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LIQUEFACTION DAMAGE TO THE GROUND DURING THE 1983 NIHONKAI-CHUBU (JAPAN SEA) EARTHQUAKE IN AKITA PREFECTURE, TOHOKU, JAPAN

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ABSTRACT

A very strong earthquake of magnitude 7.7 took place in northwest Tohoku District in Japan on May 26th, 1983. This earthquake was named the 1983 Nihonkai-Chubu (Japan Sea) earthquake by the Japanese Meteorological Agency. Liquefaction phenomena occurred widely from Akita to Aomori Prefectures. Structural damage and ground failure by earthquake-caused liquefaction was the worst in Japan since the 1964 Niigata earthquake.

We investigated the damage and mapped the liquefaction sites in Akita Prefecture, and concluded that the damaged areas in Akita Prefecture can be separated into two types: lowlands reclaimed from river beds, lagoons, marshs and weak paddies; and the borders between alluvial lowland and sand dune such as those located between sand dunes.

1. INTRODUCTION

On May 26th, 1983, the northwest part of the Tohoku District was heavily shaken by a very strong earthquake of magnitude 7.7 (Japanese Meteorological Agency scale). This earthquake was named the 1983 Nihonkai-Chubu (Japan Sea) earthquake by the Japanese Meteorological Agency. At many locations between the Aomori and Akita Plains, sand liquefaction was induced. Sand liquefaction was common in reclaimed fills, on the flood-plains of rivers, on the margins of sand dunes, and on the borders between alluvial plain and sand dune. The severity of the structural damage and ground failure produced by the liquefaction caused by this earthquake was the worst in Japan since the 1964 Niigata earthquake.

We located a great many liquefaction sites and investigated the damaged areas for 35 days, as well as examining aerial photographs of damaged sites which were taken 3 hours after this earthquake. Liquefaction caused ground settlement and subsidence, failure and settlement of embankments, failure of retaining walls, tilting of bridges and electric light poles, and collapse of houses. We investigated this damage and mapped the liquefaction sites in Akita Prefecture and here describe the distribution of liquefaction sites, the geological and geomorphological features of each site, the characteristics of liquefied sands and the damage features in Akita Prefecture produced by the 1983 Nihonkai-Chubu earthquake.

2. NIHONKAI-CHUBU EARTHQUAKE

At 0:00 p.m. on May 26th, 1983 (Japan Standard Time), a fairly strong earthquake hit

KEY WORDS: Liquefaction, Site investigation, Earthquake damage, Sandy soil, Ground disaster, Geomorphological feature
Note: Discussion open until 1 March, 1987

the northwest Tohoku District in Japan. The Japanese Meteorological Agency (JMA) named this earthquake which took place about 100 km west of Noshiro City, the 1983 Nihonkai-Chubu

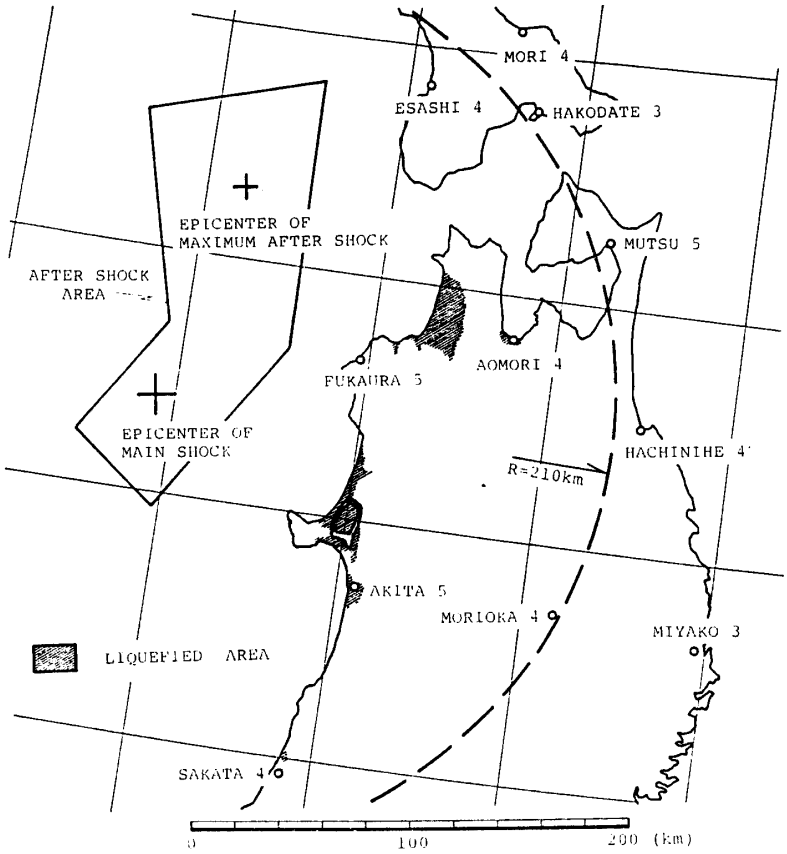


Fig. 1 Seismic intensity map of the 1983 Nihonkai-Chubu earthquake (JMA).

Table 1 Earthquakes of more than magnitude 6.5 (JMA scale) near Akita and western Aomori Prefectures. (Ref. [1])

No.	Name	Mon.	Day	Year	N.L.	E.L.	Magnitude
1	Dewa	2	3	830	39.8	140.1	7.4
2	Dewa			850	39.1	140.0	7.0
3	Dewa	4	4	857	40.3	140.6	7.0
4	Ugo	11	23	1423	39.2	140.1	6.7
5	Ugo Honjo	10	18	1644	39.4	140.1	6.9
6	Noshiro Area	6	19	1694	40.2	140.2	7.0
7	Ugo·Tsugaru	5	27	1704	40.4	140.0	6.9
8	Oshima Seigan· Tsugaru·Sado	8	28	1741	41.5	139.4	6.9
9	Tsugaru	3	8	1766	40.8	140.6	6.9
10	Nishi Tsugaru	2	8	1793	40.8	140.6	6.9
11	Kisagata	7	10	1804	39.0	140.0	7.1
12	Ugo	9	25	1810	39.9	139.9	6.6
13	Shohnai Area	10	22	1894	38.9	139.8	7.3
14	Oga Peninsula	5	1	1939	40.0	139.0	7.0
15	West-offshore Aomori Prefecture	5	7	1964	40.3	139.0	6.9

(Japan Sea) earthquake (Fig. 1). By the JMA, its magnitude was 7.7, the epicenter was located at 138°54′E and 40°24′N, the focal depth was estimated as 5 km below sea level. The width and length of the failure plane are shown in Fig. 1. An intensity of V on the JMA scale was recorded in Akita, Fukaura and Mutsu (Fig. 1).

Table 1 lists earthquakes of magnitudes 6.5 or heigher which that have taken place in northwest Tohoku District [1]. This table indicates that earthquakes of magnitude 7.0 have occurred about every 30 years and the magnitude of the 1983 earthquake is the highest recorded among the earthquakes during a 1200-year period.

The earthquake caused extensive damage to buildings, roads, bridges, port embankments and river dikes due to soil liquefaction, and 108 persons were killed by a tsunami. At Noshiro Port, 3000-ton caissons that were under construction were washed away by the tsunami. In Akita Prefecture, 83 persons were deceased and 265 persons were injured by the earthquake. The damage to Akita Prefecture was estimated at about 1400 billion yen in an Akita Prefecture Government Report [2].

A great deal of embankments, reclaimed fills, old river bed areas and borders between alluvial lowlands and sand dunes due was damaged to soil liquefaction. The total damage caused by liquefaction was the greatest in Japan since the 1964 Niigata earthquake [3].

3. SURFACE GEOLOGY

The 1983 Nihonkai-Chubu earthquake caused extensive damage in northwest Akita Prefecture, mainly due to the liquefaction of reclaimed sand, fluviatile sand and eolian sand.

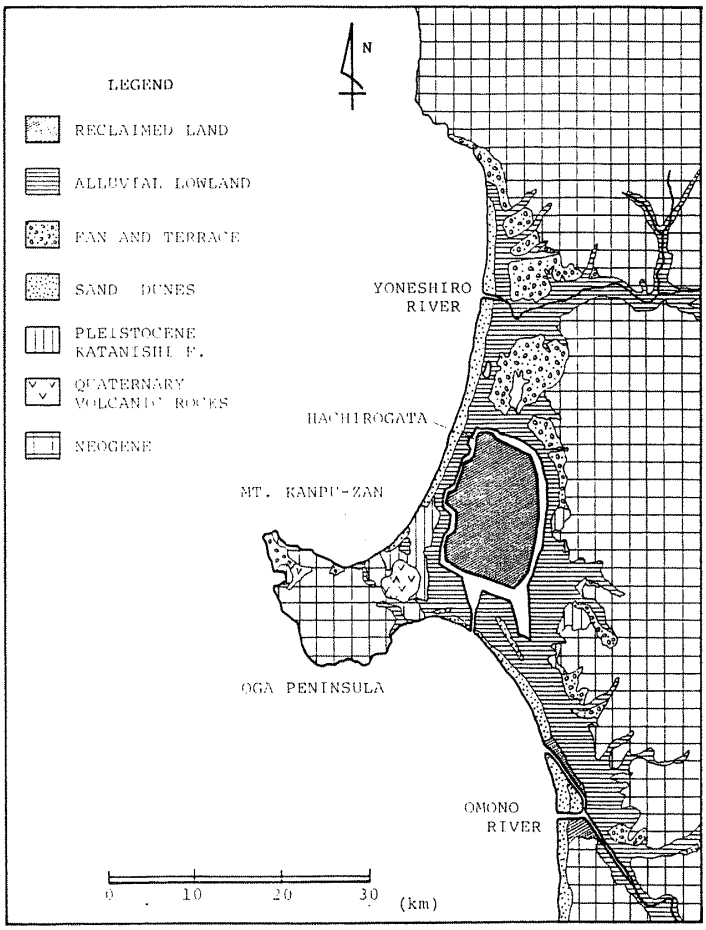


Fig. 2 Geological map of northwest Akita Prefecture.

Table 2 Ground damage caused by liquefaction in Akita Prefecture in the Nihonkai-Chubu earthquake.

Site	Location		Structure	Earthquake damage	Geomorphological feature
A1	Akita City	Araya-Motomachi	Many Houses	Tilting. Uneven settlement of footings. Floatation of a sewage treatment tank. Collapse of concrete block fences. Broken water and gas pipes. Settlement of electric light poles. Flooding and subsidence of roads.	Reclaimed fill on an old river bed
A2		Araya-Matsumicho	Houses	Uneven settlement of footings. Tilting of concrete block fences. Floatation of a sewage treatment tank.	Reclaimed fill.
A3		Yabase-Sinkawamukai	Apartment House	Floatation of a sewage treatment tank.	Reclaimed fill in a paddy.
A4		Iijima	Many Houses	Complete and partial collapse. Unused artesian well.	Alluvial lowland adjacent to sand dunes.
A5		Tsuchizaki-Minato-Nishi	Sewage Disposal Plant	Settlement of electric light poles. Uneven settlement of a buried tank. Subsidence of reclaimed ground and sewer pipes along the road.	Reclaimed fill.
A6		Akita Port (Honkoh)	Oil Storage Tank Yard	Tilting and settlement of tanks. Floatation of buried tanks. Cracks in oil fences. Tilting of electric poles.	Reclaimed fill on an old river bed.
A7		Akita Port (Honkoh)	Warehouse	Uneven settlement of floor. Sliping and bulging of quay wall. Movement of quay wall to sea. Collapse of an apron stage. Turning of conveyer tank.	Reclaimed fill on an old river bed.
			Lavatory	Tilting of building (made of concrete blocks).	
			Crane	Tilting and collapse to ground. Collapse of footing. Destruction of legs.	
A8		Akita Port (Mukohama)	Quay	Slipping and collapse. Settlement of an apron stage. Tilting of quay wall.	Reclaimed fill on an old river bed.
			Park	Tilting of electric poles. Settlement and cracking of road side.	
A9		Akita Port (Ohama)	Quay	Sliping and collapse of quay wall. Settlement of an apron stage. Movement of sheet pile to land. Opening of connection of box culvert.	Reclamation of harbor.

