CHARACTERISTICS OF LIQUEFACTION OF LEVEL SANDY GROUND DURING THE TOKACHIOKI EARTHQUAKE

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ABSTRACT

Field investigations to clarify the characteristics of liquefaction of level sandy ground were carried out at Nanaehama beach near Hakodate in Hokkaido after the Tokachioki earthquake of 1968. Three borings were carried out about three weeks after the earthquake and the results of these borings were compared with those before the earthquake. The soil stratum which was presumed to have liquefied was identified by the proposed criteria and compared with the soil test results and photomicrographs. The hydraulic fill at Nanaehama beach underwent complete liquefaction during the Tokachioki earthquake of 1968.

1. INTRODUCTION

During the Tokachioki earthquake of May 16, 1968, the liquefaction of soils were observed at some places in Hokkaido Island and Aomori Prefecture. The author carried out field investigations at Nanaehama beach in Kamiiso Town (near Hakodate) in Hokkaido Island where complete liquefaction of level ground from the ground surface to some depth was observed. At the time of the Tokachioki earthquake, the soil exploration was being carried out for the purpose of constructing oil tanks. After a week from the earthquake, the soils which were part of the sand volcanoes were taken to the laboratory to investigate the characteristics of the soils. After three weeks from the earthquake, three borings were also made for comparison with the borings before the earthquake. The standard penetration tests were carried out in the field and grain size distribution of the soil samples were determined in the laboratory. Photomicrographs of the soil particles were also taken and grain composition and roundness of the soils were studied. The author estimated the liquefied zone of the soil on the basis of the proposed criteria (Kishida: 1969) and checked the results with the observed phenomena.

2. SOIL EXPLORATION AND DAMAGE TO THE GROUND

The Nanaehama beach faces the Hakodate Bay and the liquefaction of the soil occurred at the place where reclamation was made by hydraulic fills at about three years before the earthquake. The water and the soils began to spout out from the ground

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surface soon after the beginning of the earthquake and continued for about one hour. The reclaimed area was liquefied completely from the ground surface to some depth and the soils were so soft that people had some trouble walking even after a week from the earthquake. There were many sand volcanoes, typical types of which are shown in Photo. 1. Diameters of the sand volcanoes in Photo. 1 are about from 1.0 to 2.0 m. The upward flow of water which resulted from liquefaction of the soil at some distance below the ground surface spouted out through craters of the sand volcanoes. Photo. 1-(A) type shows the clear evidence of the crater, the diameter of which varies from 50 cm to 130 cm. Photo. 1-(B) type is a conical one which has a small opening at the top of the cone, and Photo. 1-(C) type is the one which features a cluster of small craters. The uplift of a sewage pipe due to the liquefaction of the soil caused a crack on the ground surface. The crack is shown in Photo. 2-(A), and the uplift of a sewage manhole is also shown in Photo. 2-(B). These facts support that the complete liquefaction of the soil occurred during the earthquake.

Three borings were carried out in the Nanaehama beach after the earthquake and their locations before and after the earthquake are shown in Fig. 1. The thickness of the hydraulic fill was about 5.0 m at the shoreline and decreases inland. The results of the soil exploration before and after the earthquake are shown in Fig. 2.

Fig. 1. Location of borings

3. ANALYSIS OF THE RESULTS OF THE INVESTIGATION

As indicated by the author (1969), most of the complete liquefaction of the saturated sand occurred under the following condition: The soil was coarse grained sand in accordance with the unified classification system, having the 50% size of less than 2.0 mm and the uniformity coefficient of less than 10. The effective overburden pressure was less

(A)

← 1 m →

(B)

← 1 m →

(C)

← 1 m →

Photo. 1. Types of sand volcanoes

(A) Crack on the ground surface due to the uplift of sewage pipe

(B) Uplift of a manhole

Photo. 2. Uplift of sewage pipe and a manhole

(C) About three weeks after the earthquake (Boring No. 7 (June 3~4))

Fig. 2. Results of soil exploration

(C) About three weeks after the earthquake (Boring No. 8 (June 5~6))

(C) About three weeks after the earthquake (Boring No. 9 (June 7~8))

Fig. 2. Results of soil exploration

than 2.0 kg/cm^2 , the relative density was less than 75% and no fine grained soil strata lay above the saturated sand.

On the basis of the proposed criteria of the possibility of liquefaction of saturated sand, the standard penetration test results before the earthquake were analyzed as can be seen in Fig. 3. From the ground surface to a depth of about 5 m, the standard penetration test results show a high possibility of liquefaction and this soil stratum corresponds to the hydraulic fill. The soil in the depths from about 5 m to 12 m has a medium possibility of liquefaction. Fig. 4 shows in detail the change in the number of blows before and after the earthquake in the hydraulic fill. The number of blows by the test increased clearly after the earthquake in the hydraulic fill as can be seen in Fig. 4.

In Fig. 4, the number of blows following the earthquake in the upper part of the hydraulic fill decreases from those before the earthquake and increases again about three weeks after the earthquake. This change might depend on the variation of the soil properties of the hydraulic fill or result from the change of excess pore water pressures due to the liquefaction of the soils.

