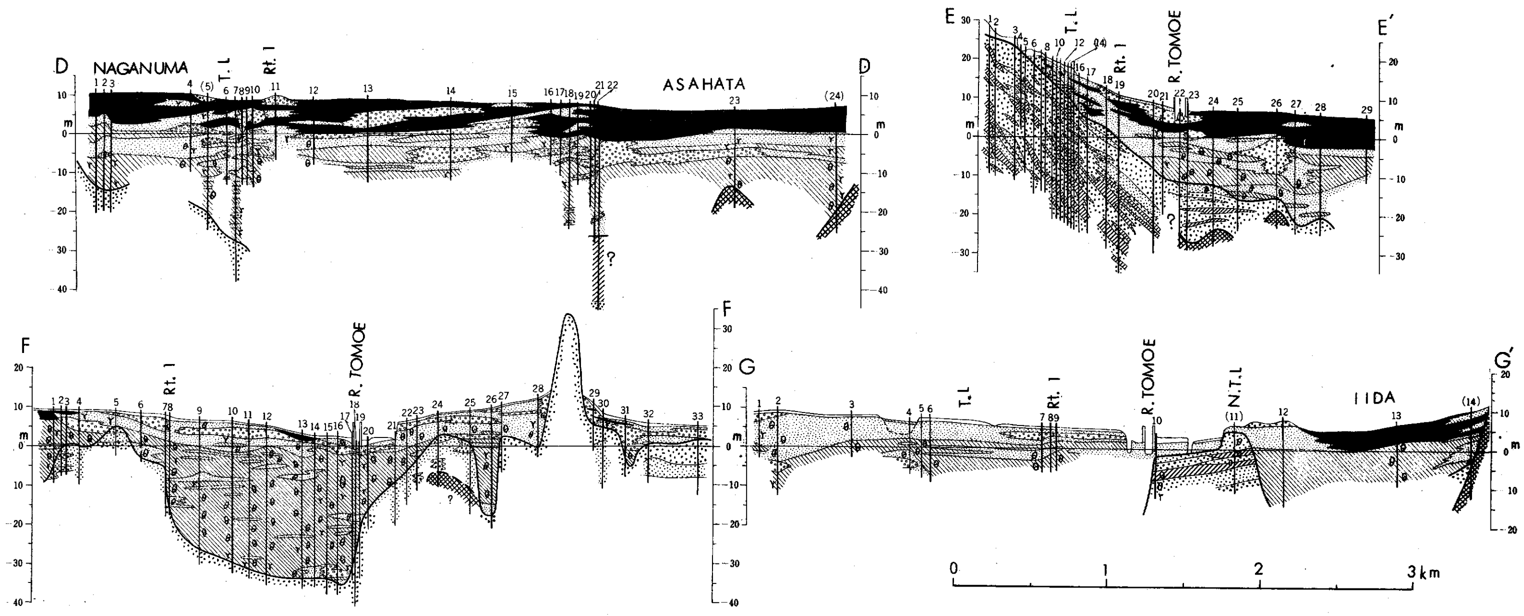

Fig. 5　Geological sections.

Location of section is shown in Fig. 2.

A1: "Alluvial Deposits" - 1: Clayey soils in the Um Layer, rich in organic soils (N<5), 2: Clayey soils in the Lm Layer (N=5-20), 3: Sand and sandy soils (N=5-20), 4: Sand-and-gravel soils (N>30), 5: Sand-and-gravel soils with clay (N>20).

D1: Pleistocene - 1: Clayey soils (N>10), 2: Sand and sandy soils (N>20), 3: Sand-and-gravel soils (N>50).

B1: Basement layers - 1: Neogene Tertiary rocks (N>50*), 2: Alkali basaltic rocks (N>50*).

X: Others - 1: Cultivated soils, banked soils and filled-up soils.

sh: With shells, or: With organic materials, N: Approximate value of N of the standard penetration-test. *Except for the weathered part. Thick line indicates the base of "Alluvial Deposits".

Table 4 Classification of ground-type in the Shizuoka-Shimizu Region. Distribution of ground-types is shown in Fig. 6.