Table 2 (continued)

Site	Location		Structure	Earthquake damage	Geomorphological feature
A10		Akita Port (Gaikoh)	Crane	Off the track. Collapse and destruction of legs.	Reclaimed fill on shallow sea bed.
			Quay	Collapse of sheet pile. Movement of caisson pier. Settlement of an apron stage 1.5 m.	
			Warehouse	Destruction of column head. Uneven settlement of floor. Cracking and opening of on surface of the parking lot.	
A11		Kanaashi	Showa By-Pass	Settlement of culverts. Cracking and settlement of roads.	Reclaimed fill in paddies.
B	Showa Town	Motogi	House	Tilting of house 10 degrees. Collapse of concrete block fences.	Reclaimed fill in a paddy.
C	Koto-oka Town	Kado	Itonagare Bridge	Collapse of access road. Damage to paddy.	Alluvial lowland.
D	Tennoh Town	Egawa	Egawa By-Pass	Cracking and collapse of access road. Tilting of retaining wall.	Reclaimed fill in lagoon.
E1	Oga City	Funakoshi	Houses	Destruction of footing.	Reclaimed fill in lagoon
E2		Maeno	Oga Industrial High School	Floatation of a sewage treatment tank. Cracking and subsidence of ground. Uplift of a swimming pool. Settlement of school house floor 40 cm. Destruction of life lines.	Reclaimed fill in marsh.
			House	Collapse of house lot. Tilting of house.	
E3		Wakimoto	Many Houses	Complete and partial collapse. Tilting of electric poles. Destruction of gas and water pipe lines. Collapse of concrete block fences. Collapse of reclaimed lots.	Reclaimed fill in paddies.
		Ohkura	Many Houses	Complete and partial collapse. Turning of concrete block fences.	Alluvial lowland adjacent to sand dunes.
E4		Funakawa Port	Quay	Damage to warehouse.	Reclained fill on shallow sea bed.
F	Ohgata Village	East Intercepting Drain Dike	Embankment	Settlement of embankment 1 m. Shift of embankment road 1.4 m. Cracks and uneven settlement of road. Damage to siphon intake pipe lines.	

Table 2 (continued)

Site	Location		Structure	Earthquake damage	Geomorphological feature
				Uplift of colligated pipes. Damage to paddies.	
F1			Shinsei-Ohashi Bridge	Collapse of access road.	
F2			Northern Pumping Station	Turning of retaining wall. Uneven settlement of substation. Destruction of structure near main building.	
F3			Ohgata Bridge	Collapse of access road. Settlement of bridge base.	
F		Frontal Dike	Embankment	Settlement of embankment 1.5 m. Tilting of electric pole. Cracking of road. Damage to paddies. Damage to siphon intake pipe lines.	Reclaimed fill in lagoon.
F		West Intercepting Drain Dike	Embankment	Settlement of embankment 0.5 to 1.0 m. Swelling of roads. Cracks and subsidence of paddies.	
F4			Iwaida Bridge	Collapse of access road.	
F5			Noishi Bridge	Collapse of access road. Tilting of electric pole.	
F6			Gomyoko Bridge	Settlement of access road 1 m. Severe collapse of access road.	
F7			Hamaguchi Pumping Station	Destruction of fence. Uplift of a ladder's footing.	
F8		Main road	North Bridge	Cracking of abutment.	
G1	Wakami Town	Fukumesawa	House	Tilting. Collapse of reclaimed fill.	Reclaimed fill in paddies.
G2		Noishi	House	Sinking of floor.	Reclaimed fill in a paddy.
G3		Miyazawa	Houses	Tilting and nonuniform subsidence. Collapse of reclaimed ground. Sinking of a truck.	Reclaimed fill in paddies.
G4		Tamanoike Ishidagahara Yanagihara	Many Houses	Complete and partial collapse. Tilting of electric poles. Turning of concrete block fences. Severe damage to paddies. Cracking and swelling of roads.	Borders between sand dune and alluvial lowland. (Blow out depressions) Reclaimed fill in marsh.

Table 2 (continued)

Site	Location		Structure	Earthquake damage	Geomorphological feature
G5		Gomyoko	Many Houses	Complete and partial collapse. Tilting of electric light poles. Turning of concrete block fences. Severe damage to melon fields and paddies covered by vinyl.	Border between sand dune and alluvial lowland. (Blow out depression.)
H1	Hachiryu Town	Asizaki	Asizaki Branch School	Floatation of a sewage treatment tank.	Margin of sand dune.
H2		Hamada	Hamaguchi Elementary School	Floatation of a sewage treatment tank. Cracks in play ground. Complete collapse of house.	Border between sand dune and alluvial lowland.
H3		Ohmagari	Hachiryu Junior High School	Floatation of a sewage treatment tank. Cracks in play ground. Destruction of footings of the main school buildings and gymnasium.	Reclaimed fill in paddies.
H4		Ukawa	Kohoku Elementary School	Floatation of a sewage treatment tank.	Manmade ground.
I1	Noshiro City	Kuro-oka	Many Houses	Complete and partial collapse. Settlement of floors. Collapse of concrete block fences. Damage to paddies.	Border between sand dune and alluvial lowland.
I2		Naka-Asanai	Noriro Minami By-Pass	Uneven settlement of road. Large shift of road. Uplift of concrete pavement slabs. Tilting and movement of racks used as a defense against snow. Severe damage to paddies.	Reclaimed fill and alluvial lowland adjacent to sand dunes.
		Hama-Asanai	Many Houses	Complete and partial collapse. Damage to paddies.	Border between sand dune and alluvial lowland.
I3		Asanai	Many Houses	Damage to houses. Shift of road 80 cm. Unused artesian well.	Border between sand dune and alluvial lowland.
I4		Kawatogawa	Shops and Factories	Destruction of footing. Turning of concrete block fences. Tilting of gateposts. Damage to houses. Broken water pipes. Destruction of road's gutter.	Border between sand dune and alluvial lowland. Manmade ground.
			Gas Station	Floatation of buried oil tank 70 cm. Collapse of concrete block fence.	

Table 2 (continaed)

Site	Location	Structure	Earthquake damage	Geomorphological feature
I5	Tagomukai	Many Houses	Damage to half of Nagasaki Danchi. Cracks in house lots. Destruction of life lines. Settlement of electric poles.	Reclaimed fill in paddies.
	Bohgasaki	Many Houses	Partial collapse. Damage to paddies.	
I6	Santoh Marsh	Houses	Damage to houses.	Reclaimed fill in a paddy.
I7	Aoba-cho	Aoba-So Apartment House	Tilting of building (RC4F). Collapse of building (RC2F).	Borders between sand dune and alluvial lowland. Reclaimed fill in marsh and lowland between sand dunes.
		Many Houses	Complete and partial collapse. Turning of gravestones. Settlement of electric poles.	
	Shonan-cho	Many Houses	Complete and partial collapse. Collapse of house lots. Flooding of roads and house lots. Settlement of electric poles.	
	Matsumi-cho	Many Houses	Complete and partial collapse. Turning of gravestones.	
	Keirin-cho	Many Houses	Complete and partial collapse.	
I8	Midori-machi	Noshiro Commercial High School	Movement of main school building. Floatation of sewage treatment tanks. Open cracks in play ground.	Reclaimed fill in alluvial lowland.
I9	Nakagawara	Houses and Factories	Destruction of house footings. Tilting of houses. Collapse of reclaimed building lots. Damage to factories and paddies.	Reclaimed fill on an old river bed.
		River Dike	Tilting of steel sheetpile quay wall. Open cracks in embankment.	River bed.
I10	Noshiro Port	Quay	Subsidence of apron stage. Collapse of steel sheetpile quay wall.	River bed and reclaimed fill on old river bed.
	Seisuke-cho	Many Houses	Complete and partial collapse. Broken water and gas pipes.	Reclaimed fill in lowland between sand dunes.
	Hamadohri-cho	Factory and Houses	Complete collapse of factory. Damage to houses.	Reclaimed fill in back marsh.
I11	Koado	Sunny Land	Open cracks in parking lot and tennis courts. Damage to pipes that settled in the ground.	Alluvial lowland adjacent to sand dune.
		Baseball Park River Dike	Large open cracks in the ground. Cracks and subsidence.	Reclaimed fill in back marsh.
I12	Ochiai	Houses	Damage to houses. Damage to paddies.	Reclaimed fill in a paddy. Alluvial lowland.

A geological map of northwest Akita Prefecture is shown in Fig. 2. In Hachirogata, it was a shallow brackish lagoon. A reclamation plan was initiated in 1956, then drainage of the central area began in 1963, and by October of 1964, reclamation was complete and land in use for the first time at Higashiyama and Fujita [4].

It can be seen in this figure that the Quaternary System has a very large exposure in the area from the Omono River basin to the Yoneshiro River basin. The alluvial lowland is occupied by Quaternary layers, since late Pleistocene time, a so-called "Alluvium". Recent sand dunes have developed in two zones along the coast of the Japan Sea. One site runs about 40 km from Akita City to Oga City, the other runs about 45 km from Oga City to Hachimori Town.

Other Quaternary deposits mainly are those of the Pleistocene Katanishi Formation. The depositional plain of this formation forms the surface of a coastal terrace about 50 m above the sea level.

Volcanism during the Miocene left an andesitic to dacitic composition, especially on the Oga Peninsula. Sequences developed in this area are used as the standard stratigraphy for the oil-bearing Japanese Neogene and for the type locality of "Green Tuff" regions.

4. DISTRIBUTION OF LIQUEFACTION SITES

Liquefaction sites in Akita Prefecture produced by the 1983 Nihonkai-Chubu earthquake are shown in Figs. 3–4 and liquefaction and damage area at each site are given in Table 2. Liquefaction sites were recognized by miniature sand volcanos that were formed by eruptions of water and sand soon after the earthquake.

Kuribayashi and Tatsuoka [5], who reviewed liquefaction sites produced by the most recent 44 Japanese earthquakes, derived the following formula for the maximum epicentral distance of liquefied sites R(km) and the magnitude of an earthquake M:

$$\mathrm{Log}_{10}\, R = 0.77\, M - 3.6 \qquad (1)$$

Substituting 7.7 for M in Eq. 1, the maximum epicentral distance of liquefiable sites due to the 1983 Nihonkai-Chubu earthquake is estimated to be 210 km from the epicenter. The broken line in Fig. 1 represents the estimated maximum epicentral distance. The maximum epicentral distance of liquefaction for this earthquake is at Yuza Town, Yamagata Prefecture, a distance of about 180 km. All the liquefaction sites are located within this line (Fig. 1).

5. DESCRIPTIONS OF LIQUEFACTION SITES

1) Akita City

The distribution of liquefaction sites in Akita City is shown in Fig. 3. At Araya-Motomachi (Site A1) in the south of the city, liquefaction occurred in a long, narrow area running north-south. Many sand volcanos were found in house gardens and open spaces, and there was many tilts of houses, settlements of roads, and breakages of life lines. This site is on an old river bed shown on an old map drawn about 70 years ago (Fig. 5). At Araya-Matsumi-cho (Site A2) and Iijima (Site A4), the damage was less than at Araya-Motomachi.

At Akita Port, liquefaction was very widespread and much of the port's equipment was severely damaged. At Honkoh (main harbor), liquefaction occurred throughout the Akita Oil Storage Tank yard (Site A6), as shown by the uneven settlement of the oil tanks, the floatation of buried tanks and the collapse of oil fences. At D Quay and the Nakajima 1–3 Quays at the South Quay in Honkoh (Site A7), an quay wall was moved seaward. In addition to the apron stage subsidence and collapse, the foundation of a warehouse was broken, a conveyer tank was destroyed and the public lavatory was settled unevenly.