The grain size distribution, uniformity coefficient, and 50% size of soils at each soil stratum and at the sand volcano are shown in Fig. 5, and in Fig. 2-(C). The uniformity coefficient of the soils which lay from the ground surface to a depth of about 12 m and of the soils obtained from the sand volcanoes is less than 10. But the soils below a depth of about 12 m give the uniformity coefficient of more than 10. The 50% size of the soils which lay from the ground surface to a depth of about 12 m is more than 0.074 mm, but the 50% size of the soils below a depth of about 12 m is less than 0.074 mm.

Fig. 3. Possibility of liquefaction

Fig. 4. Change of standard penetration test results at hydraulic fill

Fig. 5. Typical grain size distribution curves of soils

Table 1. Grain composition and roundness of spouted sands

PLACE	GRAIN SIZE (mm)	QUARTZ	PYROXENE & HORNBLAND	CHEST	SAND-STONE	BASALT	ANDESITE	RIPARITE	TUFF	PUMICE
OUTSIDE OF SAND VOLCANO	2.0~0.84	0.3~0.4		0.5		0.6		0.5		0.4
	0.84~0.42	0.3		0.4~0.5		0.3~0.5		0.4~0.6		
	0.42~0.25	0.3~0.4	0.3~0.4	0.4~0.5	0.4	0.4~0.5		0.4~0.6		
	0.25~0.105	0.2~0.3	0.3~0.4	0.4						
INSIDE OF SAND VOLCANO	0.105~0.074	0.2~0.3	0.3~0.4	0.3~0.4						
	>20			0.4~0.6			0.6			0.5
	2.0~0.84			0.5	0.6		0.4		0.3	
	0.84~0.42	0.2~0.4		0.5	0.4	0.5		0.3~0.4		0.3
	0.42~0.25	0.2~0.3		0.4~0.5		0.3~0.4		0.4		
	0.25~0.105	0.2~0.3	0.3~0.4	0.4		0.4		0.5		
	0.105~0.074	0.2~0.3	0.3~0.4	0.3~0.4						

The Grain composition and roundness of soil particles are investigated by taking photo-micrographs of the soil particles. The results of the investigation are summarized in Tables 1 and 2. The grain composition and roundness of soil particles of the soil at the sand volcano show a fairly good agreement with those of soils at about 1 to 12 m deep.

The results of the analysis of the liquefaction of the soil based on the author's criteria (1969) and on the observed phenomena indicate the following: The soil stratum which lay between about 1 m and 5 m deep has high possibility of liquefaction and the grain composition and the roundness of soil particles in the soil stratum shows a good agreement with the soil at the sand volcanoes.

**Table 2. Grain composition and roundness of investigated soils
(Borings No. 7 and No. 8)**

DEPTH (METER)	GRAIN SIZE (mm)	QUARTZ	PYROXENE & HORNBLende	CHERT	SAND -STONE	BASALT	ANDESITE	RIPARITE	TUFF	PUMICE
1 ~ 5	2.0 ~ 0.84			0.5	0.6	0.5	0.5	0.4		0.3
	0.84 ~ 0.42			0.4	0.4			0.4		0.3
	0.42 ~ 0.25	0.4		0.4				0.5		
	0.25 ~ 0.105	0.3		0.4		0.4				
	0.105 ~ 0.074	0.3	0.3 ~ 0.4	0.3						
5 ~ 12	2.0 ~ 0.84			0.5		0.6		0.4		0.4
	0.84 ~ 0.42	0.3		0.5	0.7	0.5		0.4		0.2 ~ 0.3
	0.42 ~ 0.25	0.3		0.3 ~ 0.4	0.5	0.4				0.3
	0.25 ~ 0.105	0.2 ~ 0.3	0.3 ~ 0.4	0.4						
	0.105 ~ 0.074	0.2 ~ 0.3	0.3 ~ 0.4	0.4						
12 ~ 17	2.0 ~ 0.84	0.3		0.4 ~ 0.5		0.5			0.3	
	0.84 ~ 0.42	0.3		0.4				0.4	0.4	
	0.42 ~ 0.25	0.3		0.4				0.4	0.3	
	0.25 ~ 0.105	0.2 ~ 0.3	0.3	0.3						
	0.105 ~ 0.074	0.2 ~ 0.3	0.3	0.3						
17 ~ 21	> 2.0			0.5		0.6	0.4		0.4	
	2.0 ~ 0.84	0.4		0.5				0.4	0.3	
	0.84 ~ 0.42	0.3		0.4				0.4	0.3	
	0.42 ~ 0.25	0.2 ~ 0.3		0.4		0.4		0.4		
	0.25 ~ 0.105	0.2	0.3	0.3				0.4		
	0.105 ~ 0.074	0.2 ~ 0.3	0.4							

The soil properties of the original ground which lay below a depth of about 5 m is more complex than those of the hydraulic fill and, therefore, it can not be said simply that the change in the number of blows before and after the earthquake results directly from the liquefaction of the soil during the earthquake.

4. CONCLUSIONS

1. The hydraulic fill at Nanaehama Beach underwent complete liquefaction during the Tokachioki earthquake of 1968.
2. The criteria proposed by the author offers a plausible explanation of a complete liquefaction.

REFERENCE

- Kishida, H., (1969). "Characteristics of Liquefied Sands During Mino-Owari, Tohnankai and Fukui Earthquakes", Soils and Foundations, Vol. IX, No. 1, pp. 75-92.