Ground-Types				Thickness of Unit Layers (m)				Foundation Bearing Layers **		Landform Areas ***
Major Classification		Minor Classification		Um	Usg or Us	Lm	Total Thickness of Muddy Layers *	Depth from Ground Surface (m)	Unit Layers	
Mountains & Hill-lands	Solid Ground	Tertiary Mountains^{+}	T	(2- 5)$^{++}$	-	-	-	2- 5	Tr1, Tr2, Ab	VA, VB
		Diluvial Gravelly Hill-lands	D_1	(2-10)$^{++}$	-	-	-	2- 5	Dsg3	IIIA, IV
Plateau & Terraces		Diluvial Gravelly Plateaux & Terraces	D_2	(2-10)$^{+++}$	-	-	-	2-10	Dsg2	IIIB, IV
Lowlands	Gravelly Ground	Gravelly 1	SG_1	-	10	5	0- 5	2- 5	Usg	IAa, IAb1, IAb2, IB, IC, IF, IIBc, IIBd
		Gravelly 2	SG_2	1- 3	3-10	5	0- 5	2- 5 or 10	Usg or Lsg	IAb2, IAb3, IIC
	Sandy Ground	Sandy 1	S_1	-	3-10	0- 5	0- 5	5-10	Lsg, Dsg1 or Tr	IIBa, IIBb
	Semi-Soft Ground	Sandy 2	S_2	1- 3	3-10	5-30	5-30	5-30	Dsg1 or Tr1	IIBa
		Gravel-Sand-Mud	SGM	1- 3	1- 3	1- 3	1- 5	5-10	Dsg1	IG, IIG
	Soft Ground	Muddy 1	M_1	1- 3	-	-	1- 3	5-20	Usg or Lsg	IAc1, IAc2
		Muddy 2	M_2	3-10	-	-	3-10	5-20	Lsg, Dsg1 or Tr1	IAc, ID
		Muddy 3	M_3	1- 3	-	5-20	10-20	10-30	Dsg1 or Tr1	IAc, IE, IIAa
		Muddy 4	M_4	3-10	-	5-30	20-30	20-30	Dsg1, Tr1 or Ab	IE, IIAa
		Muddy 5	M_5	>10	-	5-30	>30	>30	Dsg1, Tr1 or Ab	IE, IIAa
	Poor Ground	Abandoned Channels^{++++}	OR	1- 3	1-10					
		Reclaimed Lands	RC	Filled-up soils						IIBe

* Total thickness of Um and Lm. ** Layers having N-value of more than 50 and bearing heavy-weight structures. For symbols of unit layers, see Table 3.

*** For symbols of landform areas, see Table 2. + Including Alkali Basaltic Rocks Mountains.

++ Weathered parts. +++ Black Humus Soils (Bm) and Yellowish Brown Clayey Soils (Ym).

++++ Composed mainly of loosely bedded sandy soils with high water content, and distributed in deltaic and coastal areas.

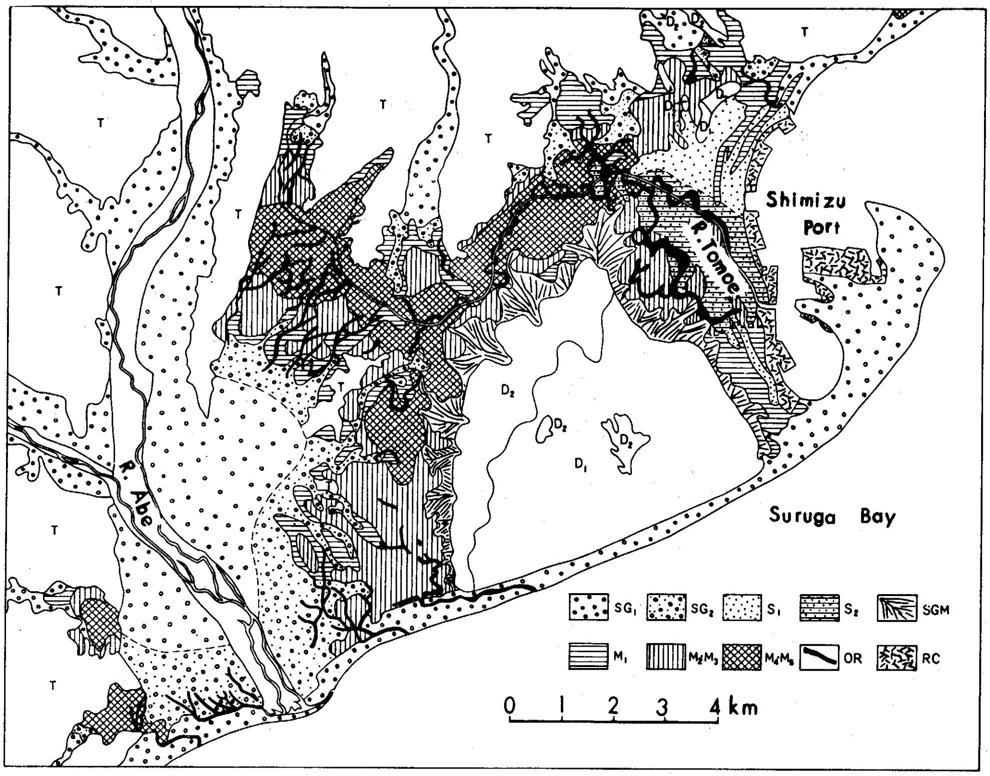

Fig. 6 Distribution of ground-types classified from kinds, compositions, engineering properties and thicknesses of unit layers.
See Table 4 for symbols.

variable, as a matter of course. However, the forecasting of danger areas from ground conditions is essential for examining the degree of danger from land use.