Photo. 1 shows the quay wall on part of Nakajima No. 1 quay, which bulged and sank into

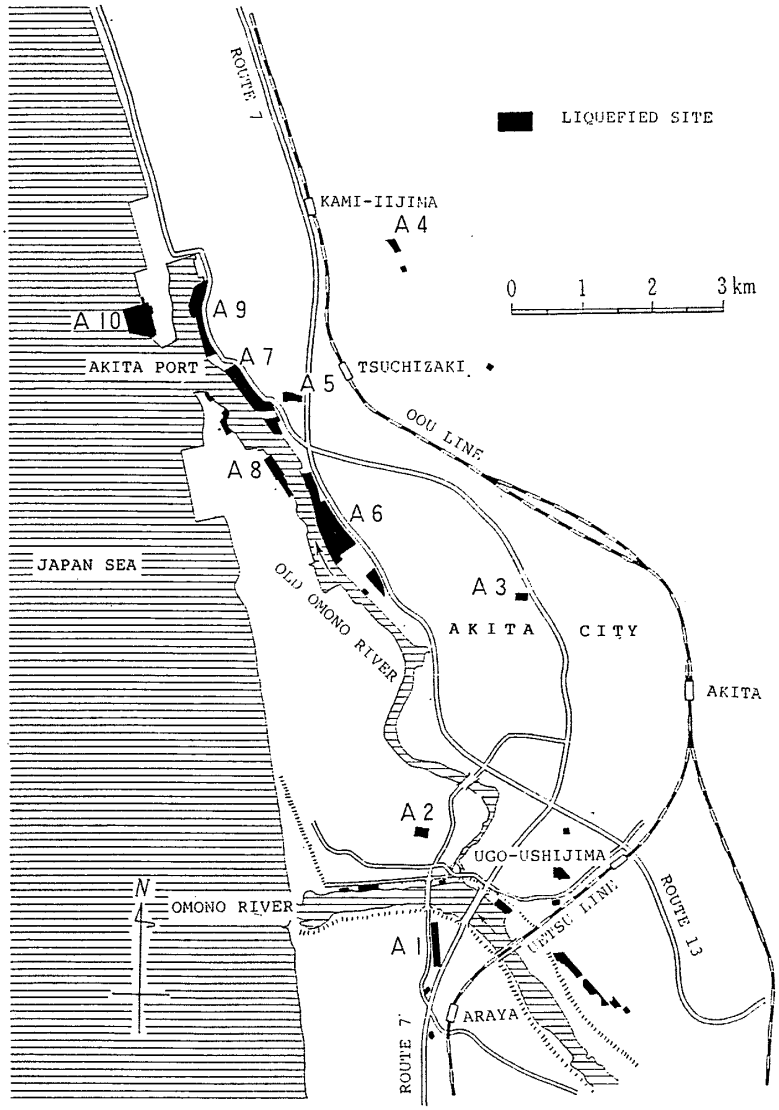


Fig. 3 Liquefaction site distribution map in Akita City after the Nihonkai-Chubu earthquake.

the sea. Photo. 2 shows the collapse of the apron stage and the destructoin of the warehouse's foundation. Photo. 3 shows the broken leg of an unloading machine at No. 2 quay buried in the ground.

At Mukohama (Site A8), a reinforced concrete quay wall was tilted approximately 10 degrees, and the apron stage settled and cracked. Many sand volcanos were present around No. 3 quay which had been constructed about the time of this earthquake. Photo. 4 shows sand volcanos found around a bench in Mukohama Park.

At Ohama (Site A9), the quay wall of the No. 2 quay, formed of a steel sheetpile, tilted toward the land and bulged after which all the foundations of this quay moved. The connection of a box culvert was opened 1 m, and the reinforcing steel broken off.

At Gaikoh (outer harbor, Site A10), a great many cracks ran in every direction and the ground surface heaved. Photo. 5 shows sand volcanos inside of open cracks in the parking lot. A caisson quay wall was moved approximately 1 m, and the apron stage near it settled and collapsed. Maximum settlement of the apron was 1.5 m, as shown in Photo. 6. Almost all a warehouse's floors near the apron were collapsed except the footing beam and the reinforced concrete column heads were destroyed.

The locales where sand volcanos and sand blows were produced at Honkoh and Mukohama

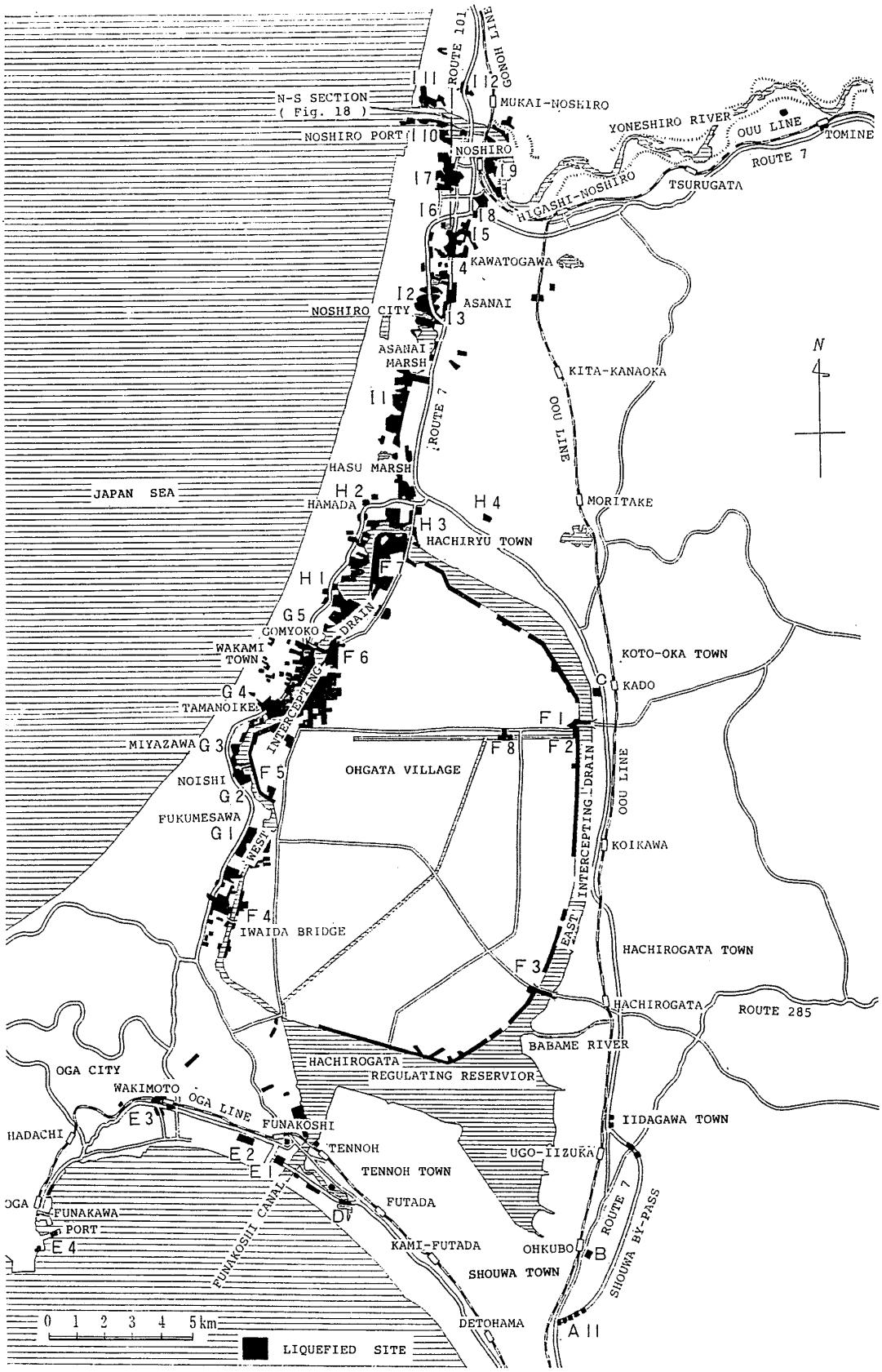


Fig. 4 Liquefaction site distribution in northwest Akita Prefecture after the Nihonkai-Chubu earthquake.

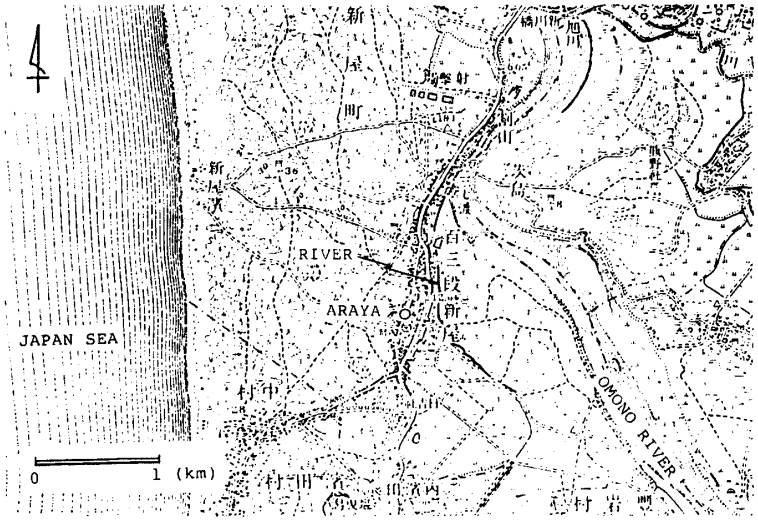


Fig. 5 Old topographic map of 1914 for the southern part of Akita City.

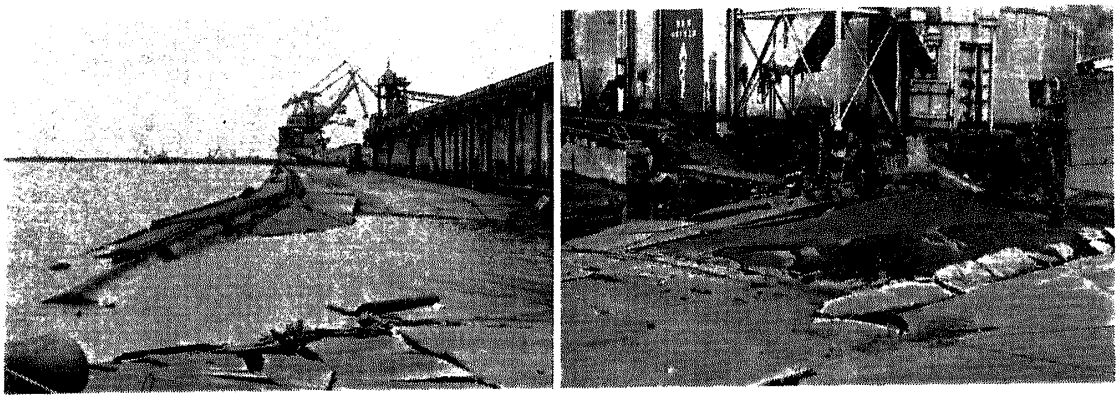


Photo. 1 Photo. 2

Photo. 1 Sunken quay wall and bulging revetment at Nakajima No. 1 Quay in Akita Port (Site A7).

Photo. 2 Damaged warehouse and collapsed apron stage at Nakajima No. 1 Quay in Akita Port (Site A7).

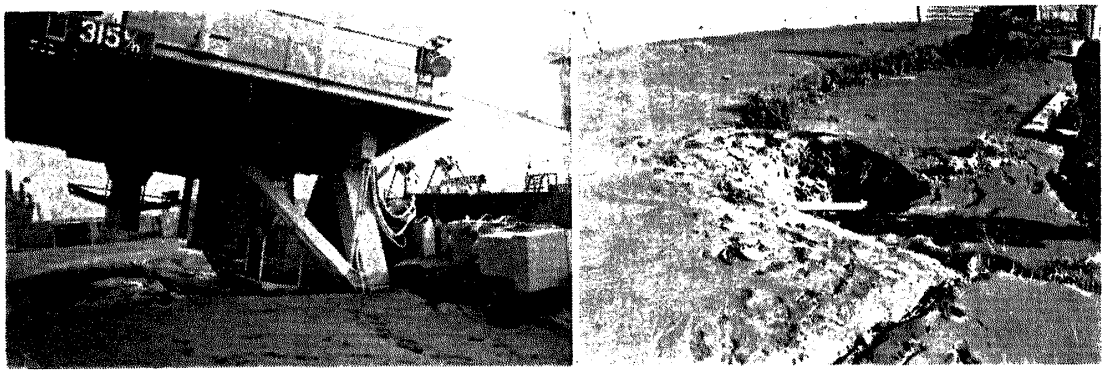


Photo. 3 Photo. 4

Photo. 3 Leg of unloading machine at Nakajima No. 2 Quay in Akita Port, broken and buried in the ground (Site A7). Photograph from Mr. Fukuhara (Tokyo Institute of Technology).

Photo. 4 Sand blow out near a bench at Mukoh-hama Park (Site A8).

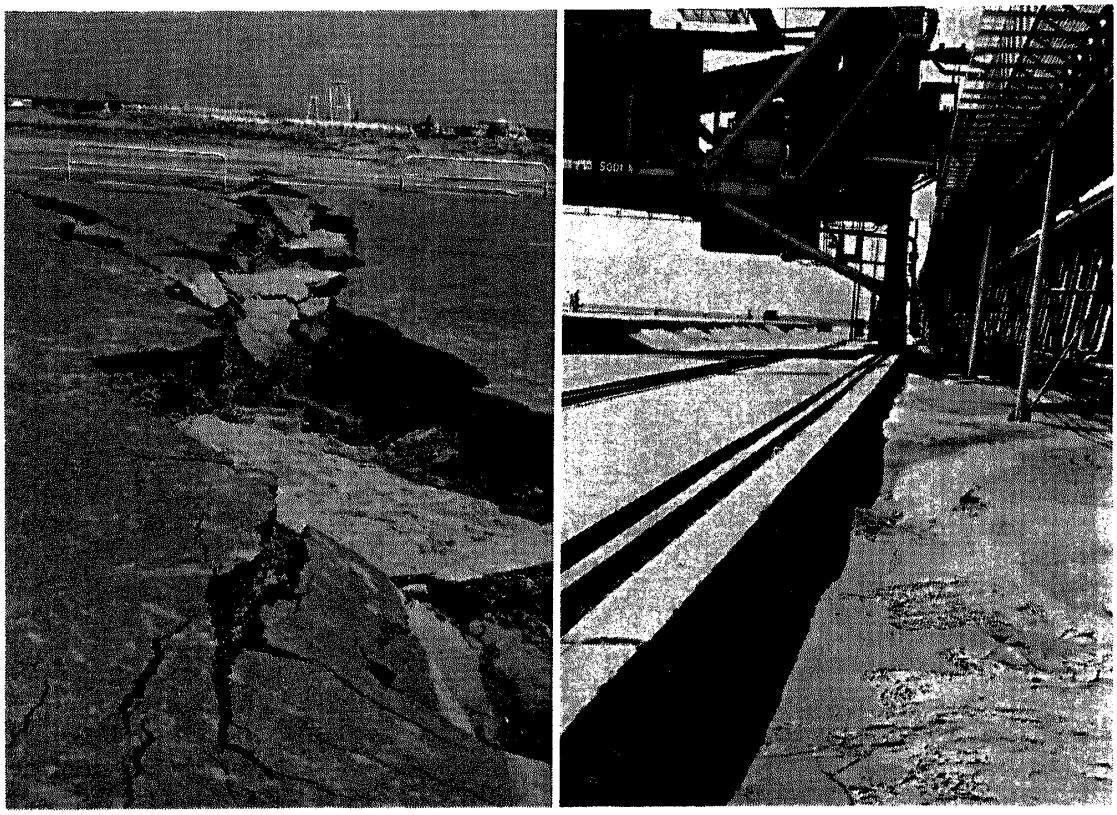


Photo. 5 Photo. 6

Photo. 5 Sand blow inside an open crack in the parking lot near the warehouse in Gaikou (outer port) Akiata Port (Site A10).

Photo. 6 Complete collapse of the apron stage at the quay wall in Gaikoh, Akita Port (Site A10).

are reclaimed and filled ground on the Old Omono River bed. The liquefaction site at Gaikoh is reclaimed land on a shallow sea bed, and the liquefaction site at Ohama is at the new quay which had been constructed just before this earthquake. All the damage caused by liquefaction in Akita Port took place on artificial or reclaimed ground. At Gaikoh, the liquefied materials were well sorted, fine-grained reclaimed sands (Fig. 6).

At the Showa By-pass between Ohoshimizu in Akita City and Midarebashi in Showa Town (Site A11), there was extensive settlement and cracking of the surface of the embankment road, side gutters and laid pipe lines under ground being broken. This damaged area was made up of

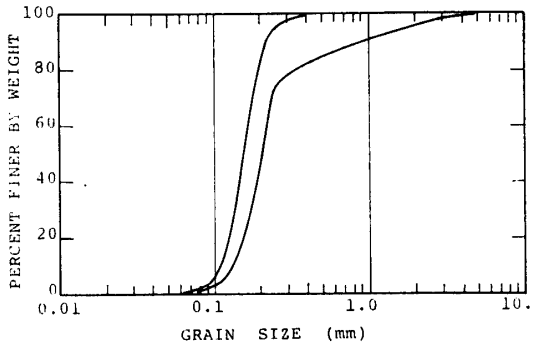


Fig. 6 Grain size distribution curves of sands liquefied by the Nihonkai-Chubu earthquake at Gaikoh (Site A10).

fill on an alluvial lowland.

2) Oga City

The distribution of liquefaction sites in Oga City is shown in Fig. 4. At the Oga Prefectural Industrial High School, constructed on reclaimed ground on a marsh at Maeno (Site E2), sand volcanos were present on the playing grounds, around the school building and inside open cracks

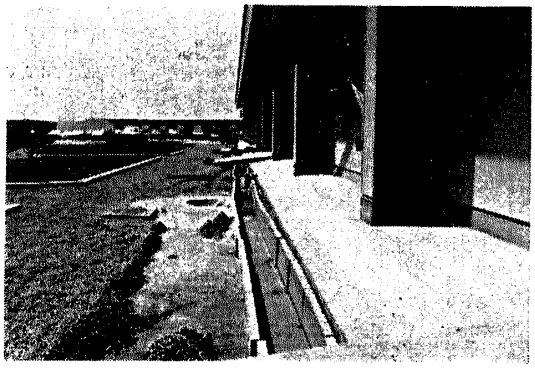


Photo. 7

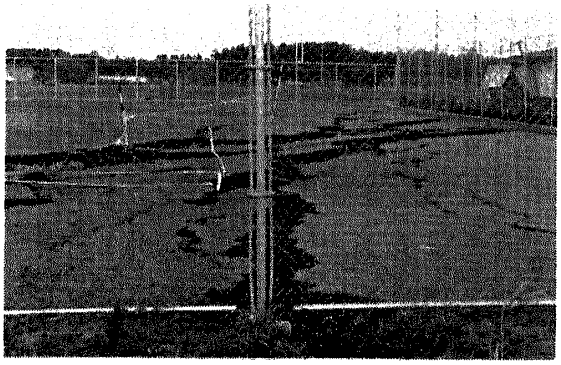


Photo. 8

Photo. 7 Sand blows around a building at the Oga Industrial High School (Site E2).

Photo. 8 Cracks in the tennis court at the Oga Industrial High School and damage to a wooden house that slipped due to collapse of its lot (Site E2).

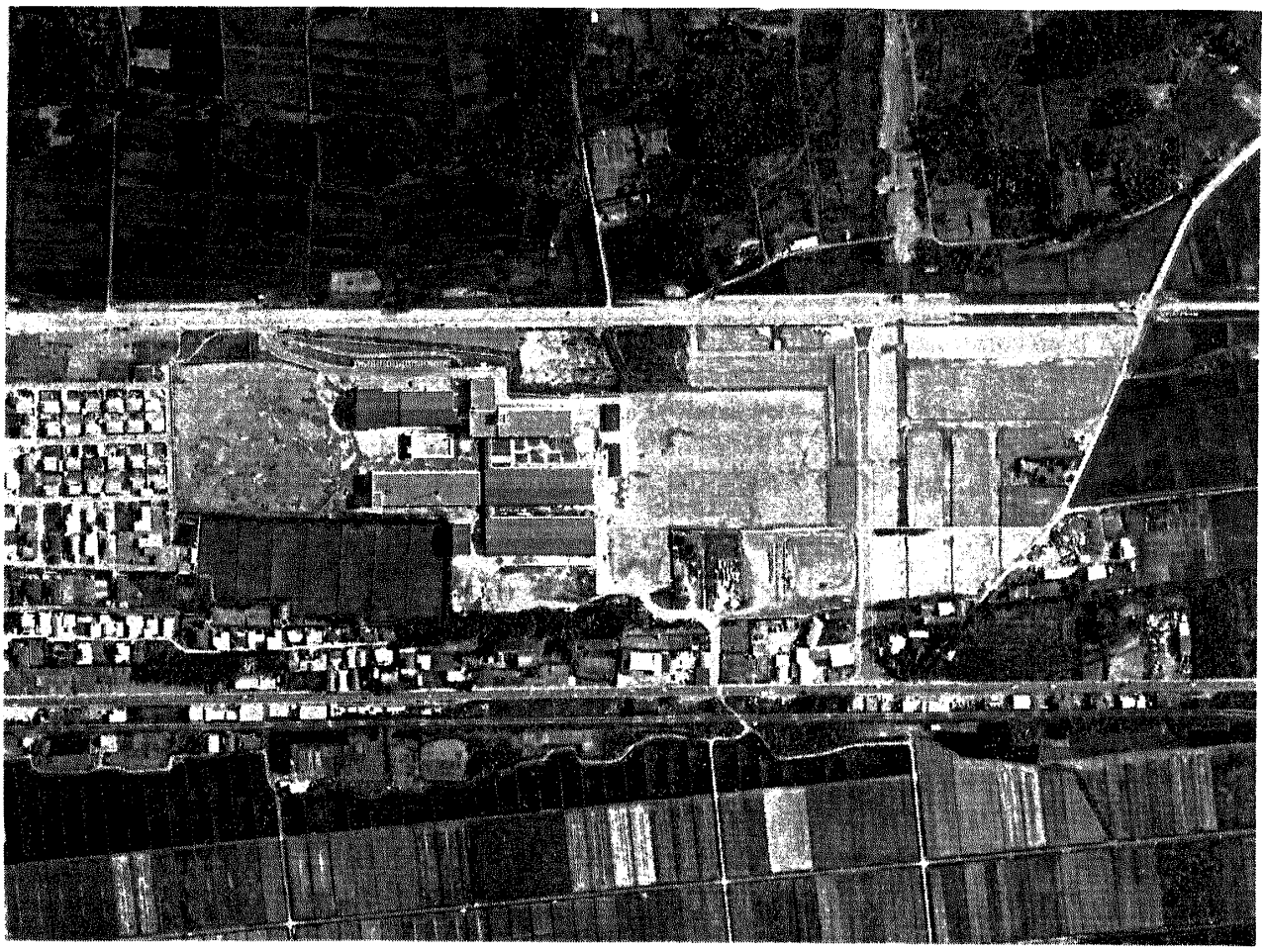


Photo. 9 Aerial photograph of the Oga Industrial High School taken the day of the 1983 Nihonkai-Chubu earthquake (Site E2).