Damage due to destructive earthquake motions is usually followed by fire disaster, and flood damage in the lowlying coastal lowlands cuased by tsunami. Danger from fire disaster due to the destruction of structures may be the greatest in the reclaimed lands around Shimizu Port (type-Reclaimed Lands) because of its poor ground conditions and the accumulation of storage facilities of such imflammable materials as petroleum and high pressure gas.

SOME PROBLEMS ON THE FUTURE DEVELOPMENT OF THE REGION FROM THE VIEWPOINT OF DISASTER PREVENTION

According to the results of the investigation, the following problems may be pointed out in connection with the future development of the soft ground areas in this region, most of which are used as paddy fields at present.

1) It is necessary to make reasonable physical planning suited to ground conditions.
2) The excessive taking up of groundwater which might cause ground subsidence owing to consolidation of soft, compressive layers should

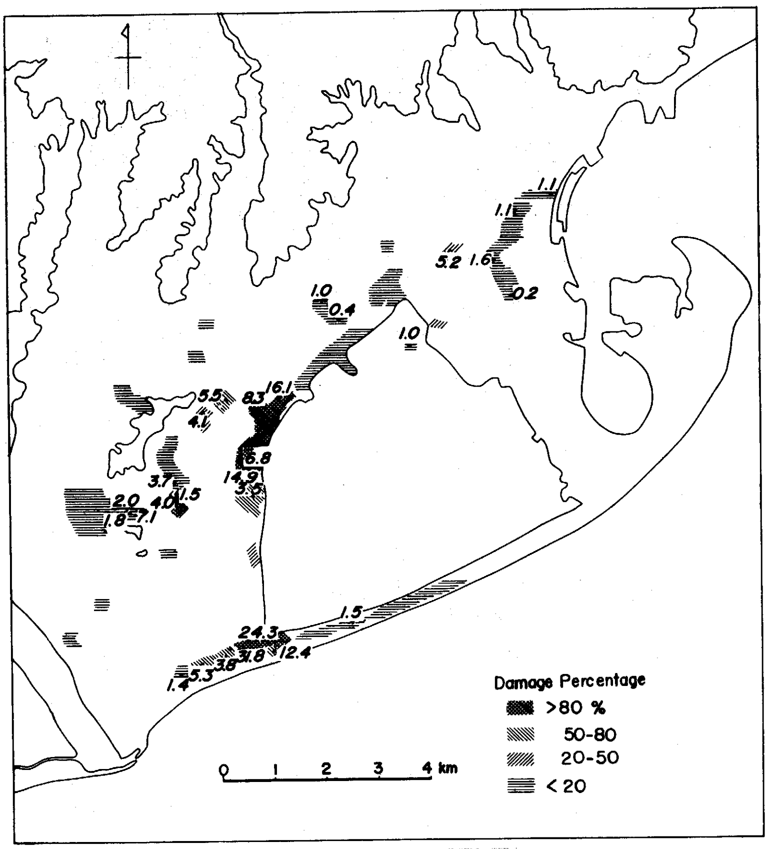

Fig. 7 Distribution of damaged houses caused by the Earthquake of July 11, 1935.

Figures indicate the percentage of totally collapsed houses in each hamlet. (After Saita, 1935, partly modified)

always be prohibited, especially in the types-M_4 and M_5 ground where soft muddy layers are thickly bedded.

3) It should be emphasized that soft ground areas lie on the poorly-drained lowlying lowlands, and construction of reasonable drainage systems before urbanization is necessary.

4) In order to plan regional disaster prevention projects, the quantitative analysis of the amount of damage to structures and the number of sufferers caused by a supposed destructive earthquake motion by each ground-type or danger area in connection with the present and the future land use pattern and population in this region is required.

5) As for the New Tokaido Line and the Tokyo-Nagoya Expressway passing through soft ground areas in the lower part of the R. Tomoe Lowland and the Osaka area, it is most important to make careful plans in order to insure safety.

Table 5 Classification of areas in danger from earthquake damage in the Shizuoka-Shimizu Region. Distribution of danger areas is shown in Fig. 8.

Degree of Danger		DP*	Ground-Types	Landform Areas	Remarks
A	Greatest	>50%	M_5, M_4, RC & OR**	Most part of ID, IF, IIAa & IIBe, & a part of IAc.	Damages due to fire and tsunami may be the greatest in IIBe Area.
B	Greater	30-50%	M_3, M_2, M_1, SGM & S_2	Most part of IAc, IG, IIG & southern part of IIBa.	Most of abandoned channels of this area may be ranked A.
C	Great	10-30%	S_1, & SG_2	Norhtern part of IIBa & IAb2, & IAb3.	Most of abandoned channels of this area may be ranked B.
D	Small	<10%	SG_1	IAa, IAb_1, IB, IC, IF, IIBd & IIBc.	Most of abandoned channels of this area may be ranked C or B.
E	Smallest	Rare	T, D_1 & D_2	III, IV & V	Landslide & land-collapse can be expected to occur.