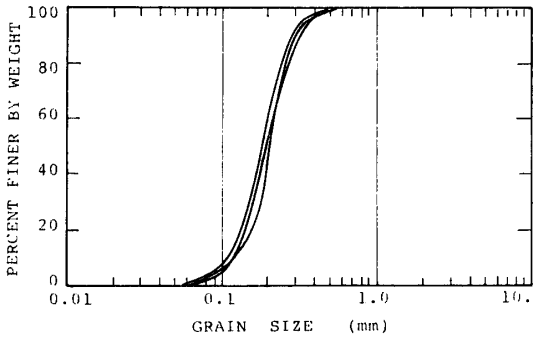


Fig. 7 Grain size distribution curves of sands liquefied by the Nihonkai-Chubu earthquake at Oga Prefectural Industrial High School (Site E2).

on the ground surface (Photo. 7). The floor of an enigneering workroom, a one-story building, showed a maximum subsidence of 40 cm. A house next to tennis courts was destroyed because the lot slipped and collapsed (See Photo. 8). An aerial photograph (Photo. 9) shows sand volcanos and cracks on the surface of the ground all around the high school and on house lots near the school, but there was neither liquefaction nor damage in weak paddies took place on Alluvial lowland. The liquefied materials at this high school were well sorted and fine-grained reclaimed sands with the mean particle size, D_{50}, o f about 0.2 mm and the uniformity coefficient, U_c, of about 1.8 (Fig. 7).

At Wakimoto (Site E3), there were many sand volcanos from the Ekimae to Ohkura Districts. There was much damage to structures: Approximately 30 houses were partially or completely destroyed, concrete block fences were destroyed and water service pipes were damaged.

3) Ohgata Village

Distribution of liquefaction sites in Ohgata Village is shown in Fig. 4. The central reclamation zone at Hachirogata Lagoon was the most severely damaged area. All the embankments around this zone (Site F) showed subsidence and bulging except for small sections in the southeast and southwest. The total length of the damaged embankment was about 70 km. Liquefied

Photo. 10

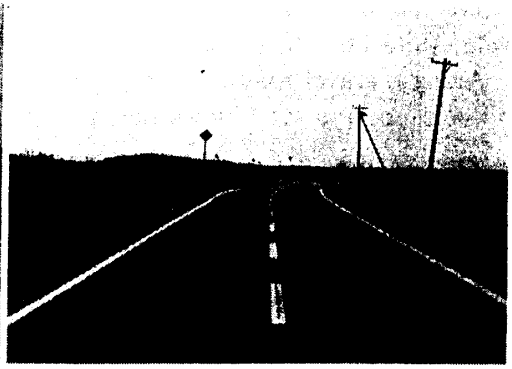


Photo. 11

Photo. 10 Broken embankment along the northern part of the east intercepting drain in Hachirogata Lagoon.

Photo. 11 Shifted embankment road, its center line moved 1.4 m in the northern part of the east intercepting drain in Hachirogata Lagoon.

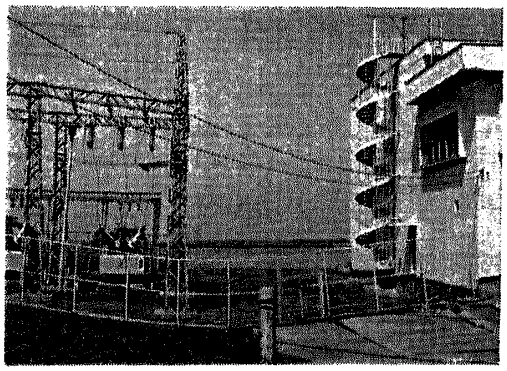


Photo. 12

Photo. 13

Photo. 12 Uneven subsidence of ground at the Northern Pumping station in Hachirogata Lagoon. (Site F2).

Photo. 13 Sand volcanos in the side gutter of the embankment road to the southern Ohgata Bridge in Hachirogata Lagoon.

sand blows were present everywhere around the embankments. Reclamation of Hachirogata Lagoon was completed in October 1964 and Ohgata Village established.

At the northern end of the east intercepting drain dike, the embankment subsided more than 1 m, and the center line on the embankment road shifted about 1.4 m and heaved (Photos. 10–11). Waving and meandering of the embankment road also were found in parts of the east and west intercepting drains.

At the Northern pumping station (Site F2), ground visible from the building settled, and the foundation of the electronic substation subsided (Photo. 12). The bottom of the retaining wall bulged about 50 cm.

At Ohgata Bridge (Site F3), the bridge base was subsided, also the road from the bridge was subsided and collapsed. Along the embankment's gravel road and its gutters south of Ohgata Bridge to the frontal dike many sand volcanos and sand blows were present inside cracks (Photo. 13). A siphon pipe line was damaged and colligated pipes uplifted along the east intercepting drain.

At the west intercepting drain dike, the embankment settled 0.5 to 1.0 m, in some parts the difference between the top of the embankment and the water level being less than 1 m. At nearby Gomyoko Bridge (Site F6), the subsidence was so great that the top of the embankment could not be seen. Along a gravel road and its gutter south of this bridge, along the west intercepting drain, sand volcanos and sand blows were present inside open cracks (Photo. 14). The access

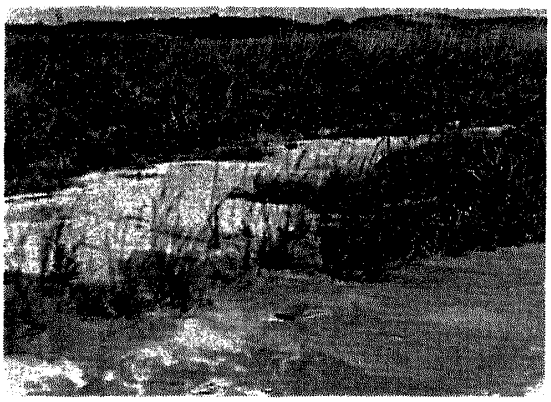
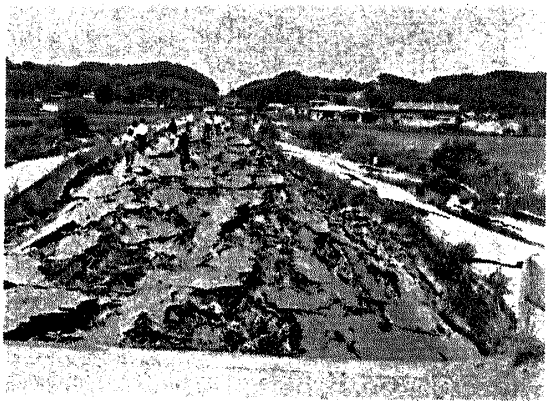


Photo. 14



Phto. 15

Photo. 14 Sand volcanos along the gravel embankment road in the west intercepting drain at Hachirogata Lagoon.

Photo. 15 Destruction of the access road to Gomyoko Bridge (Site F6).

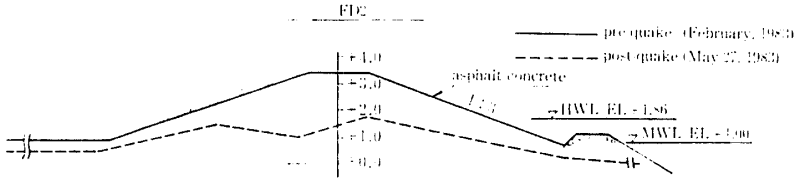


Fig. 8 Cross-section of a damaged embankment section of a frontal dike in Hachirogata Lagoon (Ref. [4]).

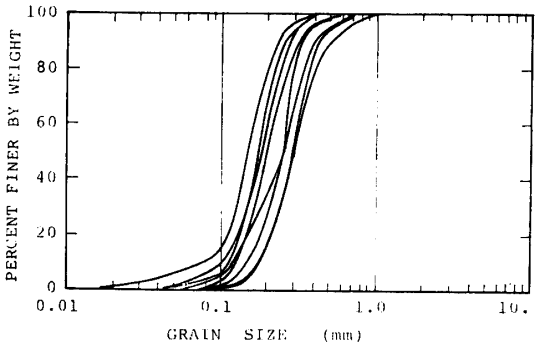


Fig. 9 Grain size distribution curves of sands liquefied by the Nihonkai-Chubu earthquake in the central reclamation zone of Hachirogata Lagoon.

road to the Gomyoko Bridge subsided and a great many cracks were formed on its surface (Photo. 15). Liquefaction was extensive in a paddy near the bridge.

Fig. 8 of Higashiyama and Fujita [4] shows a post-quake (May 27th, 1983), cross section of the damaged embankment of the frontal dike. This damaged embankment, along all of the dike in the Hachirogata Lagoon was composed of sandy soil. The earthquake caused major damage to 208 ha. of paddies in Ohgata Village.

Grain size distribution curves for eleven liquefied sand samples taken along the embankment of the Hachirogata Lagoon (Site F) are shown in Fig. 9. The soil's mechanical parameters for the liquefied sands are in the following ranges; mean particle size, D_{50}, from 0.15 mm to 0.30 mm and the uniformity coefficient, U_c, from 1.7 to 2.4.

4) Wakami and Hachiryu Towns

Along the Oga Road between the sand dunes and the Hachirogata Lagoon, settlement and

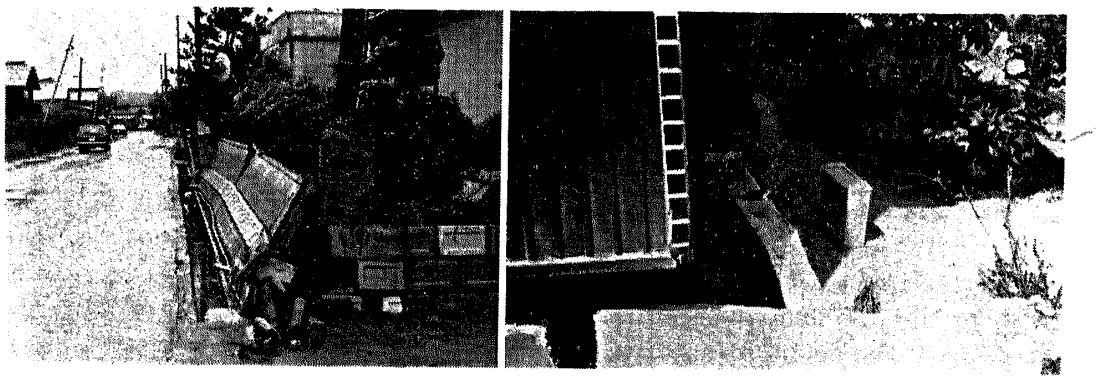


Photo. 16 Photo. 17

Photo. 16 Damage at Kami-Gomyoko bus stop in Wakami Town.

Photo. 17 Damage to the concrete footing of wooden house and a slipped shed at Gomyoko, Wakami Town (Site G5).

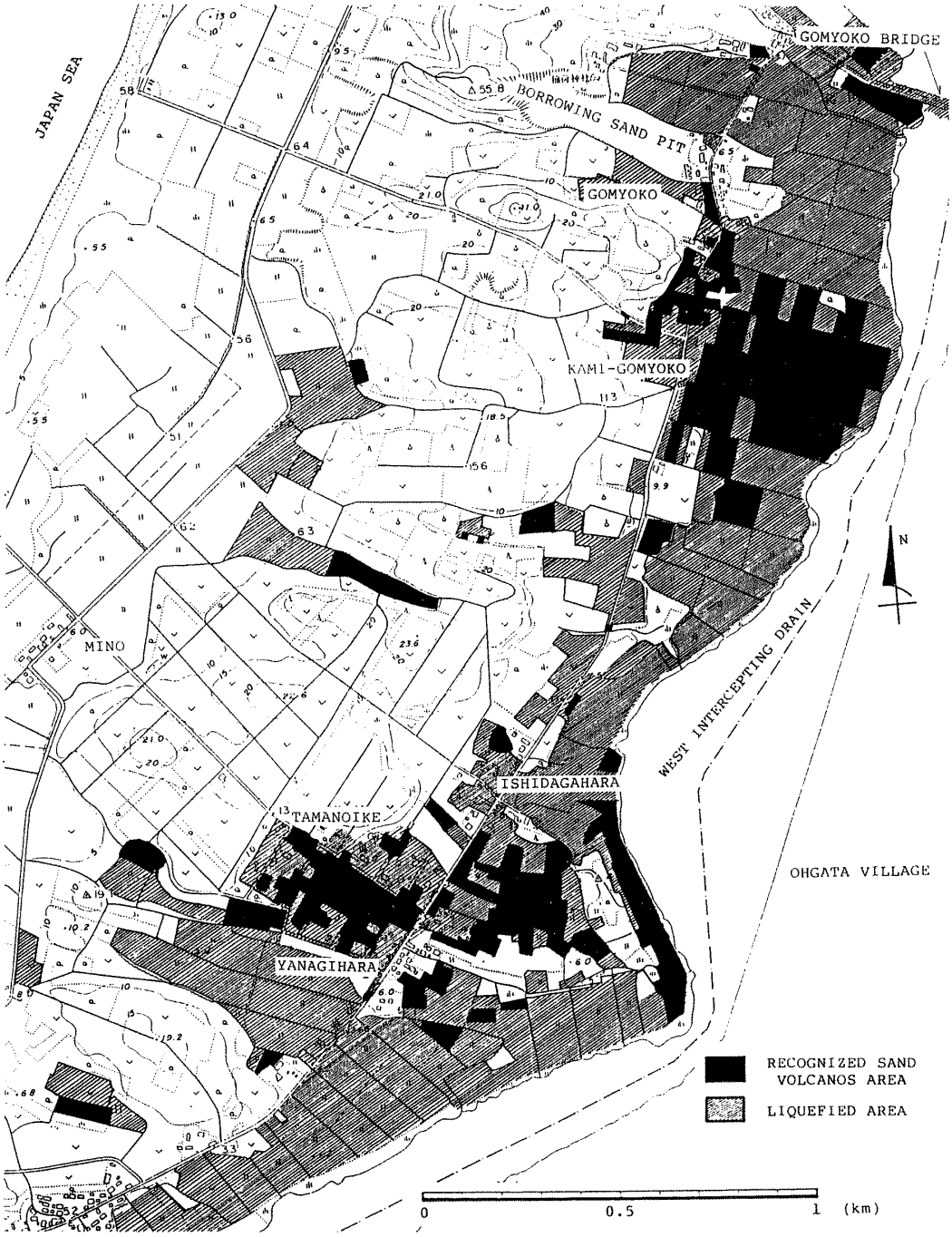
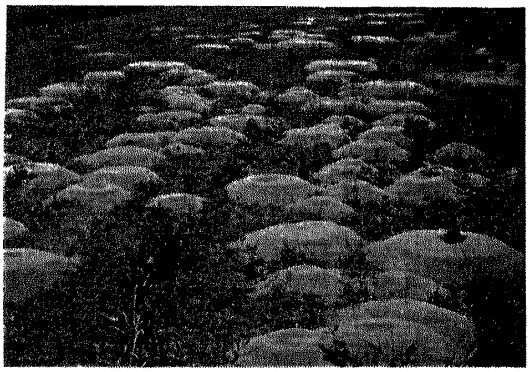


Fig. 10 Liquefaction site distribution map after the Nihonkai-Chubu earthquake in northern Wakami Town.

cracks in the surface of road can be seen. There is also complete and partial collapse of houses, tilting and destruction of concrete block fences and tilting of electric light poles. There was heavy damage to paddies and to farms. Damage caused by liquefaction was especially marked at Tamanoike (Site G4) and Gomyoko (Site G5) in Wakami Town.

The detailed distribution of liquefaction locations at Tamanoike and Gomyoko, is shown in Fig. 10 which combines data from field investigations and aerial photographs of these sites. Photo. 16 shows damage near the Kami-Gomyoko bus stop. Photo. 17 shows a plain concrete strip footing without reinforcing steel that broke onto which the shed has slid.

Numerous sand volcanos were present in melon fields and paddies covered by vinyl on the



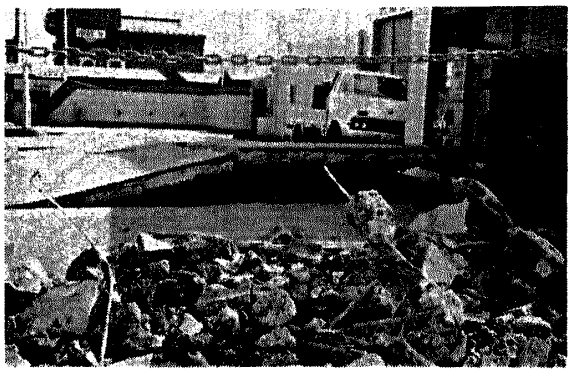


Photo. 18 Photo. 19

Photo. 18 Typical sand volcanos in fields at Gomyoko, Wakami Town (Site G5).

Photo. 19 Uplift of a buried oil tank 70 cm at a gas station in Kawatogawa, Noshiro City (Site I4). Photograph from Mr. Fukuhara (Tokyo Institute of Technology).

margins of the sand dunes. Photo. 18 shows typical miniature sand volcanos in a paddy. A crack with a depth of more than 1 m was present at this site.

Many paddies had been reclaimed from clayey soil between Wakami Town and Asanai Noshiro City and had vinyl laid along the margins of the sand dunes. The vinyl was torn by liquefaction and there was extensive damage to the paddies.

5) Noshiro City

Damage caused by liquefaction was distributed widely in Noshiro City. The area the following two types of the damage; alluvial lowlands and reclaimed fills as at Nakagawara (Site I9), and the borders between sand dune and alluvial lowland as at Kuro-oka (Site I1).

The former type, which included liquefactions of reclaimed fill on a river, on a marsh and on a weak paddy were present at the Noshiro Minami By-pass (Site I2), the Nagasaki Danchi (Site I5), the west side of the Santoh Marsh (Site I6) and Ochiai (Site I12). Detailed distribution of liquefaction locations in the Asanai district is given in Fig. 11. In particular, sand volcanos were present in many paddies near Naka-Asanai. At the Nohsiro Minami By-pass, national route 7, the surface of the road had been bent into a convex shape and collapsed. The center line of the road had shifted and the racks used as a defense against snow at the side of the road were tilted and were slipped out of the road.

The second type of liquefaction was present at Asanai (Site I3), Kawatogawa (Site I4) and

Photo. 20 Poto. 91

Photo. 20 Displaced side gutter along the road at Kawatogawa, Noshiro City (Site 14).

Photo. 21 Boiling sand being spewn out at a baseball park (Site I11). Photograph from Noshiro City.

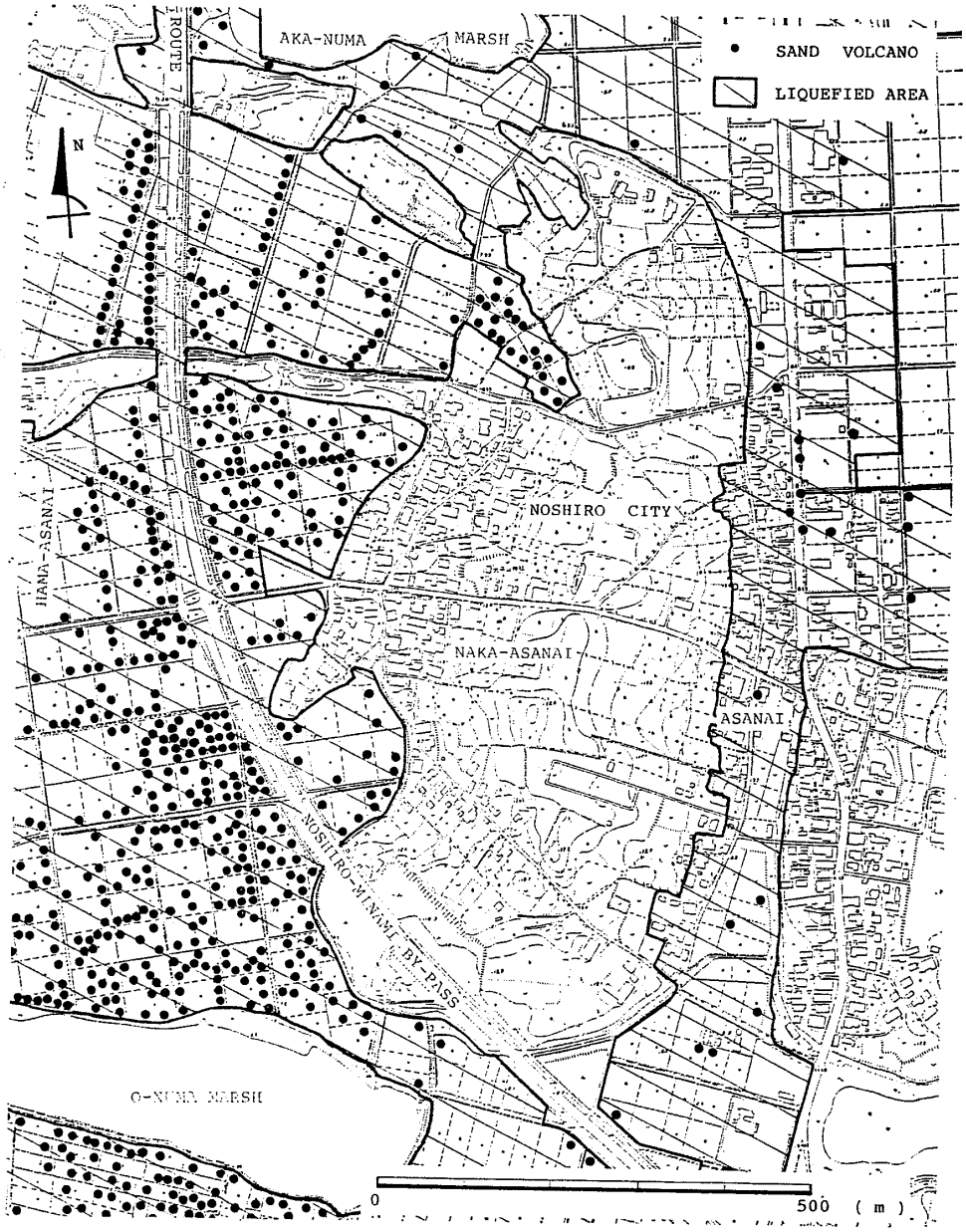


Fig. 11 Liquefaction site distribution map after the Nihonkai-Chubu earthquake at Asanai, Noshiro City.

Koado (Site I11). At Kawatogawa, many gateposts and concrete block fences were tilted or destroyed. A buried oil tank at a gas station was raised about 70 cm, and the footing of a house and both edges of the road were badly broken (Photos. 19–20). Liquefied sand sample at the side of a road at Asanai was fine-grained with a mean particle size, D_{50}, of 0.33 mm and a uniformity coefficient, U_c, of 1.9 (Fig. 12). The detailed distribution of the liquefaction sites at Kawatogawa is shown in Fig. 13.

In the town areas of Aoba-cho, Shonan-cho, Matsumi-cho and Keirin-cho (Site I7), many wooden houses were destroyed. The detailed distribution of liquefaction sites for these areas is shown in Fig. 14. A resident related that much water spewed from the ground soon after the earthquake and that houses at this site were flooded about 40 cm above ground level.

The Aoba-so apartment houses, reinforced concrete buildings of 4 and 2-stories. The building of 4-stories with a pile foundation tilted about 2 degrees. The reason for this damage is believed to be liquefaction of the building lot which destroyed the friction of the building piles.