* Damage percentage of totally collapsed houses due to a supposed great earthquake having a magnitude of more than 8.0 occurred within 100 km. of this region. On the supposition that the Scale of Seismic Intensity on the Japan Meteorological Agency Classification was greater than Class VI recorded at the Meteorological Observatory of Shizuoka, which is located on the type-SG_2 ground.

** Damage to heavy structures due to "liquefaction of sandy soils" can be expected to occur.

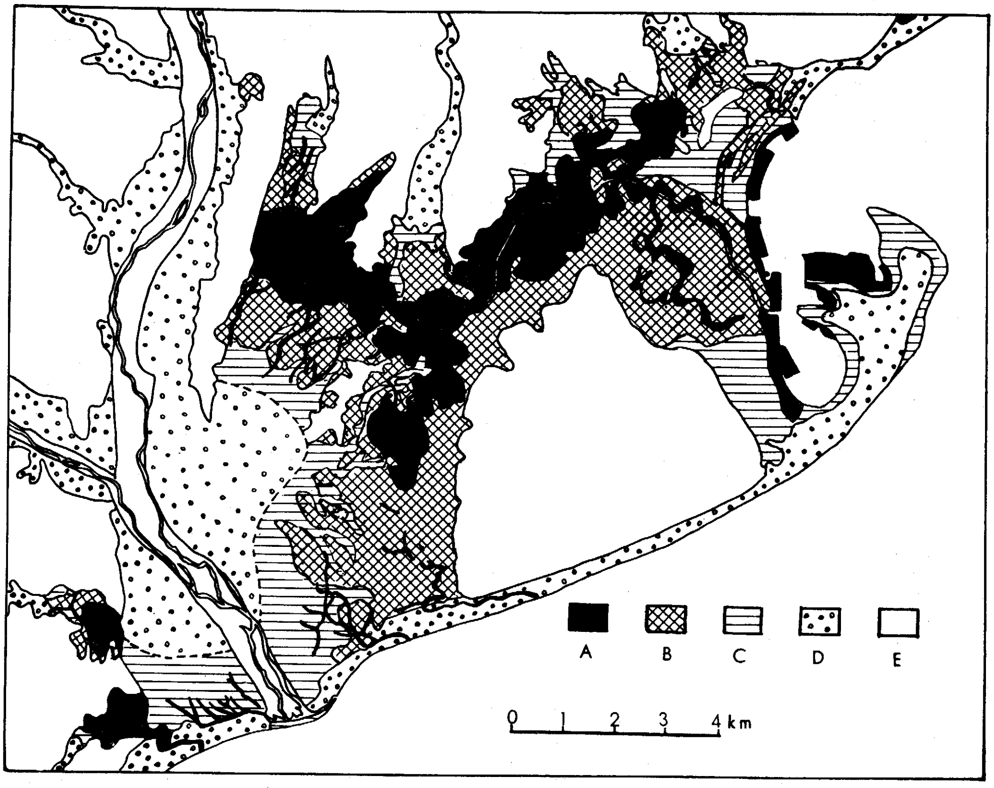

Fig. 8 Map showing the areas in danger from earthquake disasters inferred from ground conditions.

A, B, C, D and E denote the degree of danger in descending order. For details see Table 5.

CONCLUSION

Many areas with soft ground conditions are distributed on alluvial and coastal deltaic lowlands of Japan where rapid regional development is now in progress. In such areas, the detailed investigation of ground conditions as well as examination of the danger areas from natural disasters due to soft ground conditions are necessary to allow reasonable plans for regional development and disaster prevention. The methods and procedures discussed in this paper may be applied to other regions having similar ground conditions and similar problems to the studied region in mapping the danger areas from natural disasters, especially earthquake damage, as well as in planning regional development. For the purposes photo-geomorphological analysis of soft ground conditions supplemented by geological and geophysical field investigations, and data analysis of previous disasters would play an important role.

In conclusion, mention should be made of future studies related to this paper. The following must be investigated for future development of this study:

1) The statistical analysis of information on ground conditions extracted from aerial photographs and its application to the establishment of danger areas from disasters.
2) Aerial photo analysis of geophysical properties of the ground, especially of dynamic behavior of the ground due to destructive earthquake motions.
3) Experimental studies on the characteristics of ground vibrations by using models having various kinds of boundary conditions of soft ground areas. For this the collaboration with engineering seismologists is necessary.

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