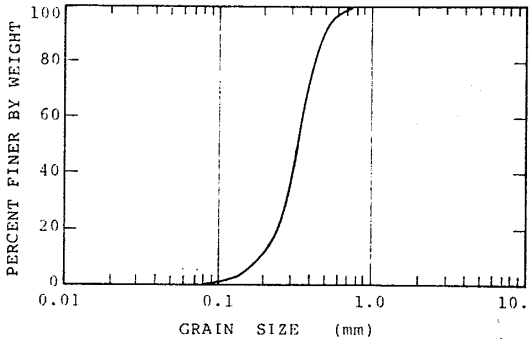


Fig. 12 Grain size distribution curve of sand liquefied by the Nihonkai-Chubu earthquake along the road at Asanai (Site I3). Data from Dr. S. Yasuda.

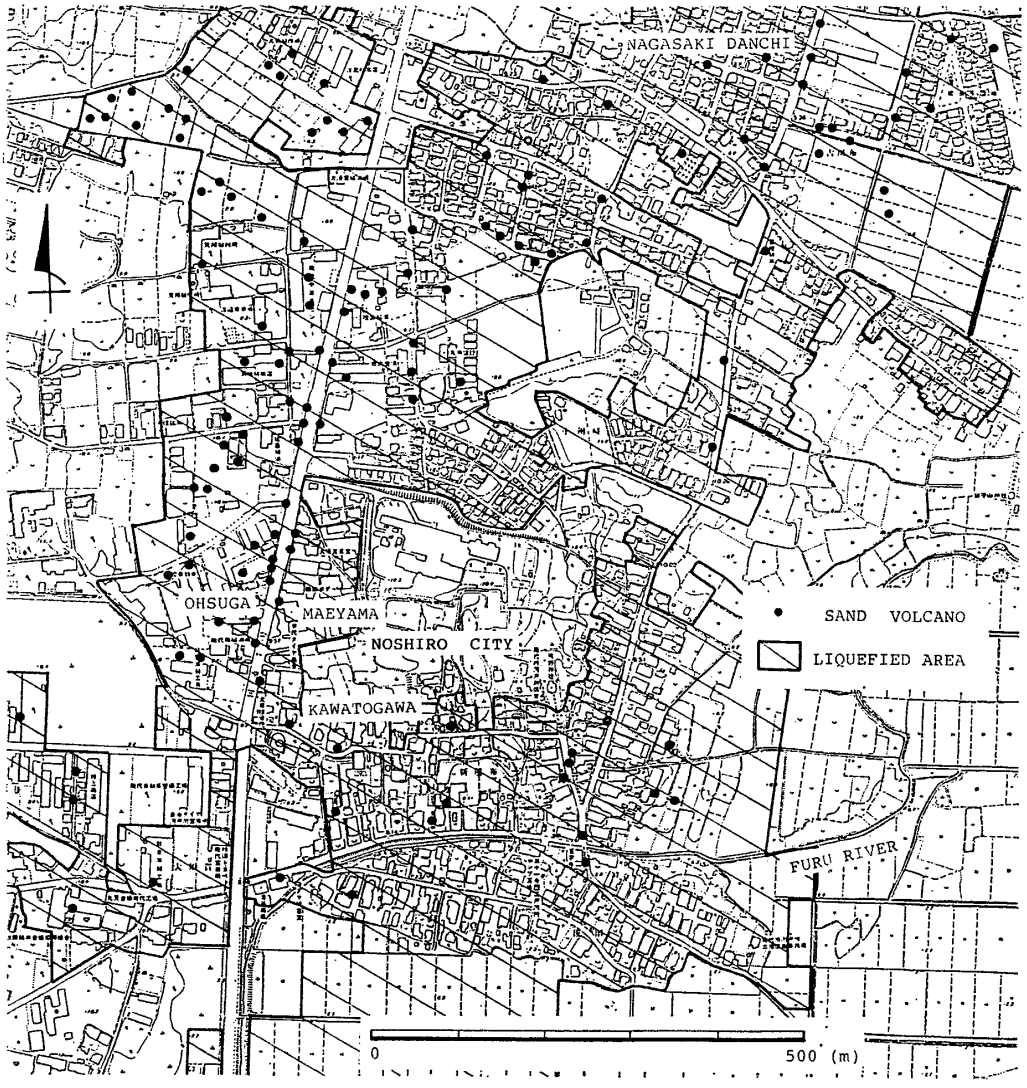


Fig. 13 Liquefaction site distribution map after the Nihonkai-Chubu earthquake at Kawatogawa, Noshiro City.

A semidetached, reinforced concrete apartment house of 2-stories was so badly damaged and as so the house had to be destroyed after the earthquake.

A remarkable photograph, taken by a resident (Photo. 21), shows water and boiling sand

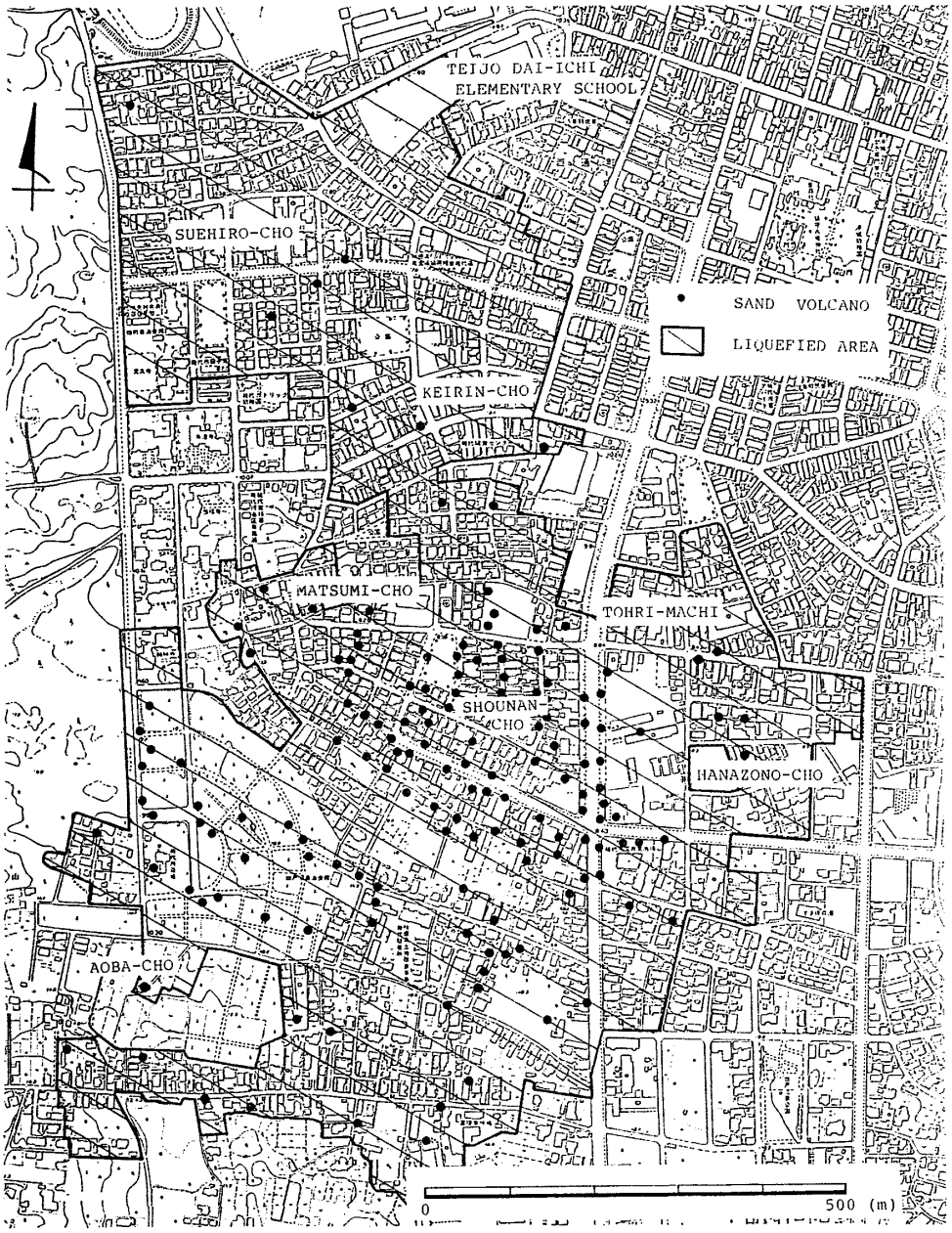


Fig. 14 Liquefaction site distribution map after the Nihonkai-Chubu earthquake in the main part of Noshiro City.

spewing out at a baseball park (Site I11) soon after the Nihonkai-Chubu earthquake.

6. GEOMORPHOLOGICAL CONDITIONS AT LIQUEFIED SITES

Geomorphically, Araya-Motomachi in southern Akita City where major damage caused by liquefaction occurred is a lowland situated between sand dunes and a river. The sites of liquefaction are in reclaimed fill on an old river bed shown on a topographical map of 1914 and the liquefaction distribution map for Araya-Motomachi (Figs. 3 and 5). This site was reclaimed during the first part of the Showa period (about 55 years ago) when the Omono Drainage Canal was constructed.

The east-west ground section of Araya-Motomachi estimated by Kotohda and Wakamatsu

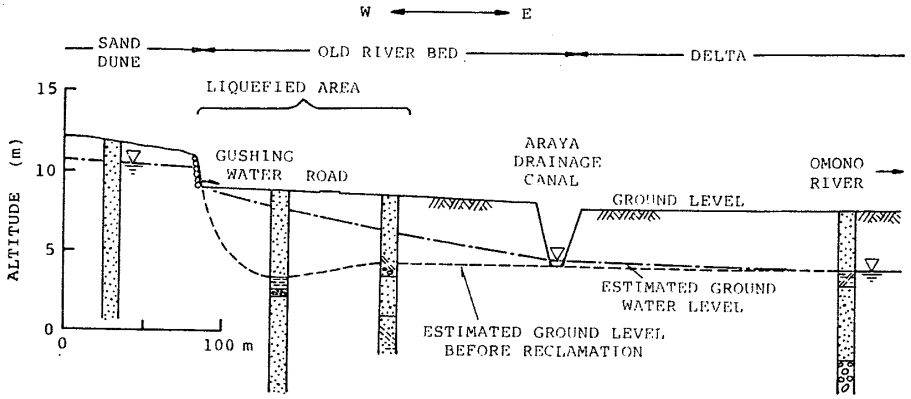
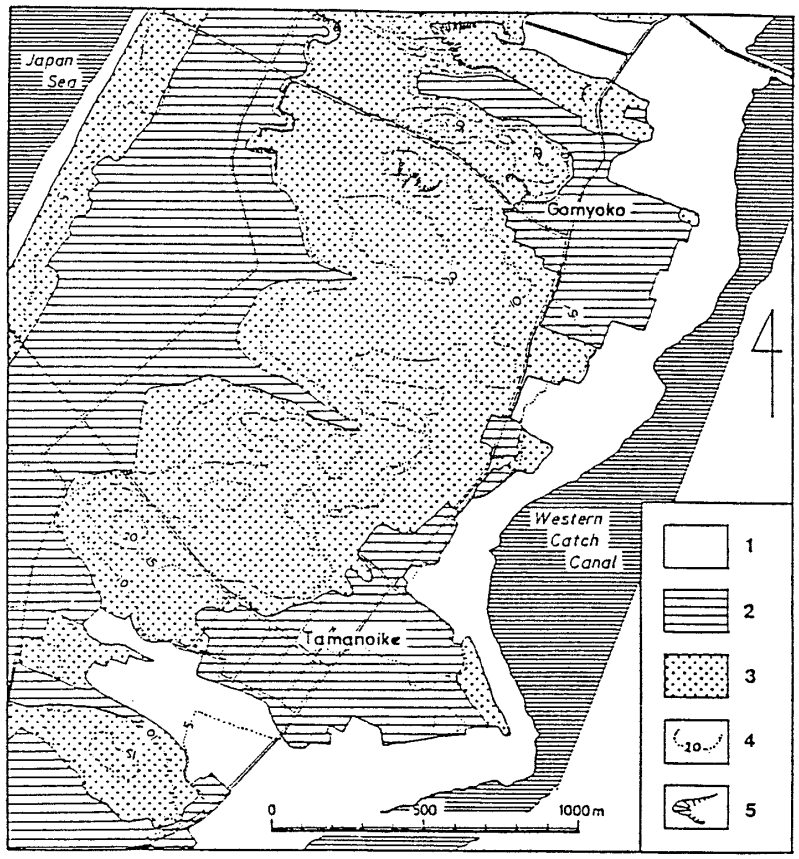


Fig. 15 Estimated east-west ground section of Araya-Motomachi, Akita City (Ref. [6]).

[6] for the area damaged by liquefaction is shown in Fig. 15. The ground water level was shallower [6] at the time when the area was damaged by the liquefaction, also, the ground water level was shallower than at the time this area was reclaimed. The estimated ground water level, divided between the area damaged by liquefaction and the area of no liquefaction, is about G.L. −2 m. The reclaimed fill is a weak sand layer whose N value is 5 based on the Standard Penetration Test.



LEGEND

1. BEACH AND LACUSTRINE LOWLAND 2. TERRACE
3. SAND DUNES 4. CONTOUR LINE (m)
5. CLIFF OF BORROWING SAND PIT (See note to Fig. 10)

Fig. 16 Geomorphologic map of northern Wakami Town (Ref. [7]).

Liquefaction occurred widely and there was extensive damage from Gomyoko to Tamanoike in north Wakami Town. A geomorphological map of the northern part of Wakami Town drawn by Shiraishi [7] is reproduced in Fig. 16. The recognized miniature sand volcano area was limited to a terrace and lucustarine lowland (lowest alluvial plain) zone, the sand dune zone showing no liquefaction when Fig. 10 is superimposed over Fig. 16.

Numerous sand volcanos were presented on the terrace in the Gomyoko and Tamanoike districts. An old topographical map (1914) of the northern part of Wakami Town is shown in Fig. 17. Arched, elevated ground looking like small hills are located along the lacustrine line of the Hachirogata Lagoon. Mii [8] described these elevated mounds as Recent sand dunes. In this area, the present topographical features are the result of recent rapid natural conditions due to human usage of the land.

Kuwahara et al. [9] has reported that the most common ground failure areas in Aomori Prefecture caused by the liquefaction produced during this earthquake were blow-out depressions of parabolic sand dunes at the Tomiyachi district, Shariki, Aomori Prefecture. Probably, the terraces in the northern part of Wakami Town reported by Shiraishi [7] are blow-out depressions

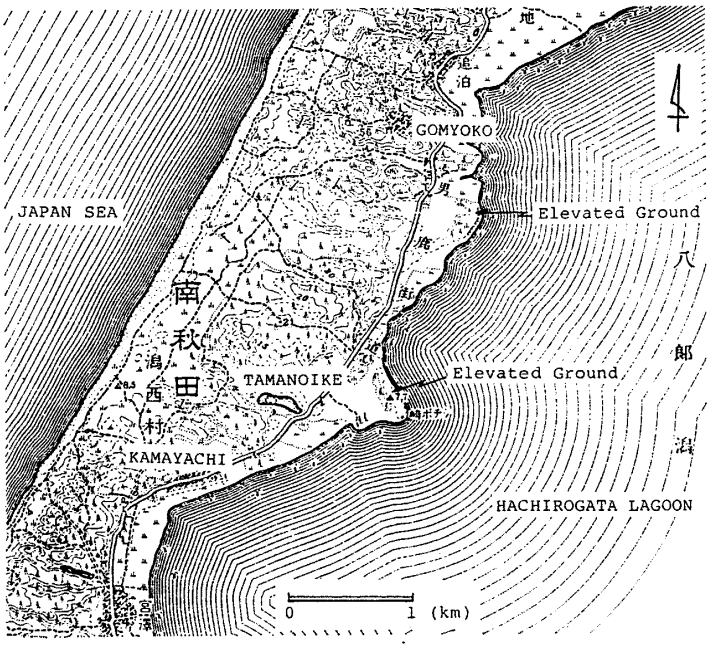


Fig. 17 Old topographic map of 1914 of northern Wakami Town.

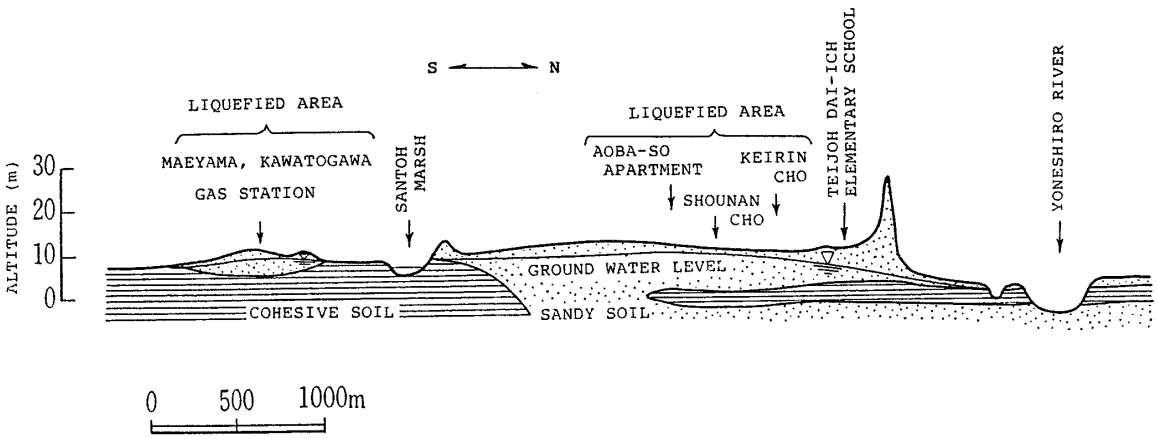


Fig. 18 Estimated north-south ground section at Noshiro City (Ref. [3]).

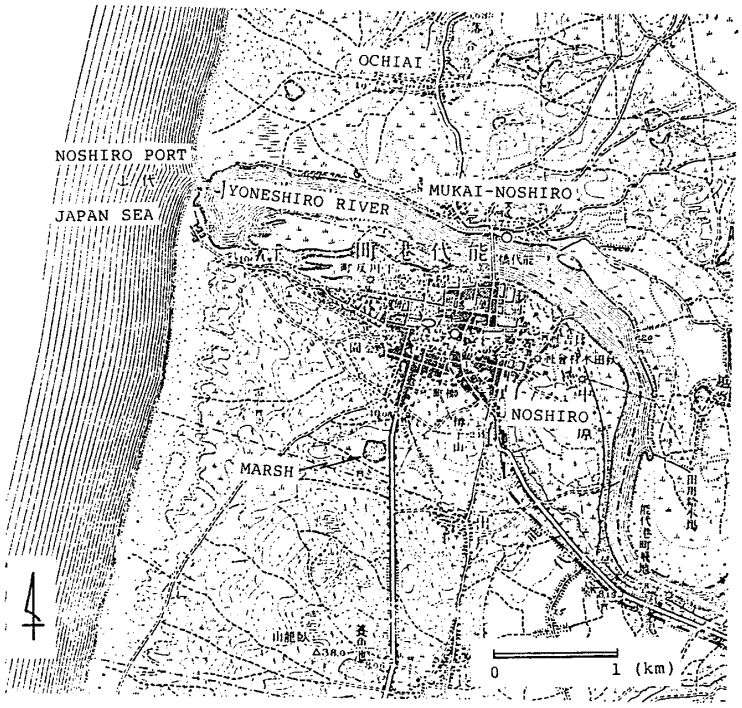


Fig. 19 Old topographical map of 1914 of the main part of Noshiro City.

of parabolic sand dunes (Fig. 16).

The estimated north-south section of ground changed in Noshiro City is shown in Fig. 18. A sand dune was formed at south of the Yoneshiro River, flat lowland continuing from Keirin-cho to Kawatogawa behind it. Damaged parts of Noshiro City centered along the borders of sand dunes and in the alluvial lowlands. No liquefaction was presented along the northern part of the sand dune at the Teijoh Dai-ichi Elementary School (Fig. 18). Old topographical map of 1914 (Fig. 19) shows there was a marsh at Shonan-cho, an area reclaimed in 1967 by the Noshiro City Office.

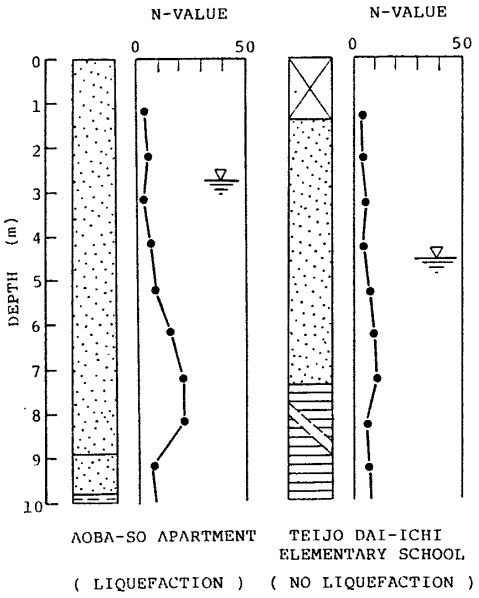


Fig. 20 Soil profiles in urban Noshiro City. Data from the Tokyo Soil Research Co. Ltd. and Noshiro City Office.

The sites damaged in this earthquake are separable into natural and artifical ground. Typical natural ground damage by liquefaction were located on the borders of sand dunes and in the lowlands between dunes as at Noshiro City.

Typical soil profiles in urban Noshiro are shown in Fig. 20. Severe damage caused by liquefaction occurred at the Aoba-so apartment houses, but no liquefaction phenomena were found at the Teijoh Dai-ichi Elementary School. The figure suggests that a ground water level of G.L. -2 m, separates the damage sites. Generally speaking, the ground water level in damaged natural ground made up of eolian sand deposits is high.

Many of the areas damaged by the liquefaction are found on reclaimed fill in an old river bed, on a marsh and on a weak paddy. Especially severe damage occurred at embankments at the Hachirogata Lagoon and at Akita port.

The ground liquefied by this earthquake consisted of reclaimed sand, fluviatile sand and eolian sand. The soil mechanical parameters for these liquefied sands have the following ranges: mean particle size, D_{50}, 0.15 mm to 0.33 mm and the uniformity coefficient, U_c, 1.5 to 2.4. Soils liquefied by the 1978 Miyagiken-Oki (Off-Miyagi Prefecture) earthquake consisted of sands with a mean particle size, D_{50}, of 0.13 mm to 0.5 mm [10]. The mean particle sizes of the sands liquefied in Akita Prefecture by the Nihonkai-Chubu earthquake fall within the range of values for sands liquefied by the 1978 Miyagiken-Oki earthquake.

7. CONCLUSIONS

The total damage caused by liquefaction in the 1983 Nihonkai-Chubu earthquake was the worst in cost and the largest in area since the 1964 Niigata earthquake. We here have described and shown the type of the damage caused by the liquefaction in Akita Prefecture. The area damaged was wide, but on natural ground, the liquefaction phenomena were found only along borders between alluvial lowland and sand dune, as lowlands between dunes. This type of ground is composed of eolian and fluviatile deposits, and the ground water level is high. In two typical damaged areas, Noshiro City and Araya-Motomachi in Akita City, the sites had G.Ls. of -2 m.

Reclaimed ground was particularly prone to liquefaction. Most damage occurred on reclaimed ground, except along borders between sand dunes and in alluvial lowlands.

ACKNOWLEDGMENTS

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